WATER RESOURCES BULLETIN
VOL. 32, NO. 2 AMERICAN WATER RESOURCES ASSOCIATION APRIL 1996

LONG-TERM AQUATIC HABITAT RESTORATION: MAHOGANY CREEK, NEVADA, AS A CASE STUDY[1]

Thomas J. Myers and Sherman Swanson[2]

ABSTRACT: We compared the recovery from abusive grazing of aquatic habitat due to different range management on two geomorphically similar rangeland streams in northwest Nevada. Managers excluded livestock from the Mahogany Creek watershed from 1976 to 1990 while allowing rotation of rest grazing on its tributary Summer Camp Creek. Bank stability, defined as the lack of apparent bank erosion or deposition, improved through the study period on both streams, but periodic grazing and flooding decreased stability more on Summer Camp Creek than flooding alone on Mahogany Creek. Pool quantity and quality on each stream decreased because of coarse woody debris removal and sediment deposition during a drought. Fine stream bottom sediments decreased five years after the removal of livestock, but sedimentation increased during low flows in both streams below road crossings. Tree cover increased 35 percent at both streams. Thus, recovery of stability and cover and decreased sedimentation are compatible with rotation of rest grazing on Summer Camp Creek. Width/depth ratio and gravel/cobble percent did not change because they are inherently stable in this stream type. Management activities such as coarse woody debris removal limited pool recovery, and road crossings increased sedimentation.
(KEY TERMS: watershed management/wildland hydrology; sedimentation; environmental monitoring; climatic perturbations; aquatic habitat; rangeland streams.)

INTRODUCTION

Degraded riparian zones and aquatic habitat are often linked to abusive grazing (e.g., Gunderson, 1968; Platts and Nelson, 1985a, 1985b; Platts *et al.*, 1983). Most research on grazing-aquatic habitat interactions compares grazed and ungrazed conditions along the same stream by using exclosures and riparian pastures. The small scale of exclosure studies complicates their extrapolation to complete watersheds. There is also increasing recognition that watershed conditions affect improvement from exclosure fencing (Kondolf, 1994; DeBano and Schmidt, 1990), for example, because of continuing sediment supply from uplands. Besides, unless ranchers or agencies intend to fence all streams, exclosure study results have only limited applicability (Platts and Wagstaff, 1984).

A few watershed-scale studies provide guidance for managers. For example, Chapman and Knudsen (1980) found that grazing reduced the percent of overhead cover, grassy banks, and woody vegetation and reduced cutthroat trout biomass on many streams in Washington. Myers and Swanson (1991, 1992) found that pool percent and bank stability varied significantly with ungulate damage and stream type on rangeland streams in Nevada. By inference from the variable ungulate damage levels in the studied watersheds, these studies suggested that basinwide management effects differ among stream types. However, none of these studies provided information about grazing strategies other than ungulate damage levels and, therefore, are not very useful in designing grazing strategies.

Other management activities and climatic perturbations limit the improvement of aquatic and morphologic variables. For example, removal of coarse woody debris (CWD) affects stream morphology (Heede, 1972) and pool-riffle processes (Robison and Beschta, 1990; Smith *et al.*, 1993). Road crossings provide sediment to streams that counteracts other improvements in range management (Brown, 1994). Climatic fluctuations such as floods or droughts may affect stability (Bull, 1991) and sedimentation (Schumm, 1977).

Management changes on a watershed can cause positive or negative aquatic and riparian habitat responses over a long period, but managers usually

[1]Paper No. 94182 of the *Water Resources Bulletin*. **Discussions are open until October 1, 1996.**
[2]Research Associate and Associate Professor, Department of Environmental and Resource Sciences, University of Nevada-Reno, 1000 Valley Road, Reno, Nevada 89512.

collect few data to monitor changes. The Summit Lake watershed in northwestern Nevada is an exception. It became a priority to the U.S. Bureau of Land Management (BLM) because of the listing as a threatened species of the Lahonton cutthroat trout (USFWS, 1992) in the early 1970s. The BLM built a watershed exclosure on one branch of the largest tributary to Summit Lake and reduced grazing to rotation of rest on a second tributary in 1976. The BLM monitored the recovery of each stream for 14 years beginning in 1976.

The objective of this research is to assess the long-term recovery from abusive grazing resulting from watershed scale livestock exclosure and from rotation of rest grazing as well as assessing limitations to the recovery, by using paired watersheds in northwestern Nevada. We consider the limitations to improvement due to two other management impacts, the presence of road crossings and coarse woody debris removal. Finally, we compare changes due to heavy flooding and drought within this 14-year period.

STUDY AREA

Geological Setting

The Mahogany Creek (MC) and Summer Camp Creek (SCC) watershed drains 34.4 km^2 westward from the Black Rock Mountains in northwestern Nevada (Figure 1). The geologic substrate of the watershed is predominately rhyolitic and basaltic flows (Stewart and Carlson, 1978). Elevations range from 1830 to 2590 m. MC flows 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 annual precipitation depending on elevation (Houghton *et al.*, 1975). Woody riparian vegetation consists mostly of aspen (*Populus tremuloides*) and willow (*Salix* sp.).

Both streams, MC and SCC, 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. They rate type B4 in the Rosgen (1994) stream type procedure. Rosgen (1994) describes B- streams as riffle dominated with infrequently spaced pools and a very stable profile and banks. A U.S. Geological Survey gaging station has operated since 1987 about 2 km below the confluence of MC and SCC about 4 km above Summit Lake. Random streamflow measurements taken during July and August of 1992, 1993, and 1994 indicate that SCC baseflow is 25% greater than on MC. We extended the record of monthly flows by using multiple regression with two nearby gages ($R^2 = 0.90$):

$$Q_{MC} = .569 + .565Q_{KR(i)} - .046Q_{McC(i)} - .00605Q_{McC(i-1)} \quad (1)$$

Q_{MC} is monthly flow (cms) at MC (U.S. Geological Survey gage No. 10353750); Q_{KR} is monthly flow at the Kings River near Orovada, Nevada, gage (No. 10353600); Q_{McC} is monthly flow at the McDermitt Creek near McDermitt, Nevada, gage (No. 10352500); and i and i-1 represent current and lagged months, respectively. The reconstructed and observed hydrographs are combined and presented in Figure 2. Heavy snowfall caused high flows in the early 1980s and an eight-year period with interspersed drought and normal flow years began in 1987 (Table 1).

