Time of grazing effects on stream channel stability instream sediment loads
by Thomas Martin Pogacnik

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Range Science
Montana State University

Abstract:
A study was conducted during the 1981 and 1982 summer grazing seasons to determine the effects of time of livestock grazing on stream channel stability and suspended sediment concentrations for Cottonwood Creek, a small watershed located on the Red Bluff Research Ranch in southwest Montana. Eight pastures were grazed in succession for 14 days each from June 14 through October 4, with a ninth pasture remaining ungrazed as a control. Stream channel stability, soil moisture, stream flow, and suspended sediment concentrations were monitored during each grazing period. Stream channel alterations were found to be significantly greater during the early grazing periods (June 14 - August 9), with Iate-season channel alterations (August 9 -October 14) being not different from the ungrazed control ($P < 0.01$). Periods of peak channel alterations were associated with high vegetation utilization rates and were correlated to high soil moisture ($r^2 = 0.84$). Alterations associated with the winter monitoring periods were 10 to 800 percent greater than alterations directly attributable to livestock grazing and may be an indirect repercussion of summer livestock activity. No direct relationship between peak concentrations of suspended sediment and cattle activity was discernible. Peak sediment concentrations occurred during periods of high rainfall and appear to be a function of erosion from streambanks altered during the previous season's grazing. Sediment concentrations were generally higher downstream of areas exhibiting the greatest streambank instability.

TIME OF GRAZING EFFECTS ON STREAM CHANNEL

STABILITY INSTREAM SEDIMENT LOADS

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Thomas Martin Pogacnik

A thesis submitted in partial fulfillment
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1 August 1985
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ABSTRACT

A study was conducted during the 1981 and 1982 summer grazing seasons to determine the effects of time of livestock grazing on stream channel stability and suspended sediment concentrations for Cottonwood Creek, a small watershed located on the Red Bluff Research Ranch in southwest Montana. Eight pastures were grazed in succession for 14 days each from June 14 through October 4, with a ninth pasture remaining ungrazed as a control. Stream channel stability, soil moisture, stream flow, and suspended sediment concentrations were monitored during each grazing period. Stream channel alterations were found to be significantly greater during the early grazing periods (June 14 - August 9), with late-season channel alterations (August 9 - October 14) being not different from the ungrazed control ($P < 0.01$). Periods of peak channel alterations were associated with high vegetation utilization rates and were correlated to high soil moisture ($r^2 = 0.84$). Alterations associated with the winter monitoring periods were 10 to 800 percent greater than alterations directly attributable to livestock grazing and may be an indirect repercussion of summer livestock activity. No direct relationship between peak concentrations of suspended sediment and cattle activity was discernible. Peak sediment concentrations occurred during periods of high rainfall and appear to be a function of erosion from streambanks altered during the previous season's grazing. Sediment concentrations were generally higher downstream of areas exhibiting the greatest streambank instability.

INTRODUCTION

Riparian areas are productive, yet very fragile ecosystems which serve as a focal point of management for the entire watershed. Although the riparian zone may occupy only about two percent of a watershed's area (Buckhouse nda), it is in these communities that user interest is disproportionately high. Managers of virtually every natural resource discipline focus their attention on the utilization of riparian areas, which often results in many user groups competing for a limited resource. The multitude of interests, management objectives, and values expressed by the various groups makes a conflict over riparian areas inevitable.

One such conflict concerns the effects grazing livestock exert on riparian ecosystems. The management goals established by wildlife and fisheries biologists to maintain the integrity of riparian habitat for terrestrial and aquatic organisms are occasionally in conflict with the management goals of livestock producers, who are marketing herbage through a ruminant animal and look to riparian areas as a highly productive source of forage, water, shade, and protection throughout the grazing season.

In recent years, numerous studies have equated livestock grazing with declining riparian ecosystem stability. Although many other activities can result in as much or more degradation of riparian habitat (Busby 1979, Claire and Storch in press), it is livestock grazing, because of its high visibility, which has been implicated as the principle force contributing to the destabilization of riparian areas (Busby 1979).

Damage traceable to livestock grazing occurs when improper management practices allow livestock to concentrate in riparian areas for extended periods of time (Armour 1977). The resulting impacts generally occur as destabilized streambanks, altered stream channels, increased suspended sediment loading, and excessive vegetation removal (Behnke and Raleigh 1978; Platts 1981a). The impacts livestock exert on riparian areas may be obvious immediately, as denuded vegetation and collapsed streambanks, or the damage may occur as subtle annual alterations which can take many years to detect (Platts 1981a).

Natural resource managers are being pressured to reduce the impacts livestock inflict on riparian systems, yet a lack of research pertaining to alternative grazing practices in riparian areas limits the management options available. Many studies have suggested that the only management alternative, which is compatible with maintaining the integrity of riparian habitat, is to exclude or restrict livestock use in these areas (Ames 1977, Behnke 1979, Davis 1982, and Platts 1978). However, the restriction or elimination of livestock access to riparian areas may be undesirable for the livestock producer as these areas may constitute the primary forage base of a pasture and produce the only desirable forage during late summer grazing periods.

A number of studies examining the impact livestock exert on riparian communities have been conducted in recent years. Much of this research has centered on attempting to establish to what degree livestock grazing impacts riparian areas and evaluating the effectiveness of various grazing methods to reduce livestock impacts in these areas. Much of the research to date has been based on subjective data, which may include only one year's observations with little consideration given to the measurement of quantifiable parameters or to statistical design. Many times these studies have failed to consider stocking rates, duration of grazing, or season of use in analysis of data. This results in a lack of pertinent information on which management decisions could be made. It is in regard to this fact that the need for more accurate and precise research becomes evident.

In response to the need for research concerned with minimizing livestock grazing impacts on riparian communities, a five-year study is being conducted by the Montana Agricultural Experiment Station in conjunction with Montana State University to determine the effects of time of grazing on a series of riparian ecosystem characteristics. A portion of this study is to discern that period or periods during the grazing season (June 15 - October 4) when livestock-induced streambank and channel instability and suspended sediment loading are minimized.

The principle objectives of this study were: 1) to determine what time during the grazing season streambanks were most susceptible to cattle grazing impacts, and 2) to determine if fluctuations in suspended sediment levels occured during periods when cattle were present.

LITERATURE REVIEW

The combined influences of geology, climate, soil structure, geomorphology, vegetation, and water runoff often result in unstable riparian systems, even in a state unaltered by human activity (Meehan and Platts 1978). When excessive stress is exerted on these marginally stable systems through improperly controlled land management practices, severe damage usually results (Meehan and Platts 1978).

It has been suggested that one of the most destructive forces influencing riparian ecosystems is long-term overgrazing by livestock (Behnke 1977, Davis 1982, Leopold 1975). Townsend and Smith (1977) and Cope (1979) have reported that livestock grazing degrades riparian habitat and subsequently reduces the productivity of these areas. Mismanagement of livestock can result in animals being concentrated in riparian areas, thus inflicting some degree of damage on each of the four major components of a riparian ecosystem: 1) streamside vegetation, 2) stream channel morphology, 3) streambank stability, and 4) water quality (Behnke and Raleigh 1978, Claire and Storch in press, Marcuson 1977, Platts 1979, Platts 1981a).

Streambank vegetation maintains the integrity of riparian areas by stabilizing streambanks (Meehan, Swanson and Sedell 1977, Winegar 1977), reducing erosion (White and Brynildson 1967), reducing water temperatures by shading streams (Armour 1977, Bowers et al. 1979, Platts 1978), and as a source of organic detritus and terrestrial insects which serve in the food chain of riparian systems (Cummins 1974, Meehan, Swanson and Sedell 1977).

There exists an abundance of literature regarding the effects livestock exert on riparian vegetation (Ames 1977, Boldt, Uresk and Severson 1978, Bryant et al. 1972, Buckhouse nda, Claire and Storch in press, Crouch 1979, Davis 1977, Evens and Krebs 1977, Hayes 1978, Knoph and Cannon 1982, Meyers 1981, Pond 1961, Roath 1980, Roath and Krueger 1982, Smith nda, Tuinstra 1967, Vogler 1978, Winegar 1977). These studies have reported that livestock grazing results in undesirable changes in plant succession, community productivity, species composition, reproduction, and diversity associated with riparian areas.

