Quantifying the Effects of Livestock Grazing on Suspended Sediment and Stream Morphology

Pete Bengeyfield
Beaverhead-Deerlodge National Forest, Montana[1]

Suspended sediment measurements, physical channel measurements, and allotment inspection notes are combined to describe the effects of livestock grazing on a 12-square-mile (31 km^2) watershed in southwest Montana. In years when streamflow reached bankfull stage, suspended sediment produced during the grazing period (post-1 July) was 4.3 times greater when livestock were present. In absolute terms, livestock are responsible for about 5.6 tons (5.1 metric tons) of suspended sediment per day during the grazing period. Stream channels within the watershed became wider and shallower, and had increased fines as a result of streambank trampling by livestock. Although a rest-rotation grazing system was implemented in 1974, stream surveys indicate continued shifts in channel morphology away from the most probable stable form of channel. Allotment inspection notes provide support for cause/effect suspended sediment relationships.

Keywords: *stream morphology, livestock grazing, sediment*

Introduction

Livestock trampling on streambanks leads to two major adverse effects on the functioning of the channel. First, streams become wider and shallower as trampling leads to channel widening (Braun 1986). The same disturbance mechanism often leads to increased suspended sediment concentrations either through direct introduction of particles, or by creating raw areas on streambanks that are susceptible to erosion by subsequent high flows (Skovlin 1984; Clifton 1989; Clary and Webster 1990). Overton et al. (1994) compared reference and grazed conditions to show effects on physical channel attributes. Because of its effects on spawning gravels, the amount of fine sediment in a stream channel has been used as an indicator of the quality of salmonid habitat (Duncan and Ward 1985). However, because of the difficulty in spatially and temporally measuring suspended sediment, combined with the difficulty of isolating the effects of livestock, there has been little quantification of sediment loading solely as a result of livestock use. On the South Fork of Blacktail Creek, measured suspended sediment data, quantified channel surveys, and allotment records combined to provide an opportunity to determine suspended sediment concentrations and loading for a watershed in which the only land uses were livestock grazing and occasional dispersed recreation.

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

Background and Physical Setting

The South Fork of Blacktail Creek is located in the Southwest Corner Allotment on the Madison Ranger District of the Beaverhead-Deerlodge National Forest, Montana. The mainstem and tributaries generally have the potential to be E stream types (narrow, deep channels that are sinuous and relatively flat with ready floodplain access) (Rosgen 1996) throughout their lengths, as shown by reference reaches in similar nearby valley bottoms. Table 1 displays important physical and land use characteristics of the S.F. Blacktail Creek watershed. The allotment was converted from sheep to cattle in 1974. Livestock were managed on a three-pasture rest-rotation grazing system, and thus were present in the watershed only during certain times in any given year. July 1 was the "on date" for the allotment, so livestock were not present during the peak flow period for Blacktail Creek. Pasture moves were scheduled in the permit for 11 August, but in practice that date could vary a few days either way depending on annual conditions. The pasture was rested during 1986, 1989, and 1992.

Methods

In the fall of 1985 a series of monitoring stations were established on the Beaverhead National Forest for the purpose of quantifying suspended sediment from various land uses. The South Fork of Blacktail Creek was chosen because it represented a watershed where livestock grazing was virtually the only land use taking place.

[1] Retired

Table 1. Summary of physical characteristics and land use for South Fork Blacktail Creek.

Area	12 mi^2
Annual precipitation	35 inches
Slope	30-65%
Mean elevation	8500 ft
Geology	Tertiary sediment/shale
Road density	0.4 mi/mi^2
Stream crossing density	0.1 crossings per stream mile
% watershed grazed	100%
AUM density	$109/mi^2$
Timber harvest	0
Number of mines	0

Monitoring operations began in April 1986. A stilling well and water level recorder, in conjunction with a rating curve constructed from approximately 15 streamflow measurements per year, were used to determine hourly discharge. An ISCO sediment sampler[1] collected four samples per day at six-hour intervals for an integrated daily sample. The station generally operated from early May through mid September from 1986 -1992. The area immediately around the stilling well and ISCO intake was fenced to exclude livestock.

Stream surveys were initiated on the Beaverhead National Forest in 1991 to determine the effects of land uses on channel morphology (Bengeyfield, this volume). Standard channel measuring techniques were employed (Harrelson et al. 1994). Additionally, at each survey site, fifty bankfull widths were measured to display in a cumulative distribution curve, to show the change in width along a reach of stream. In 1995 and 1999, a total of eight stream surveys were undertaken in the South Fork Blacktail watershed. Three were on the mainstem of South Fork Blacktail Creek, three were on the Bonita Fork tributary, and one each on the Greys Fork and Dukes Fork tributaries. Physical stream attributes from these surveys were compared to reference data from similar channel segments to determine the condition of the reach (Bengeyfield, this volume).

Streamflows were stratified by whether they were above or below bankfull stage. The bankfull flow is important because it is instrumental in maintaining channel dimensions and sediment transport (Dunne and Leopold 1978).