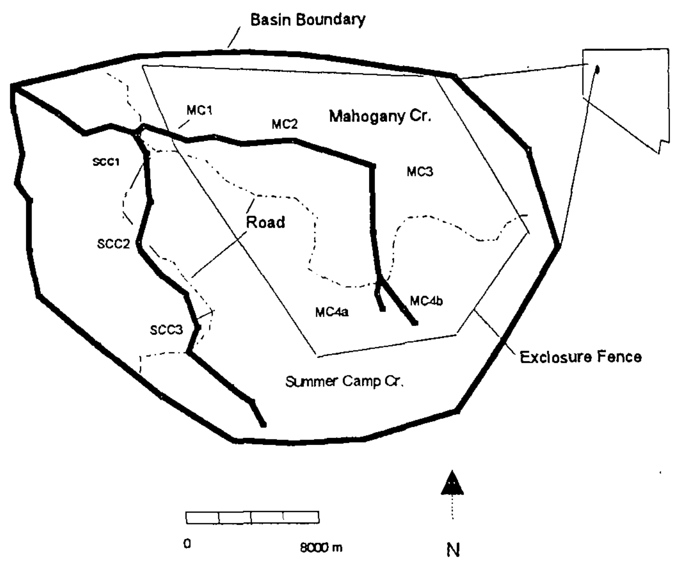


Figure 1. Location and Site Map for the Study Area in Nevada Showing the Plan of the Watershed, Stream Study Sites, Exclosure Fencing and Roads.

Land Management

The BLM built a watershed-scale exclosure in 1976 on MC (Figure 1), while SCC was grazed during five of 14 years between 1976 and 1990 (Table 1). The grazing strategy on SCC is rotation of rest although the rest periods and type of stock varied. There were approximately 300 horses in the pasture containing SCC, but the heaviest usage is south of SCC (BLM, 1993). The exclosure limited but did not eliminate

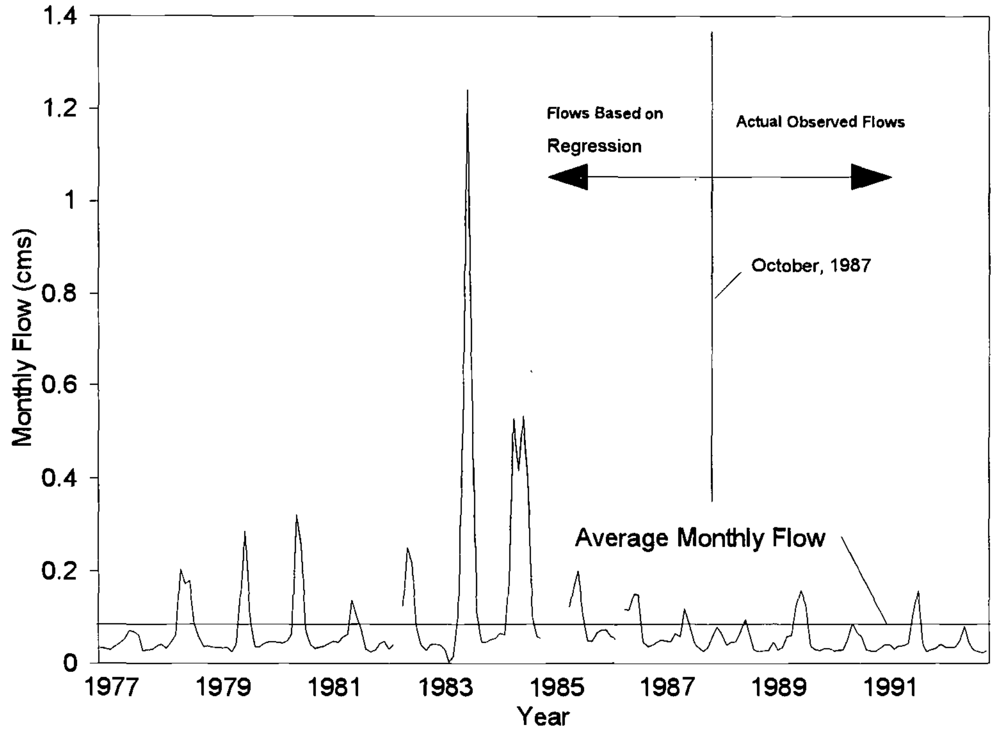


Figure 2. Measured and Predicted Monthly Flow on the U.S. Geological Survey Gaging Station on Mahogany Creek Below the Study Area. Measurements began in October 1987 and were extended with regression using two local gages from October 1976 to September 1987. Gaps on the line represent missing records at one or both gages used as independent variables.

TABLE 1. Grazing Use of Soldier Meadows Allotment in the Summer Camp Pasture and Flow Regime (high, normal, low).

Year	No. of Animals	Class	Use Period	Unauthorized Use*	Flow Regime
1977	Nonuse			2	Low
1978	Nonuse				Normal
1979	Nonuse				Normal
1980	1902	Cattle	7/1-10/31		High
1981	1844	Cattle	7/1-11/30	1	Low
1982	Nonuse				Normal
1983	Nonuse			3	High
1984	Nonuse				High
1985	Nonuse				Normal
1986	2500	Sheep	4/11-6/30	1	Normal
1987	2100	Sheep	7/1-9/30		Low
1988	2100	Sheep	6/1-11/15		Low
1989	Nonuse				Normal
1990	Grazing occurred after stream survey				Low

*Number of reported incidences of unauthorized grazing by one or more cattle.

horse usage of MC. Observations by the senior author during several weeks of field work during 1990, 1992, 1993, and 1994 suggested that horses were rarely present in the watershed. Stud piles of horse manure were rare in the MC or SCC watersheds but were common in the watershed south of SCC. We do not consider horse trampling or grazing to have had much impact on the study area streams.

Other management activities affected these watersheds. There was approximately two km/km^2 of road on both basins with two crossings per stream within the study reach (Figure 1). Also, managers cleared coarse woody debris (CWD) from both streams in the 1970s to clear fish passages (Jack Piccolo, Summit Lake Tribal Fisheries Biologist, personal communication, 1993). This was still obvious in 1994 as seen from old debris on the floodplain and terraces and sawcuts on riparian shrubs.

METHOD OF ANALYSIS

Field Methods

BLM stream surveys (BLM, 1978) included cross-section, pool, substrate, and bank stability characteristics. A monitoring station was a randomly chosen stream reach with four cross-channel transects spaced at 30.5 meter intervals. There were five stations on MC (labeled MC#) and three stations on SCC (labeled SCC#) (Figure 1). Thus, monitoring occurred on almost 1 km of the total 12 km of stream in the watershed.

BLM surveyors measured stream cross-sectional properties across each transect as a fraction of water width. We averaged the fractions to determine station values expressed as a percent of stream width. We analyzed pool percent, real pool percent, percent that pool percent is of a perceived optimum (pool measure), pool quality, percent gravel and cobbles, percent silt (silt, clay and fine organic matter), bank stability, vegetation type, ungulate bank damage, habitat condition index (HCI), and water width/depth ratio (Table 2).