The effects of livestock grazing on riparian vegetation can generally be termed as negative (Buckhouse nda). As early as 1946, livestock were reported to concentrate in riparian communities and utilize the vegetation more intensively than in adjacent habitat types (Reid and Pickford 1946). The impacts of excessive herbage removal in riparian areas can be categorized by vegetation structure: utilization of herbaceous vegetation and utilization of woody vegetation (Buckhouse nda).

The primary effect of excessive livestock grazing on herbaceous vegetation is the replacement of native bunchgrasses by invader grasses and forbs (Dobson 1973, Evenden and Kauffman 1980, Hayes 1978, Volland 1978). Grazing has been reported to increase the number of undesirable species found in riparian areas (Everden and Kauffman 1980) by opening up the vegetation and creating niches in which ruderal species may become established (Dobson 1973, Hayes 1978). Information regarding productivity of streamside vegetation, as influenced by grazing is conflicting (Buckhouse nda). Numerous studies have reported decreases in productivity due to livestock grazing (Duff 1979, Gunderson 1968, McClean, Nicholson and Ryswyk 1973, Marcuson 1977, Pond 1961). However, Roath (1980) and Volland (1978) found livestock grazing had no significant affect on biomass production and Kauffman et al. (in press) observed greater production in grazed communities over similar ungrazed areas.

The effects of herbivory on shrub and tree production and reproduction is a critical impact to riparian ecosystems (Buckhouse nda). Marcuson (1977) found shrub production to be 13 times greater in an ungrazed area than in a severely grazed area. Carothers (1977) and Glinski (1977) report that excessive grazing pressure prevents the establishment of seedlings or suckers resulting in communities which are even-aged and non-reproducing. Vogler (1978) found light browsing may stimulate sprouting of riparian woody species, yet, persistent livestock use can result in the elimination of woody species (Crouch 1979).

Season of use appears to have an affect on the ability of riparian vegetation to withstand grazing pressure. Claire and Storch (in press) and Roath (1980) in Oregon have shown late-season grazing has little impact on either herbaceous or woody riparian vegetation, while Myers (1981) concluded that livestock use of riparian habitat in the spring is more conducive to shrub survival than during the "hot period" of late summer.

Perhaps the greatest impact of excessive livestock grazing in riparian communities is the subsequent destabilization of streambanks following vegetation removal. The first sign of riparian damage, as a result of livestock activity, will occur as reductions in vegetative cover and a subsequent increase in streambank and stream channel instability (Platts 1981a, Skolvin 1967). Studies by Berry (1978) Hayes (1978) and Winegar (1977) all indicate that accelerated streambank undercutting occurs after excessive vegetation removal by livestock. Platts (1981b) reported less stable streambanks when utilization rates were 65 percent or greater, while utilization rates of 25 percent or less resulted in little or no streambank damage. Similar results were presented by Hayes (1978), who reported increased streambank instability after vegetation utilization rates exceeded 60 percent. Cooper (1979) states that streambank damage may be independent of animal numbers though and that it does not take full utilization of streambank vegetation to seriously damage sensitive banks.

The impact of livestock grazing on stream channel morphology and streambank stability varies depending upon the nature of the stream being studied (Buckhouse nda). It has been suggested that streambank susceptibility to livestock impact may be determined by soil structure and bank rock content (Behnke and Raleigh 1978, Cooper 1979, Gunderson 1968, Marcuson 1977, Platts 1979). Cooper (1979) states that banks containing a higher percentage of rock significantly impede ungulate damage. Streambanks with low percentages of bank rock as well as soils with sandy textures are reported to be highly susceptible to trampling damage (USDI 1978).

Numerous studies have reported the effects of livestock trampling on soil compaction and soil disturbance (Alderfer and Robinson 1979, Bryant et al. 1972, Orr 1960, Rauzi and Hanson 1966, Roath 1980). Roath (1980) states that the greatest impact livestock exert on riparian areas is trampling damage and he notes that the amount of impact appears to be dependent upon soil moisture. Cooper (1979) speculated that moisture frozen in streambanks may supply the soil with sufficient support to withstand heavy weight.

Livestock grazing has been shown to alter stream channel shape, resulting in channels which are typically wider and shallower than comparable areas not being grazed (Armour 1977, Duff 1979, Gunderson 1968, Kauffman et al. in press, Marcuson 1977, White and Brynildson 1967). A stream channel receiving heavy grazing pressure from sheep was reported by Platts (1981b) to be four times as wide as an area receiving light grazing. Kauffman et al. (in press) found a riparian system grazed under a stocking rate of 2.5 ha/AUM lost over three times as much streambank as an ungrazed control area.

However, these findings conflict with those reported by Buckhouse et al. (1981), Hayes (1978), and Roath (1980). Hayes (1978) found fewer changes in streambank shape within pastures being grazed by cattle than in pastures which receive no grazing. Both Buckhouse Skolvin and Knight (1981) and Roath (1980) report insignificant streambank alterations following livestock grazing in Oregon. They surmize that the naturally occurring impacts of water flow (Roath

1980) and ice damage (Buckhouse et al. 1981) resulted in more channel alterations than were contributed by cattle. Buckhouse (1980) states it is accepted that livestock do impact streambanks, but it is important to quantify how much of the damage is in excess of naturally occurring changes.

Trampled streambanks have been reported to increase overland water and sediment flow, resulting in higher suspended sediment levels in streams (Armour 1977, Johnson et al. 1978). Rosgen (1975) reports a good correlation between streambank stability, water flow and suspended sediment levels. Rosgen's relationship is based on the assumption that a given water discharge can transport a set amount of sediment in suspension and the availability of sediment is dependent upon streambank stability. As bank damage increases, sediment levels also increase (Cooper 1979).

Increased levels of suspended sediment in the water column have been identified as the most damaging impact livestock have on stream productivity (Armour 1977, Duff 1979). Berry (1978) and Cordone and Kelley (1961) found that suspended sediment decreases a stream's total organism productivity. Numerous studies have indicated that overgrazing by livestock may result in increased suspended sediment levels and increased levels of sediment in the streambed, resulting in reduced fish biomass production and lowered salmonoid numbers within the fish population (Armour 1977, Behnke and Raleigh 1978, Bowers et al. 1979, Claire and Storch in press, Cordone and Kelley 1961, Duff 1979, Gunderson 1968, Marcuson 1977).

There is general agreement among aquatic biologists that the introduction of particulate matter into a body of water can result in adverse ecological consequences (Cairns 1968). There is, however, a lack of agreement as to the amount of suspended sediment which can be assimilated before threshold values for aquatic organisms are reached (Cairns 1968, and Hoak 1957). McKee and Wolf (1963) state that water containing suspended sediment levels of 80 mg/l is not harmful to aquatic organisms. Peters (1962) reported that levels of 200 mg/l were found to inflict 75% mortality for incubating embryo rainbow trout (<u>Salmo gairdneri</u>). Herbert and Merkins (1961) reported suspended sediment concentrations of 30 ppm (parts per million) having no adverse effect on aquatic organisms yet levels of 270 ppm resulted in a 50 percent death rate among the salmonoids being monitored. In contrast, a study by Benoit, Cairns and Reimer (in press) reported young salmon could tolerate over 120 hours in as much sediment as could be kept in suspension by vigorous aeration. Reported lethal levels of suspended sediment for salmonoids range from 75 ppm to 270,000 ppm (Wallen 1951).

Although aquatic organisms can survive in water within a wide range of suspended sediment levels (Cairns 1968), it is the loss of spawning areas and food which may be most detrimental to their survival (Cairns 1968). Cairns (1968) noted that invertebrate organism production is substantially lower in sand and silt than in rubble and gravel. When inorganic sediments cover rubble and gravel, fish food and spawning areas are destroyed.