Livestock entered the allotment on 1 July each year, and their direct effect on sediment production is limited to the time they are present in the pasture in which the stream gage is located. Consequently, this analysis is focused on comparing post-grazing sediment production between years when livestock are present versus when they are absent, and between those years when bankfull flow was attained versus sub-bankfull years.

The combination of water column data (suspended sediment), physical channel data (channel morphology, cumulative width distribution), and allotment inspection notes allow a cause and effect picture to be drawn for the effects of livestock grazing on suspended sediment production.

RESULTS

Suspended Sediment Production During Grazing Period

Stream discharge varied considerably throughout the study period (Figure 1). There were three years when bankfull flow was attained (1986, 1991, 1993), two years of extremely low flow conditions (1987, 1989), and three years of moderate flow (1988, 1990, 1992).

Table 2 displays the results of sediment monitoring stratified by time of year and streamflow regime.

Post-grazing sediment loading data (measured as cubic feet per second [cfs] x mg/L x 0.0028) indicate that livestock increase post-grazing sediment loading during bankfull years by 430% (15.5 tons per day with livestock vs. 3.6 tons per day without livestock), and by 157% during low/moderate flow years (4.1 tons per day with livestock vs. 2.6 tons per day without livestock) (Table 3). It is likely that bankfull years produce greater post-grazing sediment totals because higher discharges from the peak flow period extend into the summer, providing more energy for streambank erosion and sediment transport, while at the same time, the presence of livestock on streambanks provides a source of sediment.

Figures 2, 3 and 4 are examples of bankfull years showing the dependency of suspended sediment concentrations corresponding to both streamflow and livestock presence.

The three graphs demonstrate the relationship between stream flow and suspended sediment concentration (mg/L). During the peak flow period, flow and sediment are highly correlated, especially in 1986 and 1991. In 1986, the rest year (Figure 4), and 1991, when livestock were not present until 11 August (Figure 2), sediment remains streamflow dependent. As streamflow drops, sediment remains low. In 1993, when livestock enter the pasture on 1 July (Figure 3), sediment begins to rise as stream flow declines and remains independent of stream flow throughout the time livestock are present. In 1991, suspended sediment appears to increase about the time livestock enter the pasture, but data after 11 August are lacking. During 1991 and

[1]The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

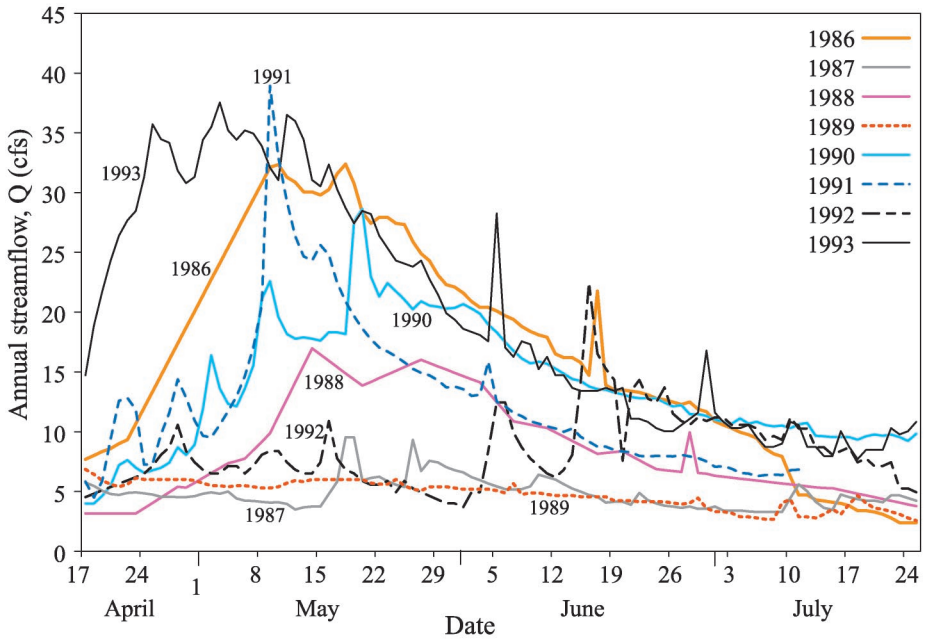


Figure 1. Annual streamflow, South Fork Blacktail Creek, 1986 - 1993.

Table 2. Suspended sediment loading, South Fork Blacktail Creek.