Pools are the deeper, placid, slow-moving, low-gradient units of a stream (BLM, 1978), which is compatible with more rigorous definitions used in different studies (e.g., Grant *et al.,* 1990; Myers and Swanson, 1994). The quality of a pool as aquatic habitat depends on depth and cover; therefore, we used the BLM definition that a high quality pool is at least 0.6 meters deep with cover on at least 25 percent of the perimeter (BLM, 1978).

Substrate measurements included percent silt, boulders, and combined gravel/cobble (2 to 308 mm) measured as a fraction of width and averaged over the four transects. Gravel and cobble provides preferred salmonid habitat (Binns and Eiserman, 1979; Kozel and Hubert 1989) while silt degrades the habitat.

Streambank monitoring included ocular estimates of bank stability, vegetation, and ungulate damage. The surveyor described conditions by using qualitative variables, or categories, such as poor, fair, good and excellent. Categories corresponded to measurable values. The BLM estimates included 30.5 meters of channel length centered at each transect. For example, BLM stability categories are totally unstable, less

TABLE 2. Definition of Aquatic and Riparian Variables.

Variable	Definition
Pool Percent	Percent of total stream width classified as pools.
Pool Quality	Percent of pools rates as high quality which is deeper than 0.6 m with cover on at least 25 percent of the perimeter.
Pool Measure	Percent that pool percent is of 50 percent considered to be optimum for fish. Pool measure = pool percent/50 or pool measure = (100-pool percent)/50 if pool percent is less or greater than 50 percent, respectively.
Real Pool Percent	Percent of total stream width classified as high quality pools.
Percent Silt	Percent of the stream bottom classified as silt, clay, and fine organic matter.
Percent Cobble/Gravel	Percent of stream bottom classified as cobble or gravel (2 to 302 mm).
Stability	Percent of banks rated as stable defined as the lack of obvious erosion or deposition.
COVER	Percent desirable bank vegetation. Assumes that forested banks are most desirable and that brush, herbs, and exposed banks are 75, 50, and 25 percent as desirable.
HCI	Habitat condition index: average of pool measure, pool quality, percent cobble/gravel, stability, and COVER.
Water Width/Depth	Ratio of the water width to the average water depth.

than 50 percent, greater than 50 percent, and totally stable. A stable bank did not have obvious signs of erosion or deposition. We converted to percent stable by using mid-range values for each category. The BLM rated bank vegetation as exposed, grassy, brushy, and forested, respectively, assuming that forested banks are most desirable. We used BLM's ungulate damage rating as a simple indicator of grazed or not grazed.

Statistical Methods

We used trend analysis to assess recovery and effects of climatic perturbations. Pool variables, stability, and silt are not normally distributed because their values approached the bounds of 0 or 100. We assessed long-term trends of these time-series data by using the Mann-Kendall sign test (Gilbert, 1987) as follows. First, we determined all possible differences x_j-x_k where x is the data and j is any year later than k. When considering a single site, there was one observation per year. When considering data pooled over the entire stream, there was more than one observation in any year. Let $sgn(x_j-x_k)$ be an indicator function equalling 1, 0, or -1 if x_j-x_k is positive, 0, or negative, respectively. Then, the Mann-Kendall statistic (S) is the sum of indicator functions over all possible comparisons. Increasing values with time give a positive S and decreasing values give a negative S. Hollander and Wolfe (1973) provide significance probabilities when the number of observations is less than 40. When the number of observations exceeds 40, the distribution of S approaches normal. Gilbert (1987) provides formulas for Var (S) and the probability distribution function Z.

Although bounded by 0 and 100, values of gravel/cobble percent and HCI do not approach these bounds and are, along with water width/depth ratio, normally distributed. To test trend with time and difference in mean and trend between streams, we used multiple regression with indicator variables (Manly, 1992; Neter *et al.,* 1985) with the following expanded general form:

$$V = \beta_0 + \beta_1 \times YEAR + \beta_2 \times I + \beta_3 \times YEAR{*}I \qquad (2)$$

where I is 0 for MC and 1 for SCC and year*I is an interaction term. β_1 is trend on MC, and $\beta_1 + \beta_3$ is trend on SCC. β_2 is the difference in mean values. The coefficients or sums of coefficients may be tested for significance with standard t-tests (Neter *et al.*, 1985). If β_3 is significant, there is a difference in trend between streams. To test trends at individual sites, we dropped I and the interaction term to determine just β_1.

To analyze trends in tree cover, we assigned to the variable TREE the value 1 for reaches predominately vegetated with trees and 0 for reaches with other vegetation. Using ordinary least squares regression and data pooled for each stream, we assessed the probability that sites were tree vegetated (Neter *et al.,* 1985):

$$TREE = \beta_0 + \beta_1 \times YEAR + \beta_2 \times I + \beta_3 \times YEAR{*}I \quad (3)$$

β_1 is the rate the probability that trees dominated a site changes with year. β_2 is the differential probability that sites on SCC were dominated by trees. β_3 is an interaction coefficient. Neter *et al.* (1985) recommended this model for binary dependent data. They indicated that the coefficients are unbiased but will no longer have the minimum variance property. They recommended weighting the analysis with $\hat{w}_i = 1/(\hat{Y}_i(1-\hat{Y}_i))$, which we did, but the final coefficients did not vary to three significant figures as expected because the mean responses were not near the bounds.

We compared among or between groups with Kruskal-Wallis one-way ANOVA and the Mann-Whitney U-test (Sokal and Rohlf, 1981), respectively. We used chi-square analysis to test the hypothesis of independence between categorical variables (Fienberg, 1980). We calculated correlation between nonnormal variables by using Spearman rank correlation (Sokal and Rohlf, 1981).

RESULTS AND DISCUSSION

Initial Conditions

Initial (1976) distributions of stability, silt substrate, and all pool variables (pool percent, quality, measure, and real pool percent) were not significantly different (U-tests, p=0.392, p=0.392, p=0.500, p=0.392, p=0.125, p=0.392, respectively). Initial means of gravel/cobble percent and width/depth ratio were not significantly different (t-tests, p=0.485, p=0.450, respectively). Similar initial conditions suggest, and we assume for this analysis, that trends observed on just one stream represent different recovery rates and responses to climate due to management between 1976 and 1990. We also base our assumption on similar basin sizes, relief, geology, and stream type on the two streams.

Bank Stability

From 1976 to 1990, bank stability increased significantly on MC but not on SCC due to cattle grazing periods and floods (Table 3, Figure 3). Grazing followed by floods caused greater stability decreases on SCC than just floods on MC. Negative correlation (r=-0.45) with flows in May and June also suggested that high flow decreased stability. We then split the data into two periods, 1976 to 1981 and 1982 to 1990. During the first period, stability increased only on MC and on station MC3. Beginning in 1982, stability increased significantly on both streams and at several individual stations (Table 3, Figure 3). Sheep grazing in 1986-1988 did not decrease stability on SCC.