Livestock have been implicated as the principle source of increased sediment levels in streams (Cooper 1979, Busby 1979, Platts 1978, Winegar 1977). Yet, studies by Gary, Johnson and Ponce (1983) and Johnson et al. (1978) have indicated little correlation between livestock activity in riparian areas and the large concentrations of suspended sediment recorded in the stream they were monitoring. Both studies concluded that, although livestock activity did result in a slight increase in suspended sediment levels, the amounts were insignificant relative to naturally occurring concentrations. Peak sediment concentrations were recorded during periods of high water flow in both the grazed and ungrazed reaches of the stream (Johnson et al. 1978), and they felt it was apparent that these high concentrations originated upstream of the study site with the cattle contributing insignificant amounts of additional sediment.

Recognizing and understanding the impacts livestock exert on streamsides is a prerequisite to formulating riparian management plans (Claire and Storch in press). Often, what is found to be good range management is not good riparian management (Platts 1979). Methods for improving riparian zone management to reduce livestock damage include: exclusion of livestock, alternative grazing methods, changes in the class of livestock, and managing riparian areas as special-use pastures (Buckhouse nda).

Several studies, reported by Buckhouse et al. (1981) evaluated various grazing methods for their compatability with the objectives of both livestock and wildlife managers of riparian areas. Some grazing methods have shown potential for preserving riparian wildlife habitat, with rest-rotation achieving the most success (Davis 1982, Claire and Storch in press, Hayes 1978, Kimball and Savage 1977, Swan 1979). Drawbacks of rest-rotation and other grazing methods includes increased trailing along fence lines, concentration of livestock in riparian areas, increased trampling damage, and streambank instability (Ames 1977, and Meehan and Platts 1978). No widely-used grazing method has been observed to be compatible with the objectives of all riparian ecosystems user groups (Ames 1977, and Meehan and Platts 1978).

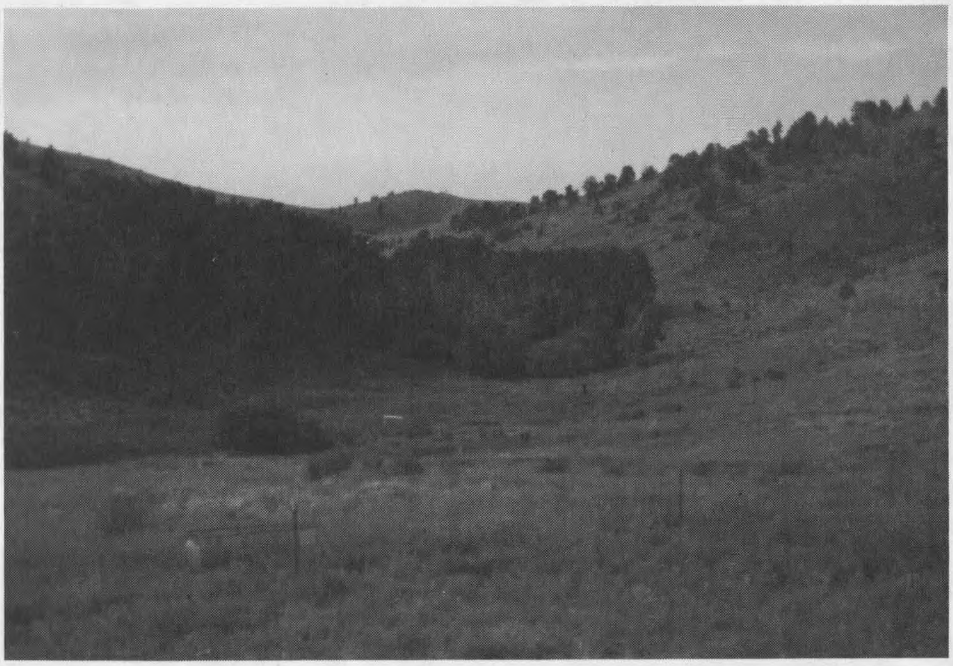
Total exclusion of livestock from riparian areas, as recommended by Ames (1977), Dahlen (1978), Davis (1982) and Platts (1978), has met with marginal benefits (Volland 1978). Although some success in restoring damaged riparian areas has been achieved by excluding livestock (Behnke 1979, Davis 1977), Volland (1978) reports that a riparian area excluded from livestock grazing for eleven years was found to produce less vegetative biomass than an area being grazed. Also, politics, funding, personnel constraints, and conflicting resource demands make livestock exclusion an unacceptable alternative for resource managers (Davis 1982).

Fencing riparian areas separately into special management pastures may be a successful multiple-use system of riparian management (Kauffman et al., in press). Studies by Johnson (1965), Kauffman (1982), Pond (1961), and Roath (1980) all reported reduced livestock damage to riparian areas when grazed late in the season. Cooper (1979) suggests that late fall grazing may have been conducive to reducing streambank damage on riparian areas in Wyoming. Further study is necessary relating to the effects of time of grazing on riparian ecosystems in establishing proper riparian grazing practices (Platts 1981b).

SITE DESCRIPTION

This study was initiated in 1981 on the north fork of Cottonwood Creek, a tributary of the Madison River in southwest Montana. Cottonwood Creek is located in the foothills of the Madison Mountain Range and drains a small watershed of approximately 1360 hectares (Figure 1). The Cottonwood watershed is situated 16 kilometers

Figure 1. View of the Cottonwood Creek Drainage Taken From the Center of the Study Site Looking South.

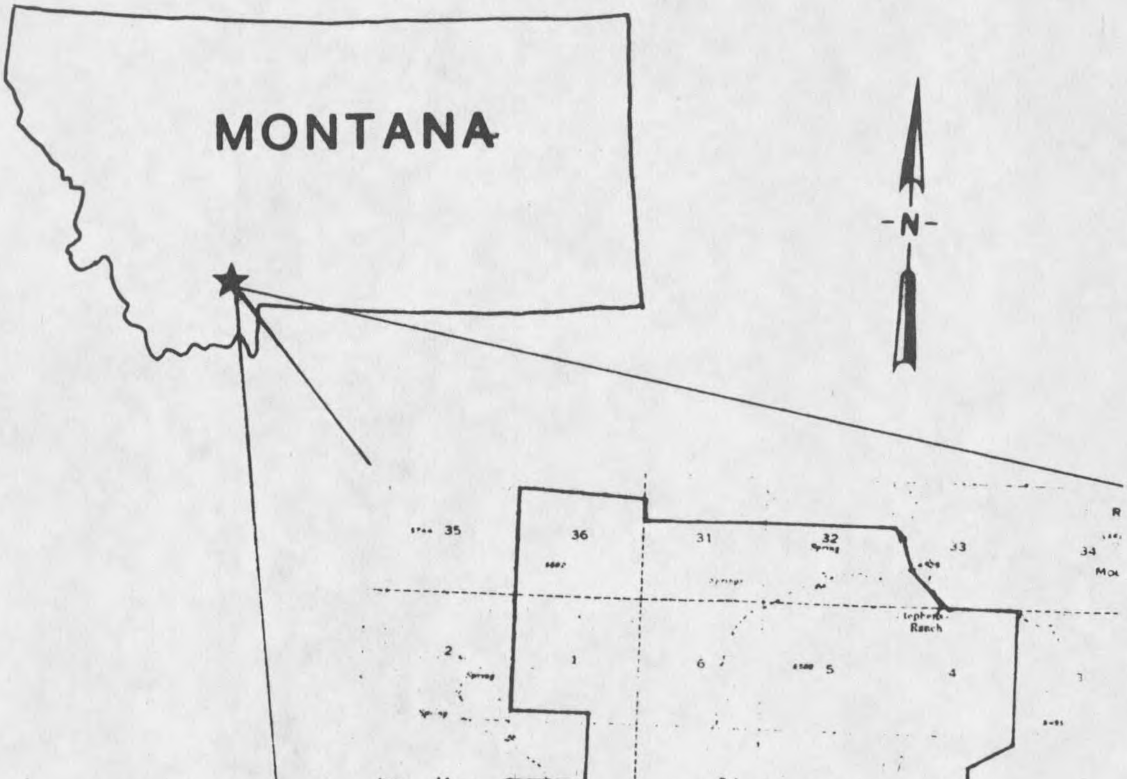


southeast of Norris, Montana on the Montana Agricultural Experiment Station's Red Bluff Research Ranch (Figure 2).