Flow Regime	Year	Streamflow (acre-feet per year)	Sediment pre-grazing (tons/ day)	Sediment post-grazing (tons/day)	Total Sediment (tons/day)	Streamflow (cfs)	Sediment pre-grazing (%)	Sediment post-grazing (%)	Livestock Present
Bankfull	1986	3289	24.8	3.6	28.4	8.29	87	13	No
	1991	2165	15.3	5.4	20.7	8.51	74	26	11 Aug.
	1993	4288	41.8	25.5	67.3	9.64	62	38	1 July
Mean		*3247*	*27.3*	*11.5*	*38.8*	*8.81*	*74*	*26*	
Low	1987	1183	3.8	2.6	6.4	4.09	59	41	1 July
	1989	1042	1.8	1.2	3.0	3.44	60	40	No
Mean		*1112*	*2.8*	*1.9*	*4.7*	*3.76*	*59.5*	*40.5*	
Moderate	1988	1756	36.6	8.1	44.7	4.59	82	18	11 Aug.
	1990	3518	7.4	1.6	9	9.83	82	18	1 July
	1992	2032	3.6	3.9	7.5	6.7	48	52	No
Mean		*2435*	*15.8*	*4.5*	*20.4*	*7.04*	*71*	*29*	

Table 3. Post-grazing sediment loading.

Flow Regime	Year	Livestock Present	Sediment (tons/day)
Bankfull	1991	Y	5.4
	1993	Y	25.5
	Avg.		*15.5*
	1986	**N**	**3.6**
Low/Moderate	1987	Y	2.6
	1988	Y	8.1
	1990	Y	1.6
	Avg.		*4.1*
	1989	N	1.2
	1992	N	3.9
	Avg.		*2.6*

Figure 2. Streamflow and suspended sediment, 1991. Livestock present after 11 August.

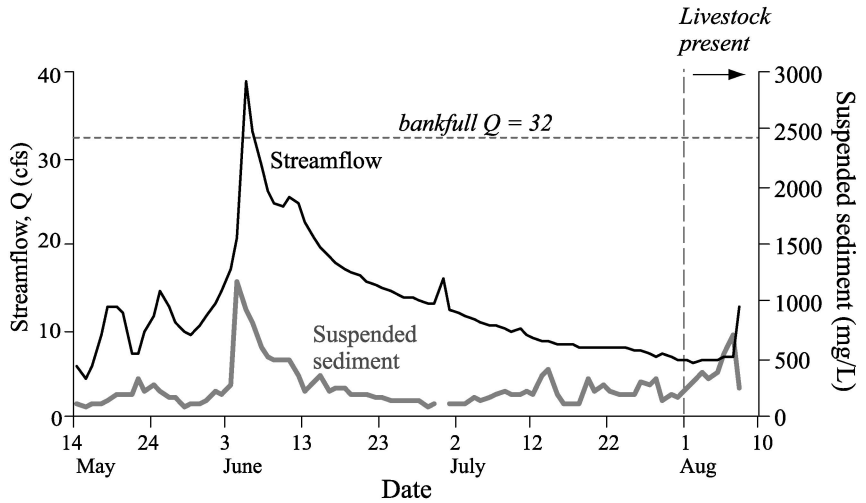


Figure 3. Streamflow and suspended sediment, 1993. Livestock present after 1 July.

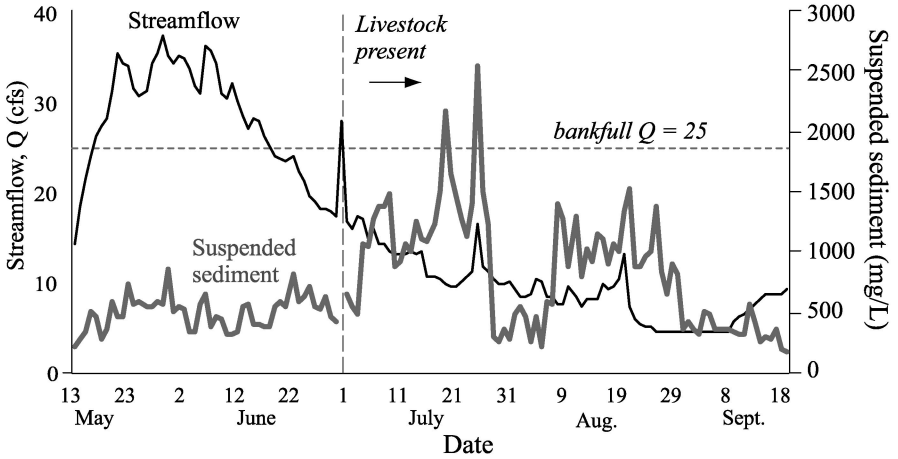
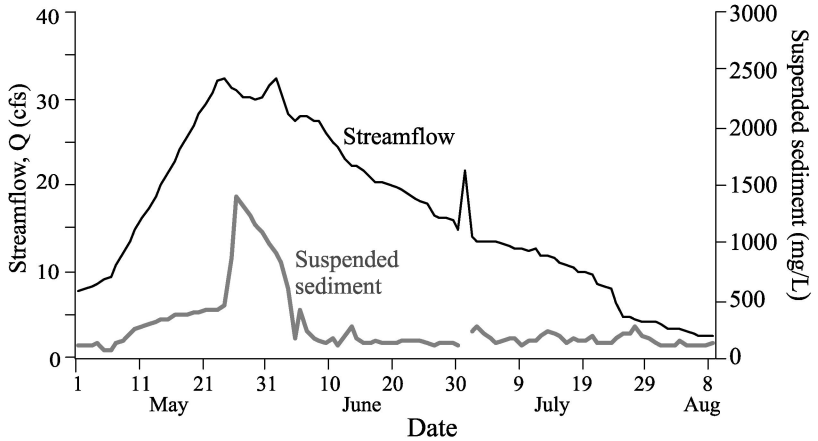


Figure 4. Streamflow and suspended sediment, 1986. Pasture rested.



