

Sediment Dynamics and Sources in a Grazed Hardwood Rangeland Watershed¹

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Abstract

From 1994 to 1998 we documented sediment transport dynamics and sources in a 137 ha grazed hardwood rangeland watershed on granitic soils at the San Joaquin Experimental Range in Madera County. Sediment transport for this watershed was determined by measuring total suspended solids, bedload and flow at an H-flume installed in 1994. Sediment movement as bedload is the primary means of sediment transport in this watershed, with minimal transport of suspended solids. This is attributed to the large sediment particle size and low stream power characteristic of this low gradient intermittent watershed. Bedload transport can be predicted by stream flow ($p < 0.0001$, $R^2 = 0.68$). Upland sediment sources were surveyed using paired hillslope plots to estimate upland erosion for three slope classes. Sediment traps were installed to compare erosion on cattle trails and adjacent non-trailed areas. Ten stream cross section profiles were averaged to determine grazing treatment and year effects on in-stream erosion and deposition along three intermittent stream channels. Due to rapid infiltration, runoff and sediment yield from the hillslope, plots averaged only 151 mm and 36 kg/ha, respectively. Unvegetated, disturbed soil surfaces in cattle trails were a significantly greater ($p < 0.002$) source of sediment ($0 = 238$ g/trap, $n = 8$ traps) than adjacent well-vegetated soil surfaces ($0 = 6$ g/trap, $n = 8$ traps). From 1994 to 1998 stream channel morphological parameters did not change in response to no grazing, winter moderate or concentrated grazing, or dry season moderate or concentrated grazing. There was a year effect on channel depth due to the dynamics of bedload transport in response to variation in peak storm events from year to year. The results of these studies suggest that sediment movement from cattle trails into stream channels is the main grazing-induced sediment source in this watershed.

Introduction

Most of California's surface water flows through the State's 6.8 million ha of annual rangeland. Sediment is the most prevalent non-point source pollutant in these surface waters (State Water Resources Control Board Staff 1999). Causes of erosion within these rangelands include natural processes and historic land use, as well as anthropogenic activities such as road construction and livestock production (Lewis and others 2001). Concerns exist throughout California's Sierra Nevada Mountains

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(Sierra Nevada Ecosystem Project 1996) that livestock grazing increases hill slope and stream channel erosion. Several research and case studies have reported livestock-induced streambank erosion leading to channel down cutting or widening (Hall and Bryant 1995, Kauffman and Krueger 1984, McDonald and others 1991, Sierra Nevada Ecosystem Project 1996). In 1994 we began documenting sediment transport dynamics and sources in a grazed hardwood rangeland watershed on granitic soils at the San Joaquin Experimental Range in Madera County.

Site Description

The 1,752 ha San Joaquin Experimental Range (SJER) in Madera County, Calif. has been a USDA Forest Service research facility since 1935 (Kie 1990). SJER lies in the lower central Sierra Nevada foothills in the oak savanna vegetation type. California State University at Fresno (CSUF) maintains a herd of 210 commercial beef cows at SJER. In 1994 an H-flume was placed at the bottom of a 137 ha watershed that is drained by an intermittent tributary to Cottonwood Creek. Cottonwood Creek is a fourth-order stream that drains into the San Joaquin River just below Friant Dam.

The Station has a Mediterranean climate with annual precipitation ranging from 250 to 800 mm, with a mean of 480 mm, coming almost entirely between October and April. Mean monthly air temperatures range from 6°C in January to 27°C in July. Elevation ranges from 213 m to 518 m. Soils are derived from granitic rocks, and most are less than 0.76 m deep. The Ahwahnee series (coarse-loamy, mixed thermic Mollic Haploxeralf) is common, covering about 96 percent of SJER. The Visalia series soils (coarse-loamy, mixed thermic Pachic Haploxeralf) are found on alluvial or swale sites (Ulrich and Stromberg 1962).