Cottonwood Creek

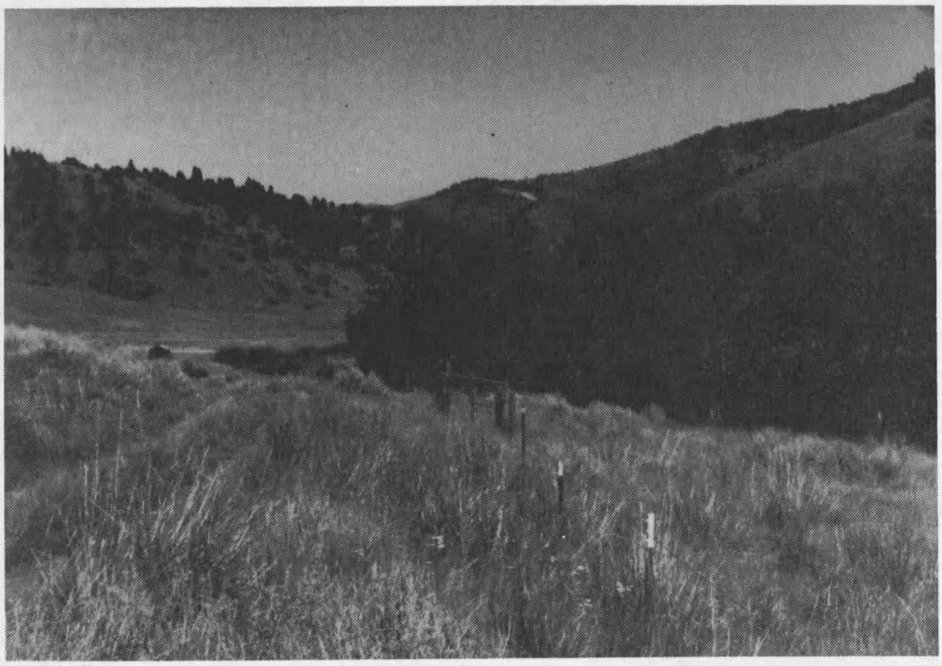
Cottonwood Creek is approximately 4 km in length and flows northeast where it joins the Madison River in Beartrap Canyon.

Figure 2. Montana Agricultural Experiment Station's Red Bluff Research Ranch in Southwestern Montana showing Location of Study Site.



Topography of the watershed is characterized by moderate to steep slopes, (Figure 3) with elevations ranging from 2000 meters at the headwater spring to 1400 meters where the creek flows into the Madison River. The creek is bordered on the south by a steep ridge with slopes of 30 to 50 percent and on the north by rolling hills with 15 to 30 percent slopes. At its source, Cottonwood Creek is situated in rolling terrain with a wide riparian zone. The riparian area becomes considerably narrower as the creek flows towards its confluence with the Madison River. Cottonwood Creek issues from a large perennial spring with numerous small, perennial and intermittent springs feeding laterally into the channel along its entire length. The south fork of Cottonwood Creek merges with the north fork of Cottonwood Creek approximately 1 km upstream of its confluence with the Madison River.

Figure 3. The Topography of Cottonwood Creek is Characterized by Moderate to Steep Slopes.



Stream morphology of Cottonwood Creek is highly variable over its entire length. The creek flows over a relatively level gradient for the initial 1.5 km below the headwater spring with the gradient becoming gradually steeper over the remaining 2.5 km. A level portion of the creek approximately 1 km downstream from the headwater spring was chosen for the study site. The creek flows along a 13 percent gradient throughout the study area.

The stream bottom within the study site has a substrate of fine gravel covering the center channel and sand and silt along the water column - streambank interface. Scattered sections of the stream are covered with deposits of small rubble and coarse gravel. Stream flow discharge as measured at the downstream end of the study area, varies considerably within season. Flow values range from 0.03 m^3/sec in June to 0.01 m^3/sec in September. Channel width and depth vary throughout the study site. Maximum channel width between banks is approximately 8 meters with a maximum depth of approximately 1.6 meters from the bank edge to stream bottom. The narrowest section of the channel is 1.1 meters and shallowest section is 0.21 meters. Cottonwood Creek is predominantly riffles, with pools being less prevalent. The primary source of debris within the creek channel results from fallen trees and branches. The banks are primarily formed of deep sandy-loam soil with little or no bank rock.

Soils

Soils of the Cottonwood Creek drainage are formed from hard, coarse-grained metamorphic rock. The metamorphic rock is composed of a complicated suite of rock types. These include granite and amphibole gneiss, amphobolite, schist, quartzite, and marble (Veseth and Montagne 1980). The metamorphic rock weathers into coarse, sandy-loam soils, which are well-drained and susceptible to erosion problems (Veseth and Montagne 1980). The study site is comprised of soils developed from colluvium and alluvium. Three soils are found on the study site (Figure 4). The north and south facing slopes are composed of colluvium deposits. The north facing slopes are comprised of loamy-skeletal, mixed Typic Cryorthents, while the south-facing exposures are a loamy-skeletal, mixed Typic Cryoboroll. The alluvial riparian zone is a fine-loamy, mixed Argic Cryoboroll. The water table in the riparian zone varies from a few centimeters to approximately one meter below the soil surface.

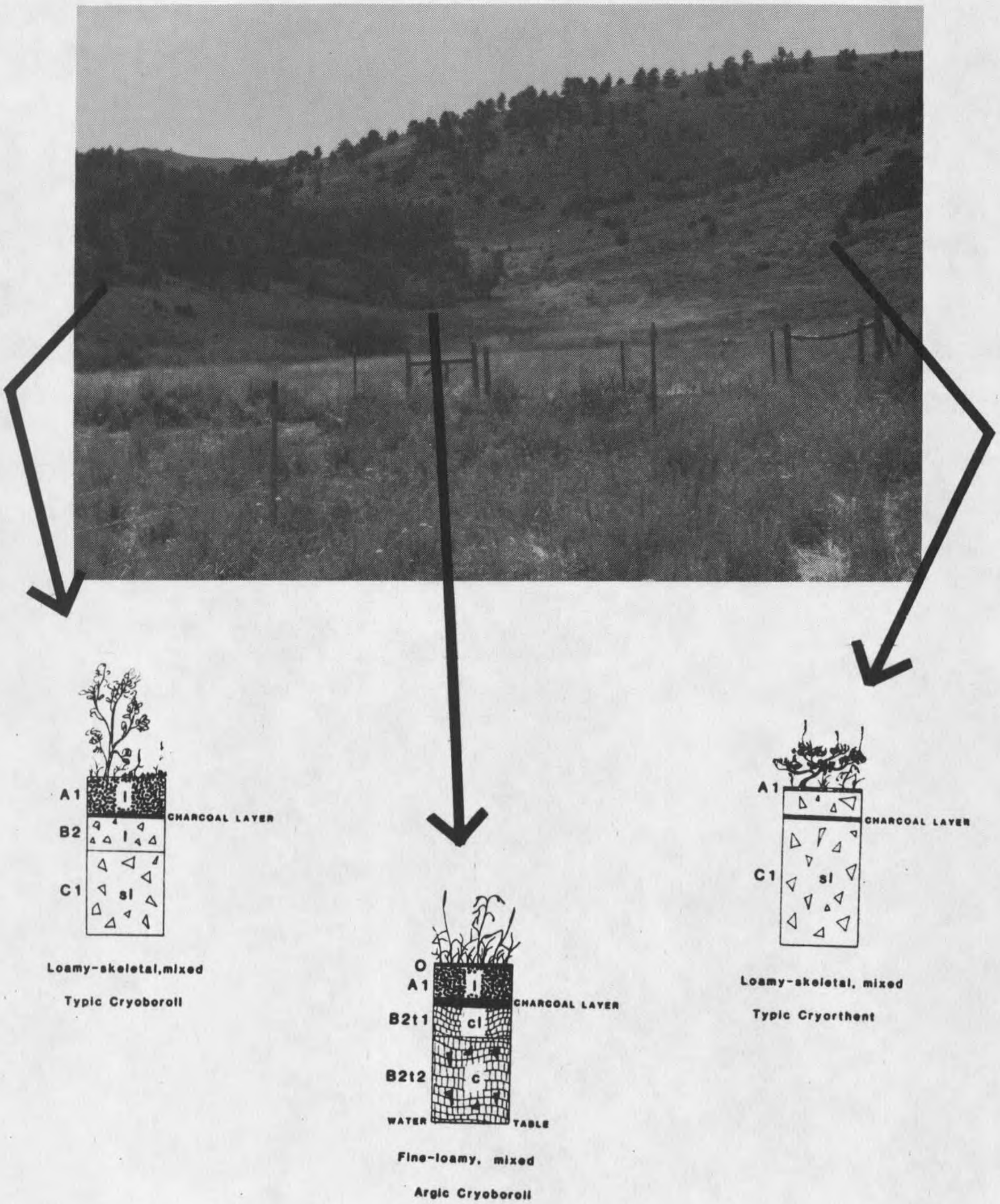
Streambank soil textures vary along the length of the stream. The predominant soil texture is sandy-loam, with some areas of loamy-sand and loam.