1993, streamflow was about the same during the post grazing period (1991 = 8.51 cfs [0.24 cms or m^3/s]; 1993 = 9.54 cfs [0.27 cms]) but the sediment concentrations are considerably higher when livestock are present (mean post-grazing concentration in 1991 = 241 mg/L; in 1993 = 878 mg/L). During the rest year, post-1 July streamflow approximates the other years (8.29 cfs [0.23 cms]), but sediment concentration is considerably less (154 mg/L).

Figure 5 displays the difference in suspended sediment production when livestock are present after 1 July during bankfull flow years.

When livestock are absent from the pasture (all of 1986, prior to 11 August in 1991), sediment concentrations are generally less than 500 mg/L. When livestock are present (post-1 July 1993), sediment concentrations are considerably elevated. During bankfull years, the falling

Figure 5. Suspended sediment production (mg/L) for post-1 July during bankfull years.

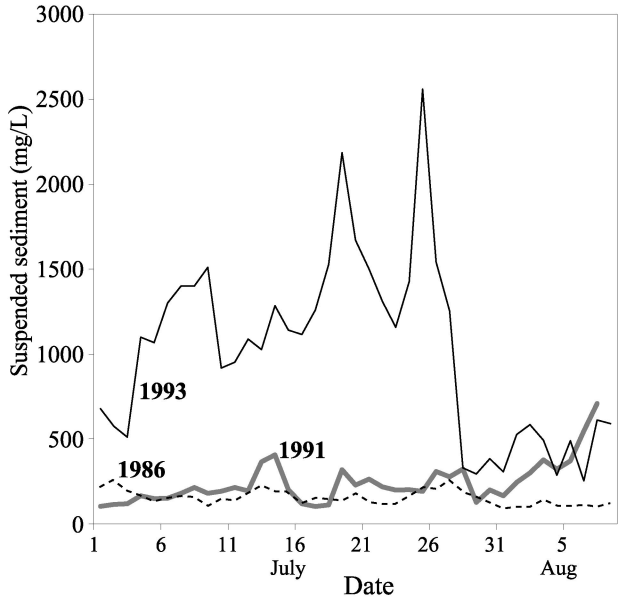


Figure 6. Streamflow and suspended sediment, 1987. Livestock present after 1 July.

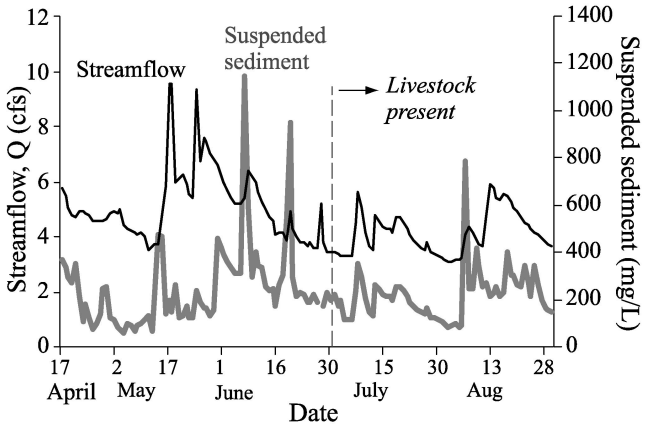
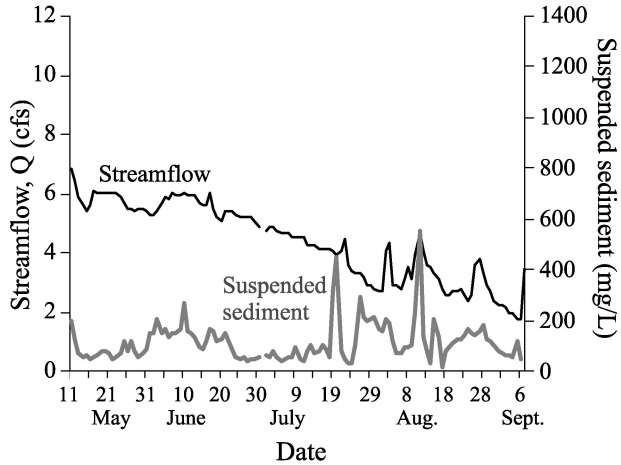


Figure 7. Streamflow and suspended sediment, 1989. Pasture rested.



limb of the hydrograph maintains higher flows into the summer. The presence of livestock on streambanks causes soil particles to be directly introduced to the stream, and trampling exposes streambanks to erosion. This combination of effects leads to higher sediment concentrations.