Stability varied significantly among cover type (Kruskal-Wallis test statistic (KWS) = 25.1, $p < 0.001$) with tree-covered banks being the most stable (Figure 4). Stability was also significantly higher (Mann Whitney U = 5.12, $p<0.001$) on stations without observed ungulate damage (Figure 5). These results agree with other studies linking bank stability to cover type and ungulate bank damage (Heede, 1972; Myers and Swanson, 1991, 1992).

Pool Variables

Pool percent (Figure 6) and pool measure, while fluctuating greatly, generally decreased through the study period (Table 4). Pool percent declined from near the biological optimum of 50 percent. In

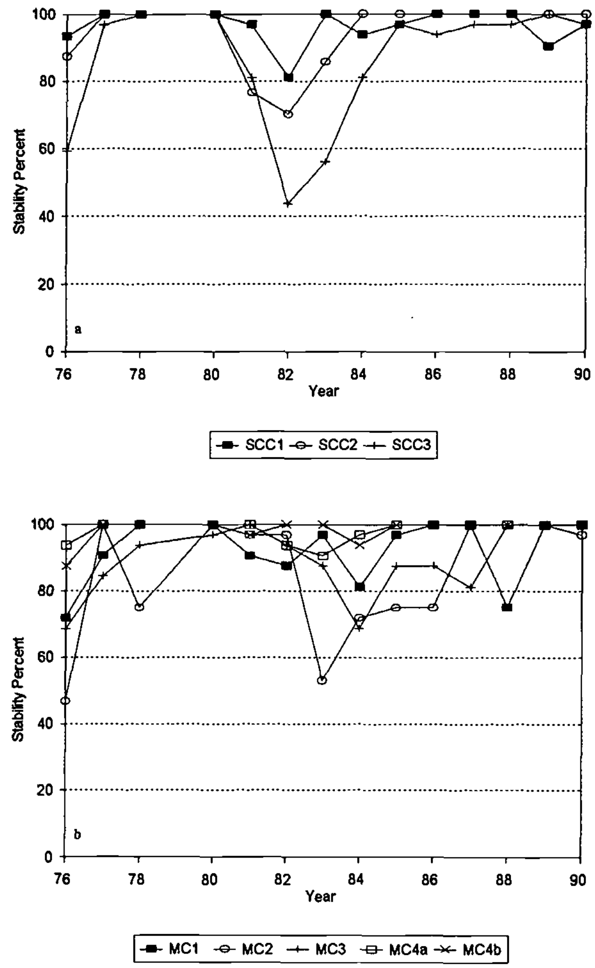


Figure 3. Time Series of Streambank Stability for Summer Camp Creek (a) and Mahogany Creek (b) (see Table 3 for significance of trends).

TABLE 3. Trend of Stream Bank Stability, S is Mann-Kendall Statistic, P is Significance Probability.

Station	1976-1990[1] S	1976-1990[1] P	1976-1981[2] S	1976-1981[2] P	1982-1990[3] S	1982-1990[3] P
MC1	22	.113	4	.242	13	.110
MC2	19	.165	3	.325	17	.049
MC3	24	.105	10	.008	12	.130
MC4a	17	.914	4	.242	19	.030
MC4b	18	.180	1	.500	4	.381
MC	460	.012	89	.019	310	.000
SCC1	-3	.457	1	.500	5	.345
SCC2	20	.152	−1	.500	15	.075
SCC3	19	.165	3	.325	26	.003
SCC	106	.225	8	.436	121	.004

[1]n=70 for MC, n=42 for SCC, n=14 for individual stations.
[2]n=25 for MC, n=15 for SCC, n=5 for individual stations.
[3]45 for MC, n=27 for SCC, n=9 for individual stations.

anecdotal comparison, pools on SCC appeared to decrease more than on MC.

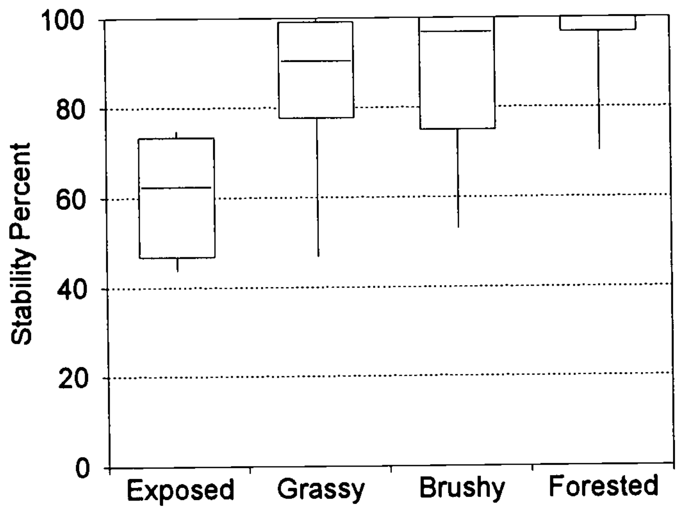


Figure 4. Variation of Streambank Stability of Both Streams with Dominant Cover Type. The rectangle envelopes the middle 50 percent of observations; the line in the middle is the median; the vertical line represents the complete range.

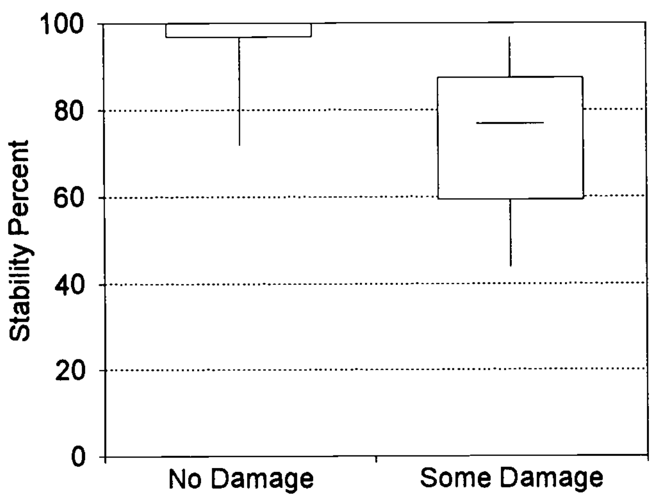
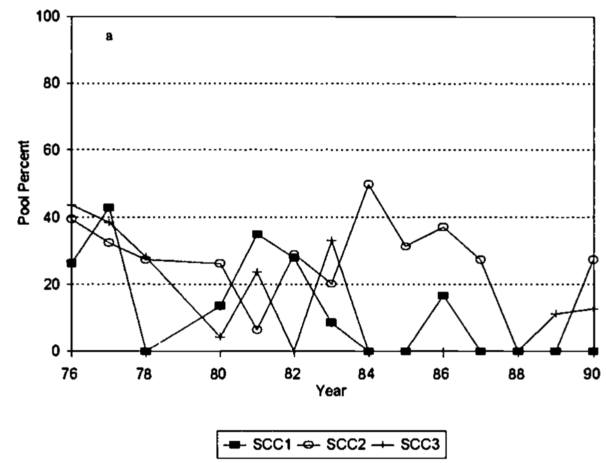


Figure 5. Variation of Streambank Stability of Both Streams with Ungulate Damage. The rectangle envelopes the middle 50 percent of observations; the line in the middle is the median; the vertical line represents the complete range.