Climate

A National Oceanographic and Atmospheric Administration weather reporting station is located at the Red Bluff Research Station headquarters.

The Red Bluff area has a frost-free period lasting 75 to 100 days. During the 1982 grazing season, temperatures ranged from a high of 31°C to a low of -3°C. The study site receives between 400 mm and 510 mm of precipitation annually, including 1,200 mm of snow. The snow collects in large drifts on the north slopes of the drainage and persists until early May. Up to 40 percent of the annual precipitation falls during the months of May and June while the period

Figure 4. View of Cottonwood Creek Indicating the Location of Three Soil Pits and Their Respective Soil Classification.



of minimum moisture accumulation occurs from November until February (NOAA 1982).

Vegetation

Vegetation along Cottonwood Creek is highly variable. Based on criteria established by Claire and Storch (in press), three different vegetation zones border Cottonwood Creek. At the headwaters, a sagebrush/grassland zone borders the creek channel, while within the study area, an aspen/grass/forb vegetation zone forms the dominant riparian component. The lower reaches of Cottonwood Creek are bordered by a mixed broadleaf shrub/coniferous tree zone. Using the predominant species of vegetation, several vegetative types can be described within the aspen/grass/forb vegetative zone found on the study site (Montana State Rural Areas Development Committee 1982) (Appendix A).

However, for the purposes of this study, vegetation types are collectively referred to as either upland or riparian communities. The riparian community is comprised of the aspen, aspen/willow, bog, meadow and streambank vegetation types while the upland community is composed of upland/grassland, sagebrush and aspen park vegetation types.

The riparian communities are dominated by Canada bluegrass (*Poa compressa* L.), redtop (*Agrostis stolonifera* L.), Timothy (*Phleum pratense* L.), smooth brome (*Bromus inermis* Leyss.), beaked sedge (*Carex rostrata* Stokes), Sprengel's sedge (*Carex sprengelii* Dewey), white clover (*Trifolium repens* L.) with an overstory of quaking aspen (*Populus tremuloides* Michx.), willow (*Salix* spp. L.), chokecherry

(Prunus virginiana L.), and swamp gooseberry (Ribes lacustre (Pers.) Poir.).

The upland communities are composed of Canada bluegrass, green needlegrass (Stipa viridula Trin.), needleandthread (Stipa comata Trin. & Rupr.), western wheatgrass (Agropyron smithii Rydb.), and Idaho fescue (Festuca idahoensis Elmer) with scattered dense stands of mountain big sagebrush (Artemisia tridentata subsp. vaseyana (Rydb.) Beetle) interspersed with woods rose (Rosa woodsii Lind L.) and Rocky Mountain juniper (Juniperus scopulorum Sarg.).

Both the upland and riparian communities have populations of several introduced species. These include: houndstongue (Cynaglossum officinale L.), spotted knapweed (Centaurea maculosa Lam.), tall larkspur (Delphinium occidentale Wats.), Canada thistle (Ciricium avarense (L.) Scop.), and cheatgrass brome (Bromus tectorum L.).

Study Site

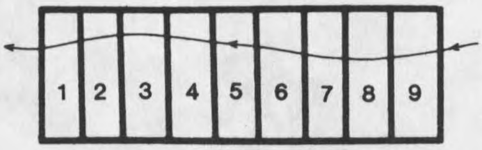
The Cottonwood Creek study site was selected for its uniformity of vegetation, soils, slope and stream morphology. Nine 0.5 ha pastures were constructed on the site to provide eight pastures for grazing treatments and one pasture for an ungrazed control. Each of the pastures contains approximately equal proportions of riparian and upland communities (Figure 5). The pastures are numbered consecutively one through nine, beginning with the pasture furthest downstream.

Pastures one through eight receive annual, fourteen-day grazing treatments. Grazing is initiated in pasture one during the second week of June each year (Figure 6). Upon completion of a grazing

Figure 5. View of Pasture 5 Showing Upland and Riparian Community Types.

Figure 6. Diagramatic View of Pasture Layout and Grazing Schedule Used During the 1981 and 1982 Grazing Seasons.

GRAZING SCHEDULE



1 : JUNE 14 - JUNE 28

2 : JUNE 28 - JULY 12

3 : JULY 12 - JULY 26

4 : JULY 26 - AUGUST 9

5 : AUGUST 9 - AUGUST 23

6 : AUGUST 23 - SEPTEMBER 6

7 : SEPTEMBER 6 - SEPTEMBER 20

8 : SEPTEMBER 20 - OCTOBER 4

9 : UNGRAZED

period, the cattle were moved to the adjoining upstream pasture to avoid confounding of water quality data with previous activity. Each pasture was grazed during the same period annually to monitor cumulative yearly effects.

Cattle

Four yearling heifers were used to provide a moderate stocking rate. Spayed Hereford-Angus-Tarentaise cross heifers weighing an average 232 kilograms were used during the 1981 season and Hereford heifers averaging 194 kilograms were used during the 1982 season. Both groups originated from the Montana State University, Bozeman Livestock Center and spent their first year in pastures and feedlots at the center. The heifers had no previous experience grazing open rangeland or riparian communities.

It should be noted that the Cottonwood Creek study site was once part of the Cottonwood grazing unit for the Red Bluff Research Ranch. This drainage receives yearly heavy grazing use from cattle, sheep and occasionally horses. In the past, grazing has occurred only during the summer and autumn with no use recorded during the winter. The site was afflicted with various levels of livestock impacts prior to the initiation of this study.

METHODS

Stream Channel Stability

Streambank stability was monitored at forty-five permanent transects located along the creek channel as it flows through the study site. Five transects, positioned perpendicular to the channel, were located in each pasture. The transects were numbered consecutively one through forty-five, beginning in the downstream end of pasture one and terminating in the upstream end of pasture nine.

Transect locations within each pasture were determined by positioning the first transect at a randomly selected distance of one to five meters from the downstream cross-fence. The remaining four transects were evenly distributed at ten-meter intervals along the remainder of the creek within that pasture. The channel area had received heavy livestock use prior to the initiation of this study, and much of the streambanks were already at various levels of instability. Areas showing excessive pre-study livestock-related impacts were avoided when positioning the channel transects. In situations where a transect line would have intersected a severely damaged streambank, the transect was repositioned immediately upstream of the damaged area. Transects were also not placed in areas subjectively determined to be inaccessible to cattle. Therefore, dense stands of willow and swamp gooseberry were avoided.