Low flow years show the same trend of similar streamflow levels producing higher sediment concentrations when livestock are present (Figures 6 and 7). During low flow years (1987 and 1989), sediment concentrations mimic streamflow quite well. Streamflows for this period are much the same for both years (1987 = 4.1 cfs [0.12 cms]; 1989 = 3.4 cfs [0.096 cms]), yet suspended sediment concentrations almost doubled when livestock were present (1987 = 216 mg/L; 1989 = 122 mg/L).

Comparing the average sediment production between grazed and ungrazed years (Table 4), we can see that the presence of livestock contributes to a dramatic increase in suspended sediment loading and concentration. Although sediment is clearly flow dependent, with more being produced during the years when bankfull stage was attained, the increase in both concentration and loading during the time that livestock are present shows the influence of grazing as well.

The average sediment concentration for the period after 1 July during rest years is 152.5 mg/L. This can be assumed to be a background concentration for the stream in its current condition. By subtracting this value from the total concentration when livestock are present, it is possible to determine the effect of livestock on sediment concentration, and to then calculate the sediment loading as a result of livestock. Livestock alone produce approximately 5.6 tons (5.1 metric tons) of sediment daily during the post-1 July period (Table 5).

The 5.56 tons per day (5.0 metric tons) that livestock increased sediment during the July through mid-September period from 1986-1993 equates to a total of 2085 tons (1891 metric tons) of suspended sediment for the period of record. The average May through September sediment loading for that period was 12.1 tons per day (11.0 metric tons), or 13,552 tons (12,292 metric tons) for the period

Table 4. Suspended sediment production for South Fork Blacktail Creek, 1986-1993.

	Suspended Sediment	
Suspended Sediment with:	**Sediment loading (tons/day)**	**Sediment concentration (mg/L)**
Livestock present (5 yrs.)	8.62	391.6
Livestock absent (3 yrs.)	2.94	152.5

Table 5. Post-grazing sediment production as a result of livestock presence.

Year	Flow Level	Post-1 July Accelerated Sediment Concentration (mg/L)	Post-1 July Streamflow (cfs)	Post-1 July Accelerated Sediment Loading (tons/day)
1987	low	63.5	4.09	0.73
1988	moderate	418	4.59	5.37
1990	low	0	9.83	0
1991	bankfull	88.6	8.51	2.11
1993	bankfull	726.1	9.64	19.59
Mean		*259.2*	*7.33*	*5.56*

Entrenchment, as defined by Rosgen (1996), is flood prone width divided by bankfull width, and indicates the degree of channel incision. A large entrenchment value describes a narrow, deeply incised stream channel; a small value describes a wide, shallow stream channel.

of record. The sediment produced by livestock during the summer months in five years was 15.4% of the total suspended sediment produced over an eight-year span.

Stream Survey Data , 1995 - 1999

The stream survey data do not directly measure sediment in the water column as was done in the above analysis, but instead give a picture of various channel components that directly contribute to sediment production. These data indicate that at the majority of the sites measured in the South Fork Blacktail Creek, channel morphology has been altered by livestock trampling of stream banks, and sources of in-channel sediment have been created and perpetuated.

The stream survey data (Table 6) indicate that the main reason for the impairment of these streams was a change in the entrenchment ratios as a result of livestock trampling [see text box, above right]. For example, the most probable stable form for all the reaches should be E stream types (Rosgen 1996), but trampling along the banks has altered the interface between the top of the bank and the floodplain so the channel has become more entrenched, and shifted to a B stream type. The average entrenchment for E stream types in southwest Montana is 11.0 (Bengeyfield, this volume), while the average entrenchment for the South Fork Blacktail Creek sites is 1.8.

The presence of a reference reach in a tributary to South Fork Blacktail Creek that is adjacent to the Southwest Corner Allotment provides an opportunity for comparison of a number of parameters between reaches. The reference reach is in a neighboring allotment, and appears to be seldom grazed. All reaches have similar valley characteristics (valley bottom width, valley slope, and drainage area, Table 7).

An example of the increase in entrenchment at these reaches is demonstrated in Figure 8 by comparing the cross-section of the Bonita Up reach with that of the reference reach. It can be seen from the bankfull and floodplain indicators that streamflows at Bonita Up are less likely to reach their floodplain than those of the reference, South Fork Blacktail Trib Down. Hence, more stream energy is contained at high flows, leading to accelerated bank erosion and sediment entrainment.

Table 6. Entrenchment, stream type and functionality of survey sites, South Fork Blacktail Creek

Stream	Entrenchment	Stream Type	Function
SF Up	8.9	E	FAR
SF Mid	2.0	B	FAR
SF Down	5.3	E	F
Bonita Up	2.0	B	NF
Bonita Mid	2.5	E	FAR
Bonita Down	1.8	B	NF
Dukes	1.3	G	NF
Greys	11.2	E	F

Table 7. Valley bottom characteristics of South Fork Blacktail tributaries.