Methods

Suspended Sediment, Bedload, and Discharge

Bedload, total suspended solids (TSS), and discharge were determined at a 90 cm H-flume installed at the bottom of a 137 ha. watershed. During the first year TSS was determined from hand collected samples. Beginning in 1995-96, TSS was determined via vacuum filtration through a 0.45 micron filter using water samples collected hourly with an automatic water sampler. Bedload was estimated during four storms in January and February 1998 and 2000. Due to low rainfall in 1999 and 2001, bedload was not measured. Bedload samples were collected using a Helly-Smith bedload sampler (Shen and Julien 1992) to collect three 1-minute samples every hour during a runoff event. Twenty-four means of three hourly samples were plotted against instantaneous discharge to develop a linear model for predicting bedload from discharge.

Upland Runoff

To estimate overland sediment transport within the watershed, three sets of paired runoff plots were constructed using methods similar to those of Singer and others (1980). The three pair were on 10, 20 and 30 percent slopes respectively. The runoff plots and surrounding rangeland were moderately grazed leaving a minimum of 1000 kg/ha of residual dry matter (Clawson and others 1982). Each runoff plot is 2

m wide by 21 m long (parallel to the slope). These runoff plots were established by cutting a 10 cm slit in the ground around the plot and installing 15 cm wide metal flashing. Surface water and sediment leaving each plot was collected and measured after each storm starting with the 1994-95 water year.

Sediment Trap Study

During September 1996, 1997, and 1998 sediment traps (Wells and Wohlgemuth, 1987) were placed in pairs near the first order intermittent stream that drains the research watershed at the San Joaquin Experimental Range. One of each pair was placed in a cattle trail near the point where the trail crosses the stream channel. The second sediment trap of each pair was placed in well-vegetated areas of similar slope and slope length adjacent to the trap in the trail. The sediment traps were emptied as needed or following large storms. Sediment samples were dried and weighed. ANOVA was used to separate treatment and year differences.

Stream Channel Grazing Impacts

Beginning in summer 1994 five grazing treatments were applied to five randomly selected 0.4 ha pastures established for a long-term study along each of three intermittent streams. During this study, streamflow began in early January following 270 to 360 mm of rainfall during October through December. The channels are 0.6 to 3 m wide, 0.3 to 1 m deep, and bedrock-controlled in many reaches. The study reaches are low gradient with less than 2 percent slope and are Rosgen Class B5 (Rosgen 1996). Stream channels 1, 2 and 3 are 2 to 3 kms apart and at an elevation of 274 to 411 m. The treatments were:

- No grazing
- Wet season moderate grazing (stubble height = 5 – 7.5 cm)
- Wet season concentrated grazing (stubble height < 5 cm)
- Dry season moderate grazing (stubble height = 5 – 7.5 cm)
- Dry season concentrated grazing (stubble height < 5 cm)

The livestock concentration treatments were designed to achieve extremely heavy use as is often associated with a feed or watering station. Each grazing treatment was applied to the same pastures in 1994-95, 1995-96, 1996-97, and 1997-98.

Dry season grazing treatments were applied between July 1 and October 1, a period of little or no rainfall. Wet season treatments were applied while the soil was moist and maintained until the end of the growing season. Typically the wet season begins in late October or early November and ends by May 1. This period includes the slow winter growth period and all of the rapid spring growth period of the growing season (George and others 2001). The moderate grazing treatments were stocked at 0.67 ha per animal unit month. Cooked molasses protein supplement and mineral blocks were placed along the streambanks in the pastures treated with the concentrated treatments, and additional animals were added to achieve the target stubble height associated with feeding and watering sites. Instantaneous stock

densities equivalent to 250 cows per ha were occasionally achieved but not maintained within the corridor delineated by the cross-section transects.