The endpoints of each transect were permanently marked with steel or wooden pegs positioned above the highwater mark at a minimum of 0.5 meters from the streambank edge. Locating the transect endpoints 0.5

m from the bank edge was done to prevent their loss to streambank sloughing and to ensure the entire channel, which may be subject to cattle impacts, is bisected by the transect line.

The length of each transect line varied depending upon the morphology of the channel. Portions of the creek with steep banks and a narrow channel were characterized by shorter transects, while sections of the channel which were dish-shaped generally resulted in longer transect lines.

Each transect was measured along two axes: 1) horizontal and 2) vertical. A nylon meter tape was stretched and leveled between the two permanent transect endpoint stakes to represent the horizontal axis. The heights of the meter tape on the endpoint stakes were recorded and then used in future transect readings to ensure consistency between measurements. A meter stick held perpendicular to the nylon meter tape was used to provide a scale for the vertical axis (Figure 7).

The horizontal meter tape was used as a baseline from which vertical measurements are made to the stream channel. Measurements of the stream channel were taken at ten-cm intervals along the baseline tape. The distance between the baseline tape and the channel was recorded to the nearest centimeter (Figure 8a). The shaded portion of Figure 8b represented the cross-sectional area of that portion of the creek.

Measurement of the water depth was conducted by recording the vertical distance between the baseline tape and the water surface, followed by a measurement of the distance from the top of the water column to the streambed.

Figure 7. Channel Measurements Were Taken Using a Horizontally Stretched Meter Tape and Vertically Held Meter Stick.

Changes in stream channel stability were recorded following three monitoring periods: 1) the 1981 grazing season, 2) the 1982 grazing season, and 3) the winter of 1981-1982.

Each transect was measured in springtime before the first grazing period. Transects within a pasture receiving a grazing treatment were remeasured immediately upon completion of the grazing period. Transects located within the control pasture were measured in the spring prior to the first grazing period and in the fall after

Figure 8a. Measurements Were Taken to the Nearest Centimeter Along the Horizontal Plane and at Ten Centimeter Intervals Across the Vertical Plane.

STREAM CHANNEL CROSS-SECTION
MEASUREMENT

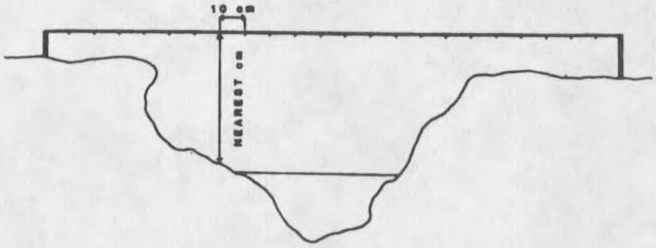


Figure 8b. The Transect's Cross-Sectional Area is Represented by the Shaded Portion of the Illustration.

STREAM CHANNEL CROSS-SECTION AREA

completion of the last grazing period. A representation of the stream channel configuration before and after each grazing treatment was derived from the transect measurements, allowing a determination of relative amounts of channel alterations which occurred during the grazing period.

Changes in the stream channel which occurred during the winter between the 1981 and 1982 field seasons were determined by comparing the channel configurations after completion of the 1981 grazing treatments and the pre-grazing measurements of the 1982 season.

Stream Flow Discharge

Five water sampling points, designated A, B, C, D and E were located immediately downstream of pastures 1, 3, 5, 7 and 9, respectively (Figure 10). Water flow and suspended sediment were monitored at each of these stations.

Water stage was measured continuously using Stevens Type-F Level Recorders mounted on Parshall flumes (Figure 11). Two sizes of Parshall flumes were used in the study. Flumes with three-inch throat widths, having a capacity of one cubic foot per second, were used at stations B, C, D and E, while a six-inch flume with three cubic feet per second capacity was located at station A. The larger flume at station A was required to accomodate peak flow levels encountered during spring runoff.

The Stevens recorders measure water stage on a continuous basis. Recorder strip charts were replaced every 14 days in conjunction with completion of a grazing period and the subsequent movement of cattle

Figure 9. Diagramatic Sketches of Each Transect Before and After Grazing Were Produced Using the Channel Measurement Data.

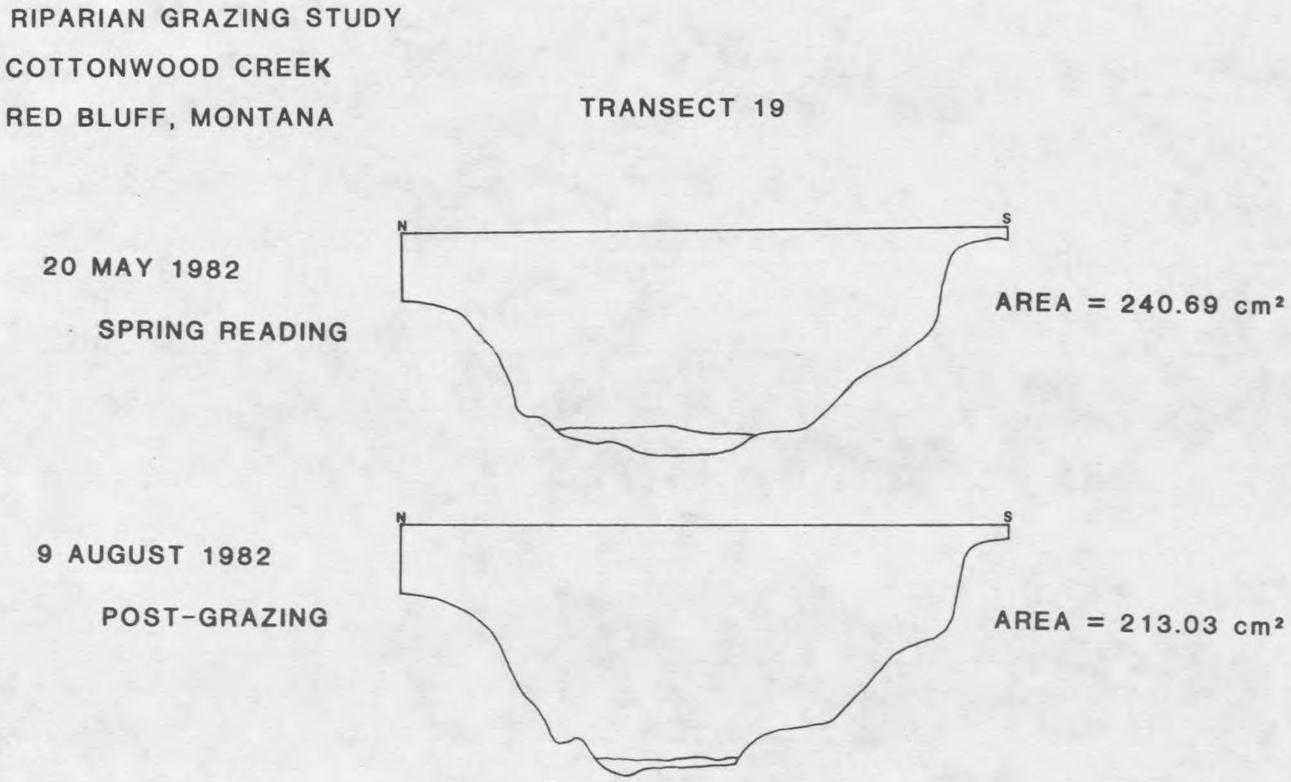


Figure 10. Diagramatic Illustration of Pasture Layout Indicating With Black Squares the Location of Water Sampling Stations. Each unit is 0.5 hectare.