Stream	Valley Bottom Width (ft)	Valley Slope (%)	Drainage Area (acres)
Reference	235	3.2	546
Bonita Up	110	4.6	288
Bonita Down	150	3.8	300
Greys	140	1.3	648

An effect of excessive trampling of streambanks is an increase in overall stream width. By comparing the cumulative width distribution of Bonita Up, Bonita Down, and Greys Creek with South Fork Blacktail Trib Down, the reference reach, we can see that this effect has occurred on the tributaries of South Fork Blacktail Creek (Figure 9). All of the tributary reaches are considerably wider than the reference reach throughout their length. For example, the mean width of the reference reach is between 1.5 and 2.0 feet (0.46 to 0.61 m), while the mean width of Bonita Up is between 4.5 and 5.0 feet (1.4 and 1.5 m).

Figure 8. Cross sections of Bonita Up and South Fork Blacktail Trib Down.

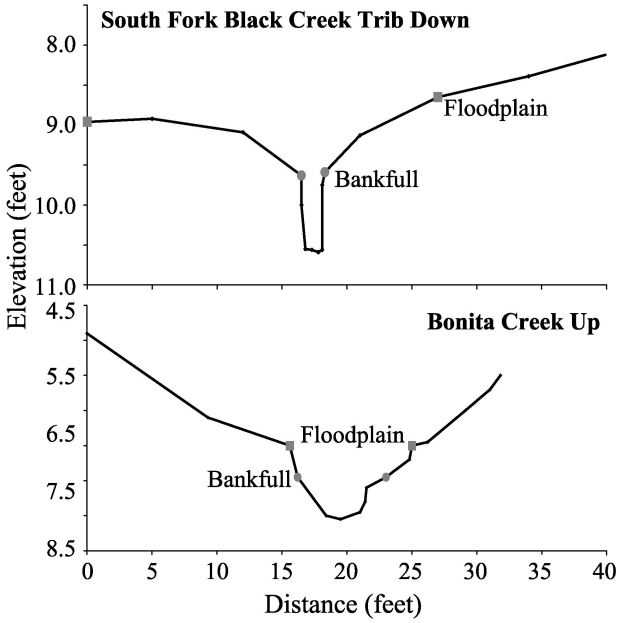


Figure 9. Cumulative width distribution for tributaries to South Fork Blacktail Creek.

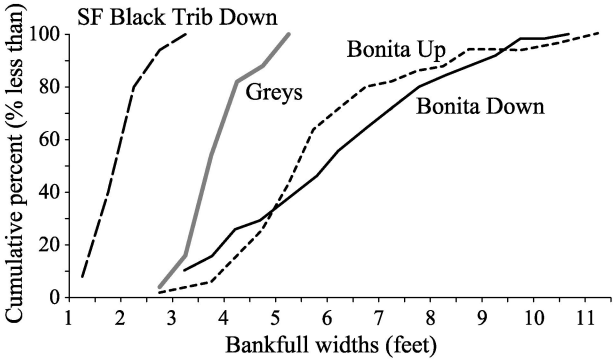
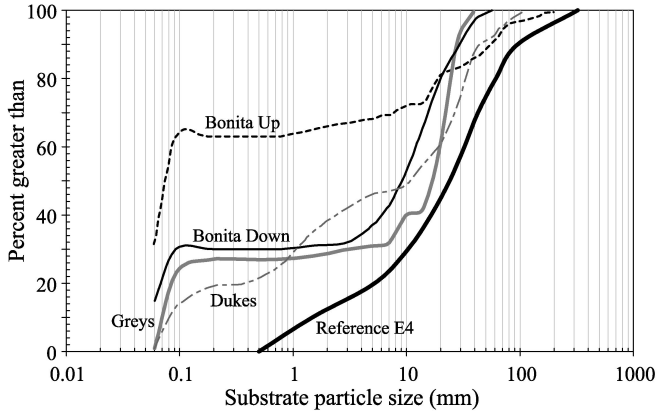


Figure 10. Substrate distribution for survey sites in South Fork Blacktail Creek.



Another effect of livestock trampling is to increase sediment in the stream channel. As fine sediment is deposited in the channel, it causes the substrate distribution to be more heavily weighted to smaller sizes. The survey sites in South Fork Blacktail Creek, as compared to a reference distribution for E4 stream types in southwest Montana, show a pattern that supports this change in substrate size (Figure 10) (Bengeyfield, this volume). All reaches show a shift to a finer substrate when compared to reference conditions. For example, about 12% of the reference reaches have fines under 2 mm in size, while about 30% of Dukes and Bonita Down are less than 2 mm.