Stream channel morphological measurements were recorded during the first week of June at the beginning of the dry season starting with a baseline year in June 1994. Channel cross sections were measured using methods outlined by Bauer and Burton (1993). For each stream reach 10 permanent cross-section transects, 6.1 m to 9.1 m long, were placed perpendicular to the stream channel at a distance of 1 to 1.5 times the channel width apart. The transects were marked with permanent stakes and referenced to a permanent benchmark. Stream elevation was determined every 15 cm along the transect using a stretched tape, laser level, and stadia rod. For each transect, width at bankfull, distance from the left permanent stake to right and left bank at bankfull height, depth every 15 cm, and maximum depth were measured. Cross-sectional area, channel average depth, and width-to-depth ratio were calculated. Pasture averages for each morphological parameter were calculated from the 10 transects in each pasture. Cross-section area of the channel was determined using bankfull elevations following the methods of Rosgen (1996). Elevation and position readings of the permanent end stakes were checked with benchmark elevations each year.

Results and Discussion

Suspended Sediment, Bedload, and Discharge

Using hand collected water samples, we estimated total suspended sediment (TSS) delivery from this 137 ha watershed to be 0.18 metric tons per ha during 1995. The NRCS soil loss tolerance value (T factor) for this soil is 5 to 12.5 metric tons per ha per year (Ulrich and Stromberg 1962). The majority of the sediment was transported from the watershed in two storms in January and March. Runoff from the watershed began January 4, 1995 and ended on May 17, 1995. Rainfall for the water year was 773 mm and produced 215 mm of runoff. The rainfall average for SJER is 480 mm. One large runoff event produced an estimated peak flow of 2152 l/sec. During saturated conditions peak flows occur rapidly following rainfall input, then recede quickly when the storm ends. This condition allows for high peak flows that are responsible for most sediment transport in these watersheds. Similar dynamics have been documented at the UC Sierra Foothill Research and Extension Center (Tate and others 1999).

During the first year we observed that most of the sediment was moving as bedload. We began measuring bedload and TSS separately in the 1995-96 water year. Our data indicate that bedload transport can be predicted ($p < 0.0001$, $R^2 = 0.68$) from stream flow where:

$$\text{bedload (g/min)} = 0.0013 * \text{flow (l/min)} + 0.4291$$

Figure 1 is an example of the discharge and TSS data collected since 1995. These results confirm that bedload is the primary means of sediment transport in the watershed, with minimal transport of suspended solids. This is attributed to the low stream power and large sediment particle sizes characteristic of this low gradient watershed. Silt and clay particles are limited in this watershed made up of granitic soils that are 75 percent sand.