PARSHALL FLUME AND SUSPENDED SEDIMENT COLLECTOR LOCATIONS

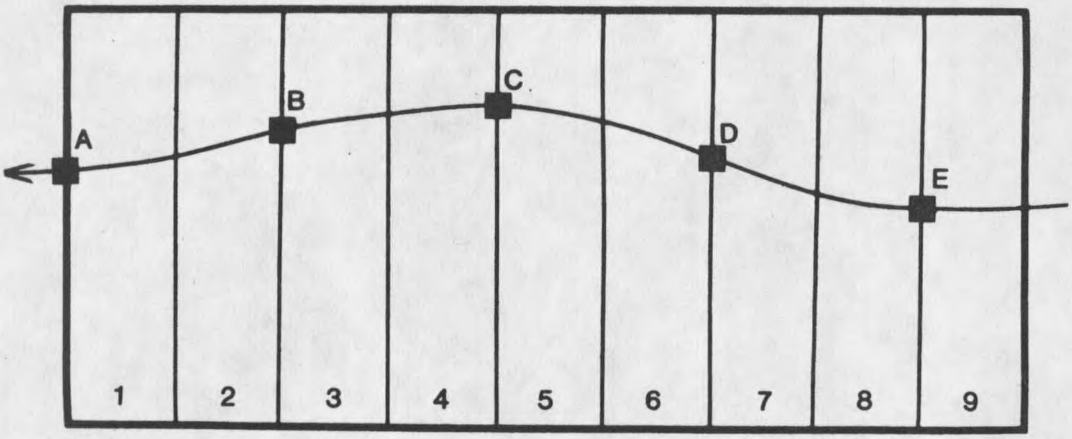
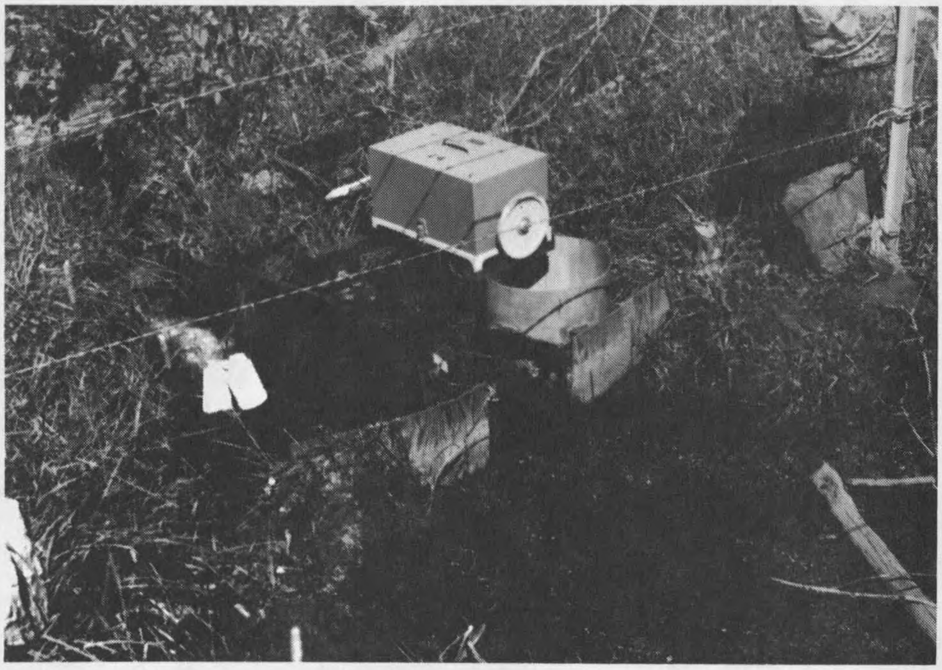


Figure 11. Parshall Flumes and Stevens Type - F Continuous Recorders Were Used to Measure Stream Flow.



to an adjoining pasture. Stream flow discharge was monitored from mid-May until mid-October of each field season.

Water flow charts were analyzed using a computerized digitizer to determine average stage during a collection period. The average water depth information was used to determine total cubic meters of water passing through a station during the collection period following procedures outlined in the Stevens Water Resources Data Handbook (1975). The information was then converted to be expressed as water discharge in cubic meters per second. This was done to present the data in a format compatible with other published water quality studies reporting suspended sediment concentrations.

Suspended Sediment

In this study. suspended sediment concentrations were sampled using modified single stage suspended sediment sampler (Inter-Agency Committee on Water Resources 1983). The modified unit is designed to sample continuously a portion of the water column. Accuracy of the sampler was determined by diverting and capturing the total water column and evaluating the total grams of sediment per unit volume of water. This was compared to a collection made by the sampler units. This procedure was repeated four times.

Results indicate considerable accuracy of the sampling units. Average total concentrations of sediment from the entire water column were 33.0 mg/l, while the sampler units collected an average concentration of 32.0 mg/l. No difference was noted between the total collection and sampler collection using an Analysis of Variance test ($P \geq .01$).

Suspended sediment samplers were located at each water sampling station. The samplers used in this study were modified single-stage, U.S. U-59 suspended sediment sampler (Inter-Agency Committee on Water Resources 1963). A battery of four sediment collections is located with each Parshall flume (Figure 12).

The samplers consisted of a 500 ml settling bottle fitted with a rubber stopper and two tubes which served as intake and exhaust ports (Figure 13). An intake port was connected by plastic tubing to a collection point positioned within the diverging outlet section of the Parshall flume. As water flowed through the tubing into the bottle, suspended sediment settled out in the bottle and sediment-free water exited through the exhaust port. This design allowed water to flow through the system permitting continuous sampling. The samplers were able to collect sediment in the size range of 63 μm to 500 μm in size. Particle sizes smaller than 63 μm will not settle out of suspension in the settling bottles and particles larger than 500 μm will generally not be carried in suspension in a creek with low flows (EPA 1979).

Figure 12. Diagramatic Views of Water Sampling Station Indicating Location of Suspended Sediment Samplers.