Allotment Notes

The Southwest Corner Allotment was grazed by sheep until 1974, when it was converted to cattle. Notes in the allotment file indicate heavy sheep grazing had an adverse effect on vegetation along ridge tops, and that the channel stability of Blacktail Creek was rated as Poor. It was speculated however, that cattle were likely to cause more damage to stream banks than sheep, and that observations of utilization should be taken in the riparian area to determine the allowable AUMs (W. Page, personal communication, 1974). Cattle were managed under a rest-rotation system from the outset, but annual inspection notes indicate that their distribution across the allotment was often poor. A 50% utilization standard was most often employed as a trigger to move livestock to the next pasture. It appears that the allotment was generally inspected once a year, towards the end of the grazing season. Inspection notes reveal that the utilization standard was seldom reached in the uplands, but often exceeded in the stream bottoms. Some excerpts from the notes underscore this point:

- "Cattle concentrated in bottom of Greys Fork. Light use on upper slopes and ridges. Utilization 24%. (14 August 1974)
- "Still cows in bottoms." (4 September 1974)
- "Cattle pretty well used bottoms. Most of use is where cattle were dropped in drainages." (12 October 1975)
- "95% of cattle were between forest boundary and Dukes Fork. All of these cattle were in the stream bottom." (16 July 1981)
- "Need to keep rider to move cows out of bottoms." "The creek bottoms are used enough for this year, however cattle are scheduled to stay for one more month." (14 August 1987).
- "Inspected utilization in riparian areas and adjacent benches. The cattle should be removed from the allotment." (26 September 1988)

- "Bottoms averaged 60-70% use. 31% average streambank disturbance." (11 October 1991)
- "Dukes Fork and Greys Fork are at or beyond riparian guidelines with very little use in the uplands." (1994)

DISCUSSION AND CONCLUSIONS

Livestock grazing has been shown to adversely affect stream channels through the alteration of physical dimensions of the channel and by adding sediment (Kaufman and Krueger 1984; Clary and Webster 1990). This effect has been demonstrated in a number of case studies (Platts 1983; Clifton 1989), and literature reviews (Skovlin 1984). Overton (1994) compared reference and grazed conditions to show effects on physical channel attributes. Because of its effects on spawning gravels, the amount of fine sediment in a stream channel has been used as an indicator the quality of salmonid habitat (Duncan and Ward 1985).

A major factor that contributes to sediment loading is the condition of the channel and riparian area. Channels in poor condition will have more sediment sources, and annual disturbance by livestock is more likely to make that sediment available for erosion and transport, both during the low flow and high flow periods. Data from around the South Fork Blacktail watershed indicate that much of the riparian area/stream channel network in the watershed is in poor condition with high levels of fine material in the channel. Of the eight stream surveys located on the South Fork Blacktail Creek and its tributaries above the stream gage, six are either non-functioning or functioning-at-risk, and seven were judged to be in a downward trend (Beaverhead-Deerlodge National Forest, unpublished data).

The percentage of fine sediment is consistently much higher than for reference levels for E4 stream types. The average values for all survey sites in the watershed yield a Bank Erosion Hazard Index (Rosgen 1996) of Moderate, and a Channel Stability Evaluation (Pfankuch 1975) of Poor. Reference conditions for the same protocols rate Low and Good respectively. Streambank alteration by livestock was measured at three of these sites, and averaged 73%. All of the ten reference E reaches in the Gravelly Mountains of Montana in geologies similar to those at South Fork Blacktail Creek are E3 and E4 stream types (Rosgen 1996). In reference E4 stream types the amount of material less than 6 mm in size is 22%. For the eight sites in South Fork Blacktail Creek the average is 49% of the substrate less than 6 mm. The only management activities in the watershed are livestock grazing (109 AUMs per square mile) and dispersed recreation, which has a negligible effect on sediment production. There is one road in the watershed, with two stream crossings. In reviewing these data describing existing conditions and land use, it can be concluded that livestock grazing has created unstable stream channels that contain excessive fine sediment. It seems that conditions exist on the ground that would support the above analysis of suspended sediment concentrations and loadings.

It is the presence of livestock in the riparian area that leads to both changes in channel morphology and increases in sediment production. Trampling of stream banks increases width/depth ratios, while at the same time weakening stream banks, making them more susceptible to erosion. Additionally, hoof action on stream banks directly introduces sediment to the channel, and livestock walking in the channel disturb and entrain already deposited sediment. The analysis concerning the post-grazing time period demonstrates that the combination of these activities appreciably increases both concentration and loading of suspended sediment. During that period, sediment concentration is more livestock dependent than flow dependent (Figures 2-4). However, when livestock are present and flows are bankfull or greater, increased shear stress leads to particle detachment and higher loadings. It is likely that during the post-grazing period in low flow years, most of the sediment being entrained is generated by livestock moving in the channel and disturbing the bed and banks. When stream power increases with higher flows, more of the available sediment is entrained by erosion throughout the channel area.

Although most of the annual sediment load (68%) is created when livestock are not present, the stream bank alteration and bed disturbance by livestock during the grazing season create nearly continuous sediment sources that are available when stream flows rise in the spring. That these sources do indeed exist is evidenced by a comparison of physical channel parameters with reference conditions in similar valley bottoms. Increases in entrenchment, stream width, stream bank erosion hazard, and fine substrate material, coupled with a decrease in channel stability, all indicate changes in stream bank composition and sediment supply. Consequently, a high percentage of the 16.8 tons (15.2 metric tons) of sediment produced daily during the pre-grazing time period is attributable to livestock. These data enable us to assess the effectiveness of management on the allotment in terms of maintaining riparian condition and reducing sediment.