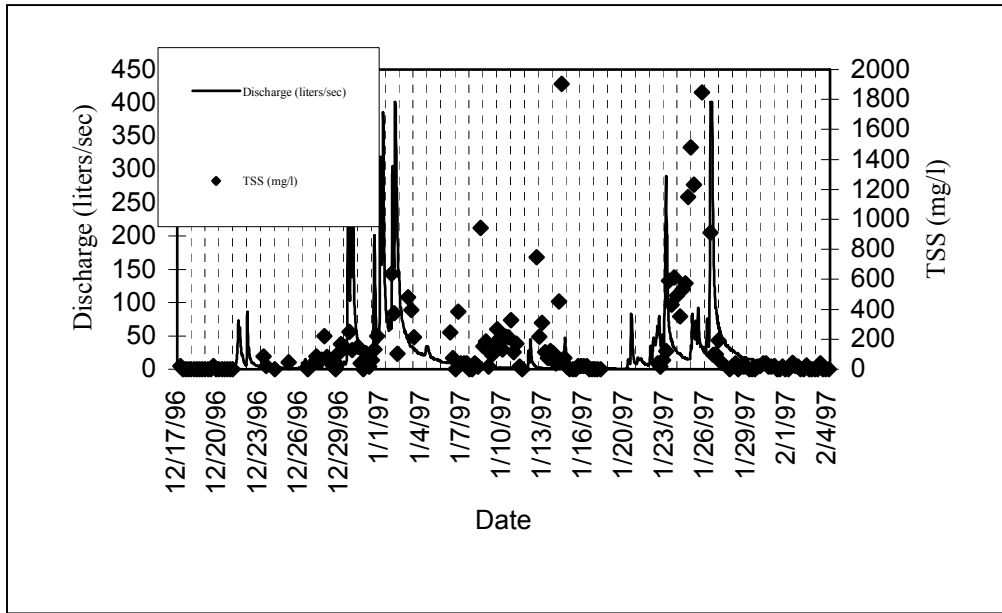


Figure 1—Discharge and total suspended sediment for a small watershed at the San Joaquin Experimental Range in 1995-96.

Upland Runoff

The infiltration rate on these granitic soils is rapid, resulting in little surface runoff or erosion (*table 1*). While surface runoff is low, water reaches the collection system rapidly during storm events. This suggests that rapid lateral subsurface flow through the soil matrix and via macropores is the dominant flow path from the uplands to the stream channel. We suspect that much of the runoff measured at the runoff plots is subsurface flow from up slope. This was particularly evident in March 1995 when the lowest gradient runoff plots generated the greatest amount of water (*table 1*).

Table 1—Monthly runoff and sediment yield hill slope runoff plots for 1994-95.

Slope (pct)	Jan	Feb	Mar	Total
Runoff (mm)				
10	0.75	0	225	225.75
20	2	0	90	92
30	15	0	120	135
Sediment yield (kg/ha)				
10	2.25	.225	16.1	18.6
20	5.84	.337	20.9	27.1
30	27	.562	33.7	61.2

Sediment Trap Study

Sediment transport was significantly greater in cattle trails than in vegetated areas in the rainfall years ending in 1997 and 1998 (fig. 2). There was no significant difference in 1999. In 1997 and 1998 there was sufficient rainfall to generate measurable runoff and the intermittent streams began flowing in January of those two rainfall years. Rainfall in 1998-99 was low, resulting in little runoff and sediment movement in cattle trails. While cattle trail crossings affect a very small total of the channel length within the watershed, the results of this study suggest that trails can be an important conduit of sediment from the uplands to the stream channel. Where livestock trailing is extensive, animal distribution practices (Harper and others 1996) that minimize trailing should be implemented to reduce nonpoint sources of sediment.