Spearman rank correlations of pool percent (0.21 and 0.29) and pool measure (0.21 and 0.22) with fine gravel and silt percents indicated weak correspondence between substrate type or sediment deposition and pool formation. This agrees with theories of pool formation by scouring of fines (Milne, 1982) and velocity reversal (Keller, 1971; Keller and Florsheim, 1993), and it suggests that these processes operate on these sites. At base flow, pool velocity is low due to wider cross-sectional area. At high flow, cross-sectional area increases faster in the riffle and eventually the pool velocity exceeds the riffle velocity. Velocity vectors converge in pools and scour the substrate. This process description explains increases in pool area after high flows in 1983 (Figure 6). As flow decreased after peak flow events, fine substrate settled in the pools, decreasing their area.



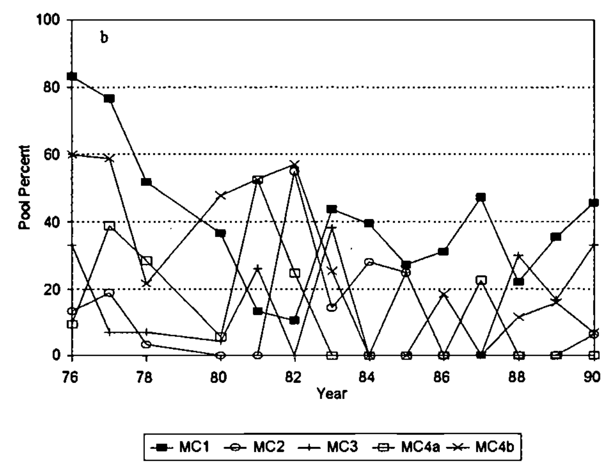


Figure 6. Time Series of Pool Percent for Summer Camp Creek (a) and Mahogany Creek (b) (see Table 4 for significance of trends).

Pool quality decreased rapidly through the period (Figure 7). Probably, initial poor quality pools disappeared and high quality pools became shallow, decreasing both the pool percent and quality. Quality increased moderately in 1983, mostly on the ungrazed MC, due to increased pool depth. However, localized scour probably limited improvements in quality by

TABLE 4. Trend of Pool Variables Defined in Table 2 from 1976 to 1990.

Station*	Pool Percent		Pool Measure		Pool Quality		Real Pool Percent	
	S	P	S	P	S	P	S	P
MC1	–23	.117	17	.194	–8	.042	–6	.394
MC2	–18	.180	–18	.180	**	**	–6	.394
MC3	–1	.500	–1	.500	**	**	23	.117
MC4a	–42	.012	–42	.012	**	**	–5	.415
MC4b	–50	.002	–42	.012	–46	.007	–42	.012
MC	–548	.003	–360	.033	**	**	–155	.195
SCC1	–42	.012	–42	.012	**	**	–2	.479
SCC2	–23	.117	–23	.118	–3	.457	–1	.500
SCC3	–36	.028	–36	.028	**	**	2	.479
SCC	–309	.000	–192	.017	**	**	–28	.378

*n=70 for MC, n=42 for SCC, n=14 for individual stations.
**There is too little non-zero data (35 percent of observations) for analysis.

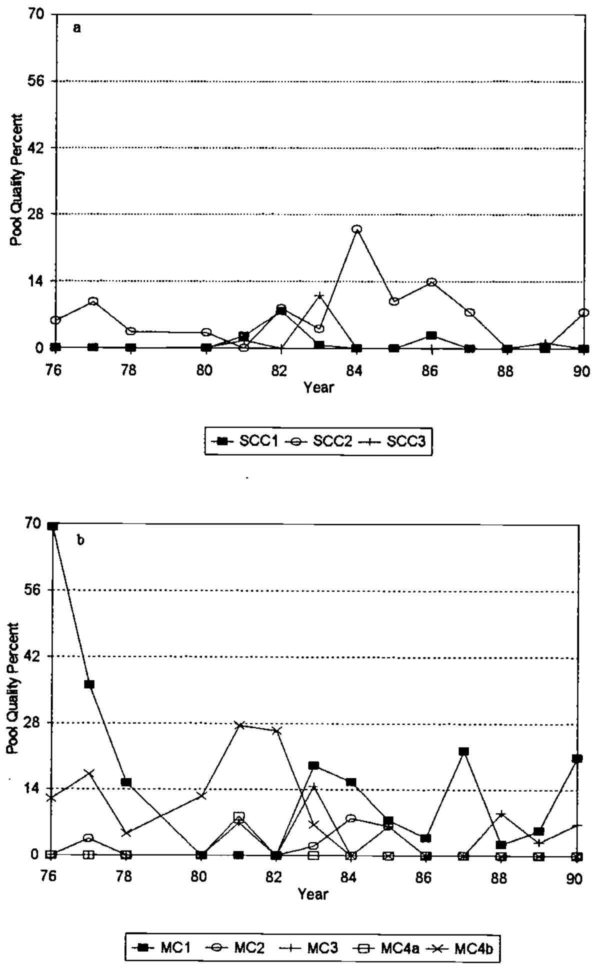


Figure 7. Time Series of Pool Quality Percent for Summer Camp Creek (a) and Mahogany Creek (b) (see Table 4 for significance of trends).

removing cover (Shields *et al.*, 1994). Pool infilling during drought decreased pool quality and pool area in the late 1980s.

All pool variables show a weak Spearman rank correlation with organic debris (pool percent- 0.26, pool measure- 0.25, pool quality- 0.25, real pool percent- 0.25), which agrees with many other studies (Carlson *et al.*, 1990; Robison and Beschta, 1990; Shirvell, 1990) in that organic debris had positive effects on pool formation and quality. By removing CWD, managers may have decreased stability of or actually removed many pools (Heede, 1972; Smith *et al.*, 1993). As discussed below, trees have been recovering, but that apparently has not yet provided substantial CWD to the system. This suggests that tree recovery requires more than 15 years to substantially increase CWD. Other studies (Carlson *et al.*, 1990) suggested that vegetation recovery required 50 years to supply much CWD to the streams.