Notes taken prior to and during the period of measurement support the sediment data collected in the 1980s, and the stream surveys conducted in the 1990s. It is apparent that even with a rest-rotation system employed from the inception of cattle grazing, distribution of livestock was poor and use in the riparian area was

excessive. In this case, simply implementing a rest-rotation system was not enough to protect riparian areas and stream channels from experiencing accelerated stream bank alteration and its associated sedimentation.

Combining the management history of the watershed with the suspended sediment data collected from 1986-1993, and with the stream survey data collected in 1995-1999, provides a comprehensive picture of the effect of livestock grazing on sediment production. The following conclusions can be drawn.

1. The presence of livestock during the summer months increases suspended sediment concentrations and loading. The increases are greater during years when bankfull flow is attained because more sediment sources are available and the increase in shear stress caused by higher flows leads to particle detachment. During bankfull years, post-grazing suspended sediment was increased by 430% during years when livestock were present. During low-flow years, post-grazing suspended sediment increased 157% over livestock-free periods. Livestock are responsible for about 5.6 tons per day of additional sediment during the post-grazing period.

2. Livestock trampling of streambanks has led to an increase in both channel entrenchment and the percent of fines in the channel. Comparing measurements of these parameters with reference data from within the South Fork Blacktail watershed shows large discrepancies between reference conditions and those surveyed reaches on the Southwest Corner Allotment. High levels of streambank alteration by livestock were measured at each of the surveyed reaches, suggesting a cause-effect relationship for the changes in entrenchment and fine sediment

3. The instability along streambanks created by livestock trampling provides sources of sediment available for in-channel erosion during periods of high flows. Because of the variability of peak flows, and the general flow dependency of sediment loading, this situation could well produce more sediment than the direct effect of livestock during low-flow periods.

4. The rest-rotation grazing system is not adequate by itself to prevent livestock damage to stream banks and the resulting increases in sediment. The Southwest Corner Allotment has been managed under a rest-rotation system since 1974, but has had relatively little successful livestock management within the pastures when cows are present. To maintain acceptable sediment levels in streams, effective herding is needed when livestock are present.

Literature Cited

Braun, R. 1986. Emerging limits on federal land management discretion: Livestock, riparian ecosystems and Clean Water Law. *Environmental Law* 17:43

Clary, WP, and BF Webster. 1990. Riparian grazing guidelines for the Intermountain Region. *Rangelands* 12 (4): 209-212.

Clifton, C. 1989. Effects of vegetation and land use change on channel morphology. In: Gresswell, RA, BA Barton, and JL Kershner (eds) Practical approaches to riparian resource management. BLM-MT-PT-89-001-4351. Billings, MT: Bureau of Land Management: 121-129.

Duncan, SH, and JW Ward. 1985. The influence of watershed geology and forest roads on the composition of salmon spawning gravel. *Northwest Science* 59(3): 162-194.

Dunne, T, and LB Leopold. 1978. Water in environmental planning. New York: W.H. Freeman and Company. 818 p.

Harrelson, CC, CL Rawlins, JP Potyondy. 1994. Stream channel reference sites: an illustrated guide to field technique. Gen. Tech. Rep. RM-GTR-245. Fort Collins, CO: US Forest Service, Rocky Mountain Forest and Range Experiment Station. 61 p.

Kaufman, JB, and WC Krueger. 1984. Livestock impacts on riparian plant communities and streamside management, a review. *Journal of Range Management* 37 (3):430-437.

Overton, CK, GL Chandler, and JA Pisano. 1994. Northern/Intermountain Region's fish habitat inventory: Grazed, rested, and ungrazed reference stream reaches, Silver King Creek, California. Gen. Tech. Rep. INT-GTR-311, Ogden, UT: USDA Forest Service, Intermountain Research Station.

Pfankuch, DJ. 1975. Stream reach inventory and channel stability evaluation. USDA Forest Service, Rl-75-002, #696-260/200. Washington, DC: Government Printing Office, 26 p.

Platts, WS. 1983. Riparian-stream habitat conditions on Tabor Creek, NV, under grazed and ungrazed conditions. In: Proceedings: Western Association of Fish and Wildlife Agencies. 73rd annual conference, 1983: 162-194.

Rosgen, DL. 1996. Applied river morphology. Self-published book. Available from: Wildland Hydrology, 11210 North County Road 19, Fort Collins, CO 80524.

Skovlin, JM. 1984. Impacts of grazing on wetlands and riparian habitats: A review of our knowledge. In: National Resarch Council and National Academy of Sciences (eds), Developing strategies for rangeland management. Boulder, CO: National Research Council, National Academy of Sciences: 1001-1103.