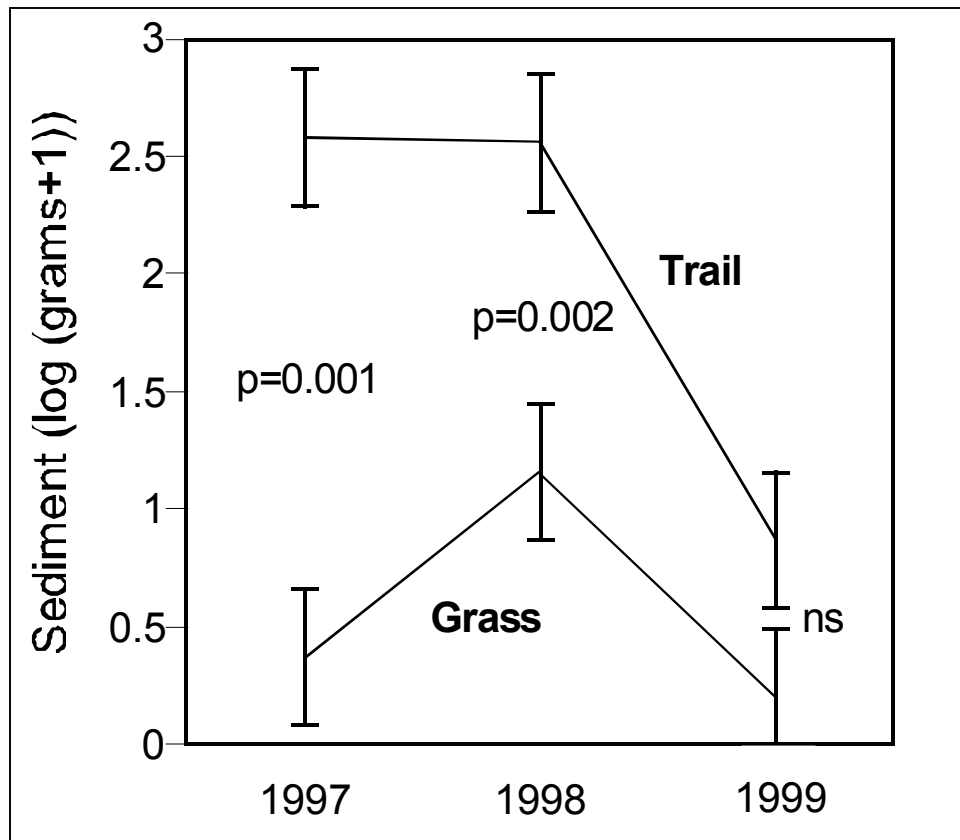


Figure 2—Comparison of sediment trapped in cattle trails and adjacent grass covered slopes.

Grazing Impacts

In 1994 we began estimating the impact of grazing cattle on streambank width and other channel morphology parameters. When stream morphological responses to the five grazing treatments were averaged across all years, no significant difference was detected for either grazing treatment on width, distance to right and left bank, maximum depth, mean depth, cross sectional area, or width-to-depth ratio ($p > 0.05$).

There was a strong year effect on stream channel depth ($p < 0.05$), reflecting the seasonal and annual movement of bedload along the stream channel bottom.

There have been conflicting reports on the relationship between grazing along stream channels and sediment loss from streambanks (see review by Trimble and Mendel 1996). Several of these studies reported that increased channel width was the result of sloughing of undercut banks. The stream channel banks in this study were not undercut, and could not achieve this form under any grazing scheme due to this substrate type (sand) and dominance by shallow rooted annual vegetation.

We observed grazing and trampling along the stream channel bank by cattle in the treated pastures, yet detected no change in channel width at bankfull. Fine textured and wet streambank soils have been shown to be a factor in vulnerability to erosion (Clary and Webster 1990, Hooke 1979, Marlow and Pogacnik 1985, Marlow and others 1987, Wolman 1959). The well-drained coarse sands in our study lack the fine particle sizes and have a low water holding capacity that may reduce their vulnerability to streambank erosion. Trimble and Mendel (1995) suggested that watersheds subjected to high intensity, long duration storms generating high stream discharges were more vulnerable to streambank erosion than watersheds that receive relatively equitable flow from snowmelt. During our study one or more high stream discharges occurred each year lasting for only a few hours during and following a storm. Lack of high intensity rainfall and runoff early in the rainy season may reduce streambank erosion. While intense grazing and trampling can leave unvegetated, loose soil at the beginning of the rainy season, low intensity rainfall characteristic of the early rainy season, results in germination and seedling establishment that stabilizes grazed and trampled soil surfaces before periods of more intense rainfall begin.

Summary and Conclusions

In summary we learned the following from this series of studies:

- Bedload is the main mode of sediment transport and TSS inadequately describes channel sediment transport.
- Grazing that leaves adequate residual dry matter in the uplands is not an important source of sediment.
- Cattle trails can be an important conduit for sediment transport from the uplands to the stream channel.
- Cattle grazing as applied in this study does not result in significant streambank erosion when compared to a control or baseline conditions.

To improve our understanding of livestock impacts on rangeland watersheds the results of these studies suggest a need for the following studies:

- Development of the predictive relationship between flow and bedload.
- Estimation of absolute amounts of sediment moving via cattle trails. This will require a study similar to the prediction of bedload from flow, but on a much smaller scale.

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