Multiple regression analyses of all pool variables with flow rates in May, June, and July were insignificant. June and July rates represented flows occurring during the survey, and May rates indicated pool forming flows. This lack of correlation with current flow rate will be counterintuitive to many managers who blame low flow conditions for poor pool conditions. Droughts may cause pool infilling, but these results and those of Kershner and Snider (1992) indicate that flow rate at the time of measurement was less important. The lack of correlation with May flows indicated that low runoff during droughts was insufficient to form pools and that increases in pools during the high flow year 1983 did not last.

Finally, no pool variables correlated with bank stability or cover, suggesting that local bank improvement did not immediately influence the riffle-pool sequence. Stream bottom processes of sediment transport and scour apparently occurred independently of bank conditions. Riparian vegetation and stable banks usually provide cover for pools and overhangs, but the lack of correlation with pool quality or real pool percent suggests that riparian vegetation had not yet matured to the point of improving pool shape or size.

Stream Bottom Variables

Silt decreased through the study period, with most decreases occurring from 1976 to 1981 (Figure 8). Fine sediment accumulation indicates excessive silt loading upstream (Lisle and Lewis, 1992). Measurement of silt provided an assessment of cumulative effects upstream of monitoring stations (Lisle and Hilton, 1992). Once sediment sources heal, streams require time to transport sediment through their system (Cushing *et al.,* 1993). This watershed required about five years beginning with the improved grazing management. After high water, silt was absent from the system and only began to substantially reappear in 1987 on MC and 1988 on SCC after several years of low flows. Most accumulations were just below roads.

There was no significant trend in gravel/cobble percent or variation between streams as represented by coefficients from the Equation (2) model. It increased until about 1984 and decreased until 1987 on the upstream stations (SCC3, MC4a and MC4b) of both streams (Figure 9). Decreases after 1985 exceeded the slight increases in silt. Apparently, increases and decreases in boulder percent on these upper stations (Figure 9) caused opposite fluctuations in gravel/cobble percents. Correlation with silt and boulder percents for upstream stations support this interpretation (r=-0.12 and -0.83, respectively).

Vegetation Changes

The probability that trees dominated stream banks on both streams increased with time:

$$TREE = -1.27 + 0.0233 \times YEAR + 0.0429 \times I \quad (4)$$

TREE is the probability that trees were dominant at a site on stream I in a given year. The interaction term, β_3, in Equation (3) was insignificant (p=0.95), and we dropped it for Equation (4) to better determine the average difference between streams, which

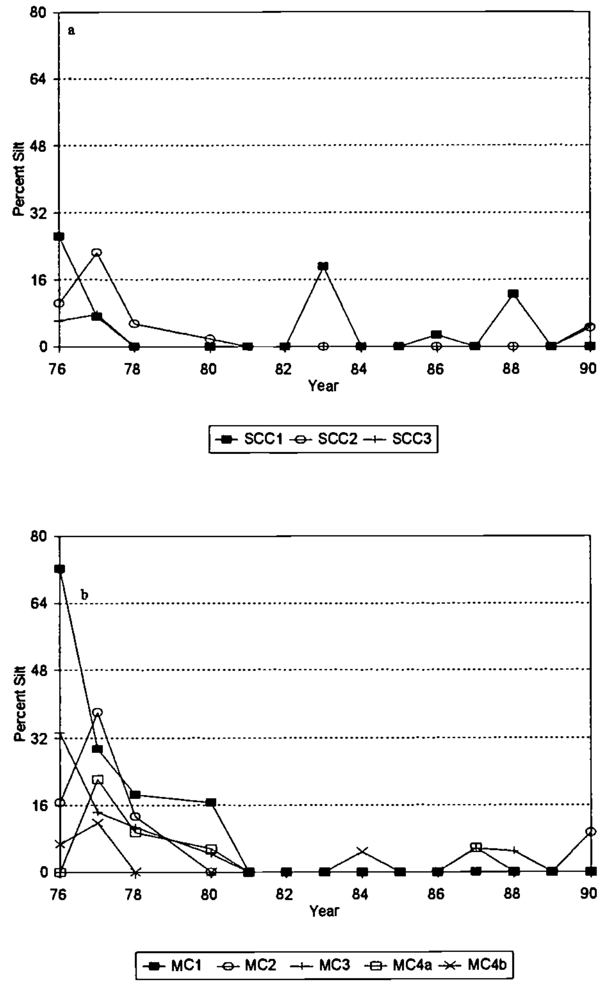


Figure 8. Time Series of Percent Silt for Summer Camp Creek (a) and Mahogany Creek (b). Decreases are significant for Summer Camp Creek, Station 2 (p=0.040), and Mahogany Creek, Station 1 (p=0.006), and Station 3 (p=0.031).

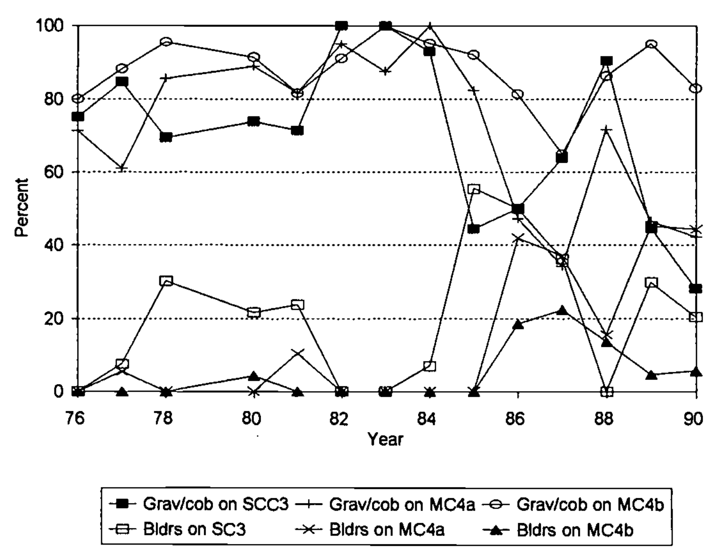


Figure 9. Time Series of Gravel/Cobble Percent (a) and Percent Boulders (b) Time Series Data for Selected Upper Elevation Stations.

also was insignificant (p=0.15). We kept β_2 in Equation (4) to illustrate that trend was much more important than between stream differences. The significant coefficient of YEAR (p=0.022) indicates a trend. Between 1976 and 1990, the probability for banks to be predominately trees increased 0.35. Increasing tree cover paralleled and probably caused the improvement in bank stability.

Categorical vegetation types (exposed, grassy, brush, forest) did not vary between streams because of equivalent increases in tree cover, but they did vary with ungulate damage (chi-square test statistic, $(\chi^2)=13.5$, p=.004). Bare or grass-covered banks had more ungulate damage than expected while tree covered banks had less than expected. This vegetation/ungulate damage relation suggested that regeneration of bank tree cover followed the decrease in ungulate damage due to the SCC grazing regime.

Habitat Condition Index

There was no general trend of HCI with time or difference between streams. Stations MC4a and MC4b had significant decreases (1.3 and 1.5 percent per year, P=0.047 and 0.030, respectively) due to decreasing pool measure and gravel/cobble percent. Lack of detected trend suggests that obvious indicators such as bank vegetation and stability may not indicate improvement of aquatic habitat if it actually occurred or that HCI is an inefficient estimator of overall quality (Myers and Swanson, 1991).

Correlations between pool variables (pool measure and pool quality) and bank variables (stability and COVER) were high (r=0.60 and 0.45, p<0.001, respectively). Correlations of all variables with the gravel/cobble percent and of pool variables and bank variables were all very low (r<0.11). Decreases in pool percent and quality and increases in stability (Figures 3, 6, and 7) counteracted each other thus limiting the value of HCI.

Width / Depth Ratio

The water width/depth ratio at base flow indicates the stability of the base flow channel (Osterkamp and Hupp, 1984) and is a shape factor (Richards, 1982) integrating cross-sectional shape into one variable. There was no trend with time or difference between the streams. Only stations MC2 and MC4a had significantly (P=0.05) higher water width/depth ratios (W/D = 30.0 for each, compared to an overall average 24.0). Only station MC4a had a significant (P=0.021, 3.2/year) trend. There were no differences in width/depth ratio with or without ungulate damage or tree cover, and correlation between width/depth ratio and stability was insignificant. Typically, stable banks have dense vegetation or high quantities of large rock (Myers and Swanson, 1992) and a strong effect on cross-sectional properties (Millar and Quick, 1993). The lack of trend and differences between groups suggests that cross-sectional shapes on these streams are stable for the range of grazing management studied here.

CONCLUSION

Both study streams improved since 1976 when heavy, season-long grazing ended. Stability and tree cover increased while sedimentation decreased without regard to grazing treatment. The fact that conditions improved on SCC and MC suggests that long-term recovery is consistent with rotation of rest grazing where rest occurred nine of 14 years. However, the stability decrease due to flooding after two years of grazing suggests that additional rest for SCC at the beginning of the study period may have been necessary. Sheep grazing after several additional years of recovery did not apparently have detrimental effects on SCC.

Some variables did not improve due to other management, initial conditions, or climatic perturbations. For example, fine sediment decreased overall, but accumulations during low flow coincided with roads which act as a source of and conduit for fine sediment to reach the stream. Significant improvements to these streams may result from a reduction in roads and crossings. Also, CWD removal possibly prevented improvement of pools.

Stream type inherently limits improvement of various parameters. In this study, both streams are type B4 (Rosgen, 1994), which may limit pool, gravel/cobble, and width/depth variables. The lack of differences in some variables between streams suggests uniformity not substantially affected by the varying management. Most pool variables decreased, but there is little indication here or in the literature as to potential values for this stream type. Gradient (Kozel *et al.*, 1989) and stream structure (Myers and Swanson, 1994; Heede, 1972) are important controls of pool variables that are slow or impossible to change. As expected, width/depth ratio did not improve on B4 streams. Managers must understand the limits imposed by geomorphology.

Land managers must understand individual components which determine aquatic and riparian habitat quality. The widely used index HCI did not distinguish between streams or among stations because of the negative correlation between constituent variables. Land managers should study individual factors rather than relying heavily on general indices. Managers should decide which parameters limit the quality of their stream and isolate the management activity that most affects that parameter. Then they can probably choose which aspect to concentrate upon. This study provides not only one example of how management can substantially improve aquatic habitat conditions but also how geology and past management may limit the options of contemporary managers.

ACKNOWLEDGMENTS

This research was funded by a Federal Aid in Sport Fish Restoration grant from the Nevada Division of Wildlife and funds from the Nevada Agricultural Experiment Stations Project 52CB. We thank Rick Rieber of the BLM for review. We also thank Gene Weller, Jim French, and Leroy McClelland of the Nevada Division of Wildlife, Jack Piccolo and William Cowan of the Summit Lake Indian Reservation, and Arne Bergland and Ron Frazer of the BLM for their many helpful comments concerning the management of Mahogany Creek. Dennis Toll of the BLM collected many of the early data.

LITERATURE CITED

Binns, N. A. and F. M. Eiserman, 1979. Quantification of Fluvial Trout Habitat in Wyoming. Transactions of the American Fisheries Society 108:215-228.

Brown, K. J., 1994. River-Bed Sedimentation Caused by Off-Road Vehicles at River Fords in the Victorian Highlands, Australia. Water Resources Bulletin 30:239-250.

Bull, W. B., 1991. Geomorphic Responses to Climatic Change. Oxford University Press, New York, New York, 326 pp.

Bureau of Land Management (BLM), 1978. Manual 6671 - Stream Surveys. USDI Bureau of Land Management, Nevada State Office, Reno, Nevada.

Bureau of Land Management (BLM), 1993. Soldier Meadows Allotment Reevaluation (draft). USDI Bureau of Land Management, Winnemucca District Office, Winnemucca, Nevada.

Carlson, J. Y., C. W. Andrus and H. A. Froehlich, 1990.. Woody Debris, Channel Features, and Macroinvertebrates of Streams With Logged and Undisturbed Riparian Timber in Northeastern Oregon, U.S.A. Canadian Journal of Fisheries and Aquatic Sciences 47:1101-1111.

Chapman, D. W. and E. Knudsen, 1980. Channelization and Livestock Impacts on Salmonid Habitat and Biomass in Western Washington. Transactions of the American Fisheries Society 109:357-363.

Curry, B. B. and W. N. Melhorn, 1990. Summit Lake Landslide and Geomorphic History of Summit Lake Basin, Northwestern Nevada. Geomorphology 4:1-17.

Cushing, C. E., G. W. Minshall, and J. D. Newbold, 1993. Transport Dynamics of Fine Particulate Organic Matter in Two Idaho Streams. Limnology and Oceanography 38:1101-1115.

DeBano, L. F. and L. J. Schmidt, 1990. Potential for Enhancing Riparian Habitats in the Southwestern United States With Watershed Practices. Forest Ecology and Management 33:385-403

Fienberg, S. E., 1980. The Analysis of Cross-Classified Categorical Data (2nd. Edition). The MIT Press. Cambridge, Massachusetts, 246 pp.

Gilbert, R. O., 1987. Statistical Methods for Environmental Pollution Monitoring. Van Nostrand Reinhold Co. New York, New York, 320 pp.

Grant, G. E., F. J. Swanson, and M. G. Wolman, 1990. Pattern and Origin of Stepped-Bed Morphology in High-Gradient Streams in Western Oregon. Geological Society of America 102:340-352.

Gunderson, D. R., 1968. Floodplain Use Related to Stream Morphology and Fish Populations. Journal of Wildlife Management 32:507-514

Heede, B. H., 1972. Influences of a Forest on the Hydraulic Geometry of Two Mountain Streams. Water Resources Bulletin 8:523-530.

Hollander, M. and D. A Wolfe, 1973. Nonparametric Statistical Methods. John Wiley and Sons, New York, New York, 503 pp.

Houghton, J. G., C. M. Sakamota, and R. O. Gifford, 1975. Nevada's Weather and Climate. Nevada Bureau of Mines and Geology, Special Publication 2, 78 pp.

Keller, E. A., 1971. Areal Sorting of Bed-load Material: The Hypothesis of Velocity Reversal. Geological Society of America Bulletin 82:753-756.

Keller, E. A. and J. L. Florsheim, 1993. Velocity-Reversal Hypothesis: A Model Approach. Earth Surface Processes and Landforms 18:733-740.

Kershner, J. L. and W. M. Snider, 1992. Importance of a Habitat-Level Classification System to Design Instream Flow Studies. *In:* River Conservation and Management, P. J. P. Calow and G. E. Petts (Editors). John Wiley and Sons, New York, New York, Chapter 12.

Kondolf, G. M., 1994. Lag in Stream Channel Adjustment to Livestock Exclosure, White Mountains, California. Restoration Ecology 2:226-230.

Kozel, S. J. and W. A. Hubert, 1989. Testing of Habitat Assessment Models for Small Trout Streams in the Medicine Bow National Forest, Wyoming. North American Journal of Fisheries Management 9:458-464.

Kozel, S. J., W. A. Hubert, and M. G. Parsons, 1989. Habitat Features and Trout Abundance Relative to Gradient in Some Wyoming Streams. Northwest Science 63:175-182.

Lisle, T. E. and S. Hilton, 1992. The Volume of Fine Sediment in Pools: An Index of Sediment Supply in Gravel-Bed Streams. Water Resources Bulletin 28:371-383.

Lisle, T. E. and J. Lewis, 1992. Effect of Sediment Transport on Survival of Salmonid Embryos in a Natural Stream: A Simulation Approach. Canadian Journal of Fisheries and Aquatic Sciences 49:2337-2344.

Manly, B. F., 1992. The Design and Analysis of Research Studies. Cambridge Univ. Press, New York, New York, 353 pp.

Millar, R. G. and M. C. Quick, 1993. Effect of Bank Stability on Geometry of Gravel Rivers. Journal of Hydraulic Engineering 119:1343-1363.

Milne, J. A., 1982. Bed-Material Size and the Riffle-Pool Process. Sedimentology 29:267-278.

Myers, T. J. and S. Swanson, 1991. Aquatic Habitat Condition Index, Stream Type, and Livestock Bank Damage in Northern Nevada. Water Resources Bulletin 27:667-677.

Myers, T. J. and S. Swanson. 1992. Variation of Stream Stability With Stream Type and Livestock Bank Damage in Northern Nevada. Water Resources Bulletin 28:743-754.

Myers, T. and S. Swanson, 1994. Grazing Effects on Pool Forming Features in Central Nevada. *In:* Effects of Human-Induced Changes on Hydrologic Systems, R. A. Marston and V. R. Hasfurther (Editors). American Water Resources Association, Jackson Hole, Wyoming, pp. 235-244.

Neter, J., W. Wasserman, and M. H. Kutner, 1985. Applied Linear Statistical Sodels (2nd. Edition). Irwin, Homewood, Illinois.

Osterkamp, W. R. and C. R. Hupp, 1984. Geomorphic and Vegetative Characteristics Along Three Northern Virginia Streams. Geological Society of America Bulletin 95:1093-1101.

Platts, W. S. and R. L. Nelson, 1985a. Impacts of Rest-Rotation Grazing on Stream Banks in Forested Watersheds in Idaho. North American Journal of Fisheries Management 5:547-556.

Platts, W. S. and R. L. Nelson, 1985b. Stream Habitat and Fisheries Response to Livestock Grazing and Instream Improvement Structures, Big Creek, Utah. Journal of Soil and Water Conservation 40:374-379.

Platts, W. S., R. L. Nelson, O. Casey, and V. Crispin, 1983. Riparian-Stream Habitat Conditions on Tabor Creek, Nevada, Under Grazed and Ungrazed Conditions. Proceedings Western Association of Wildlife Management Agencies 63:162-174.

Platts, W. S. and F. J. Wagstaff, 1984. Fencing to Control Livestock Grazing on Riparian Habitats Along Streams: Is it a Viable Alternative? North American Journal of Fisheries Management 4:266-272.

Richards, K.S., 1982. Rivers: Form and Process in Alluvial Channels. Metheum, London and New York, New York, 361 pp.

Robison, E. G. and R. L. Beschta. 1990. Coarse Woody Debris and Channel Morphology Interactions for Undisturbed Streams in Southeast Alaska. U.S.A. Earth Surface Processes and Landforms 15:149-156.

Rosgen, D., 1994. A Classification of Natural Rivers. Catena 23: 169-199.

Schumm, S. A., 1977. The Fluvial System. John Wiley and Sons. New York, New York, 398 pp.

Shields, Jr., F. D., S. S. Knight, and C. M. Cooper, 1994. Effects of Channel Incision on Base Flow Stream Habitats and Fishes. Environmental Management 18:43-57.

Shirvell, C. S., 1990. Role of Instream Rootwads as Juvenile Coho Salmon (*Oncorhynchus kisutch*) and Steelhead Trout (*O. mykiss*) Cover Habitat Under Varying Streamflows. Canadian Journal of Aquatic and Fisheries Sciences 47:852-861.

Smith, R. D., R. C. Sidle, P. E. Porter, and J. R. Noel, 1993. Effects of Experimental Removal of Woody Debris on the Channel Morphology of a Forest, Gravel-Bed Stream. Journal of Hydrology 152:153-178.

Sokal, R. R. and F. J. Rohlf, 1981. Biometry: The Principles and Practice of Statistics in Biological Research (2nd. Edition). W. H. Freeman and Co., New York, New York.

Stewart, J. H. and J. E. Carlson, 1978. Geologic Map of Nevada. Nevada Bureau of Mines and Geology.

United States Fish and Wildlife Service (USFWS), 1992. Lahonton Cutthroat Trout, *Onchorhynchus clarki henshawi* (Salmonidae) Recovery Plan. Portland, Oregon, 103 pp.