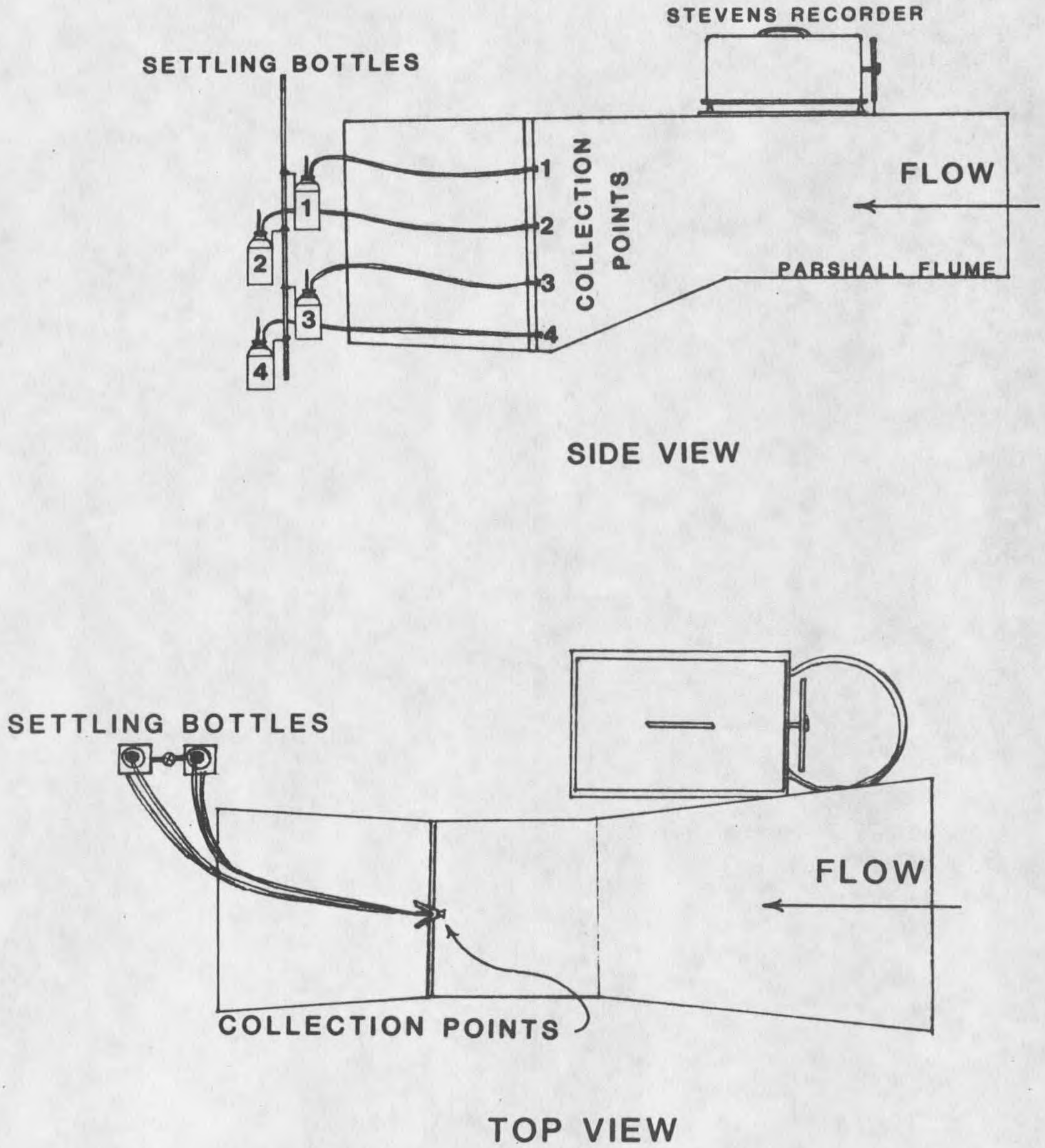
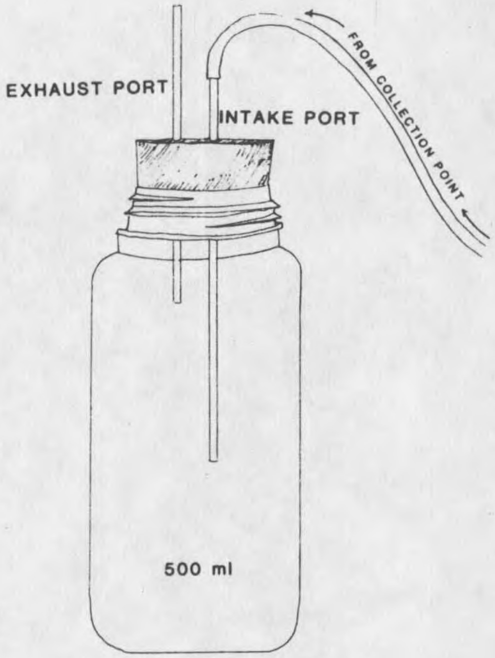


Figure 13. Modified Collection/Settling Bottles Containing Intake and Exhaust Ports to Allow for Continuous Water Flow.



The collection points, positioned within the diverging outlet section of the Parshall flume, were a series of 0.64-cm diameter copper tubes set at four heights. The collection points were numbered one through four and were positioned in a vertical array at set distances from the flume bottom. Point 1 was 23 cm from the bottom, point 2 is 12.5 cm, point 3 is 7.5 cm and point 4 is 2.5 cm above the flume bottom.

Suspended sediment was collected continuously from early June until mid-October. Settling bottles from all five sampling stations were replaced every fourteen days upon completion of a grazing period.

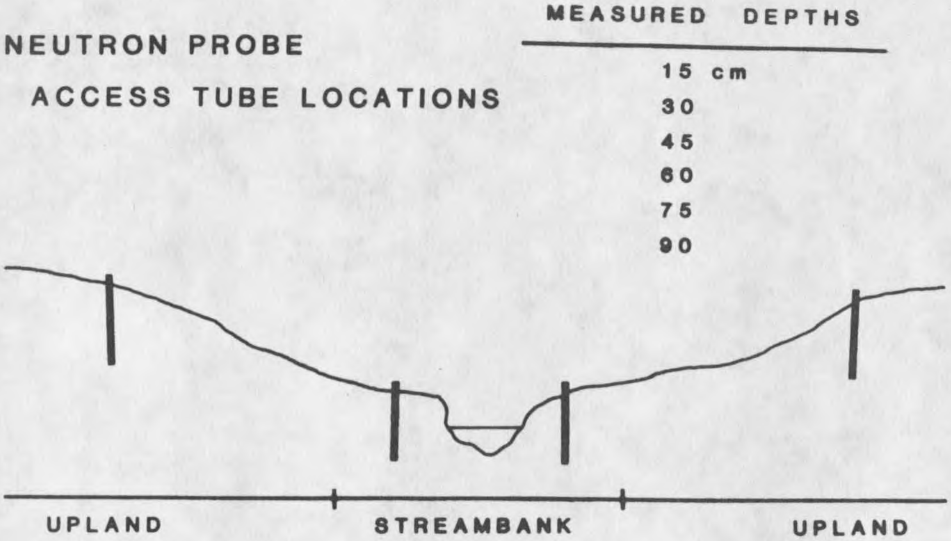
The sediment samples collected during each grazing period were dried for 24 hours at 50°C. The dried material was weighed then ashed for 12 hours at 500°C in a muffle furnace, after which the material was reweighed to determine the amount of mineral and organic matter in each sample.

To present sediment data on a gram-per-cubic-meter-of-water-basis, it was necessary to determine what proportion of the water column is actually sampled. This value was then used to interpolate the total amount of suspended sediment being transported by the water column during the fourteen-day collection period. A computer program was written, under the guidance of Dr. John E. Taylor (1983) of the Department of Animal & Range Sciences, Montana State University, to calculate sediment transport from the total water flow collected during a sampling period (Appendix B). The program calculated sediment transport by inputting average stage height, total water flow, and total grams of sediment collected during a sampling period.

Soil Moisture

Soil moisture was measured using a Troxler neutron probe. Access tubes were located in pastures 2, 4, 6, 8 and 9 along transect lines set perpendicular to the stream channel. Each transect line contains four access tubes. Two tubes were positioned in the uplands and two others on either side of the streambank for each transect line (Figure 14). Soil moisture was recorded at depths of 15 cm, 30 cm, 45 cm, 60 cm, 75 cm and 90 cm. High water tables in certain locations resulted in some tubes not being measured at all six depths during the field season.

Figure 14. Neutron Probe Access Tubes Were Positioned in the Upland and Along the Streambanks. Soil Moisture Measurements Were Taken at 15, 30, 45, 60, 75, and 90 Centimeter Depths.



Measurement of soil moisture was initiated in early-June and continued throughout the grazing season at fourteen-day intervals to coincide with completion of each grazing period. The last soil moisture reading was conducted fourteen days after completion of the last grazing treatment. Soil moisture was recorded at all twenty access tubes on each sampling date. Access tubes were not established for pasture 9 until the 1982 field season.

Neutron probe data was analyzed using standard procedures outlined by Taylor (1972).

<u>Vegetation Utilization</u>

The amount of herbage removed from a pasture during a grazing treatment was estimated at the end of that grazing period using the cage comparison method following procedures described by Brown (1954). Utilization was determined at sites randomly selected within the various vegetation types found in a pasture. The sites were protected for sampling with twelve 1 m x 2 m x 1 m grazing utilization cages. The number of cages placed in each vegetation type were subjectively determined based on the size of that type. Sampling consisted of clipping vegetation (to a height of one cm.) within a 0.25 square meter plot frame beneath the utilization cage. A complimentary plot was clipped within one to two meters outside the utilization cage. The vegetation was separated by species and dried to a constant weight to express production estimates on an oven-dry basis.

The percent of vegetation utilized during a grazing period was determined by the relation:

$$\% \text{ utilization} = \frac{P - G}{P} \times 100\%$$

where P equals the oven-dry weight of vegetation clipped from protected plots and G is the oven-dry weight of vegetation clipped from grazed plots. The percent utilization for each species was determined and then compiled by vegetation type. Utilization of the different vegetation types was pooled into upland or riparian community classifications.

RESULTS

In the following sections, pasture numbers and grazing period numbers are used synonymously to facilitate graphics and data presentation.

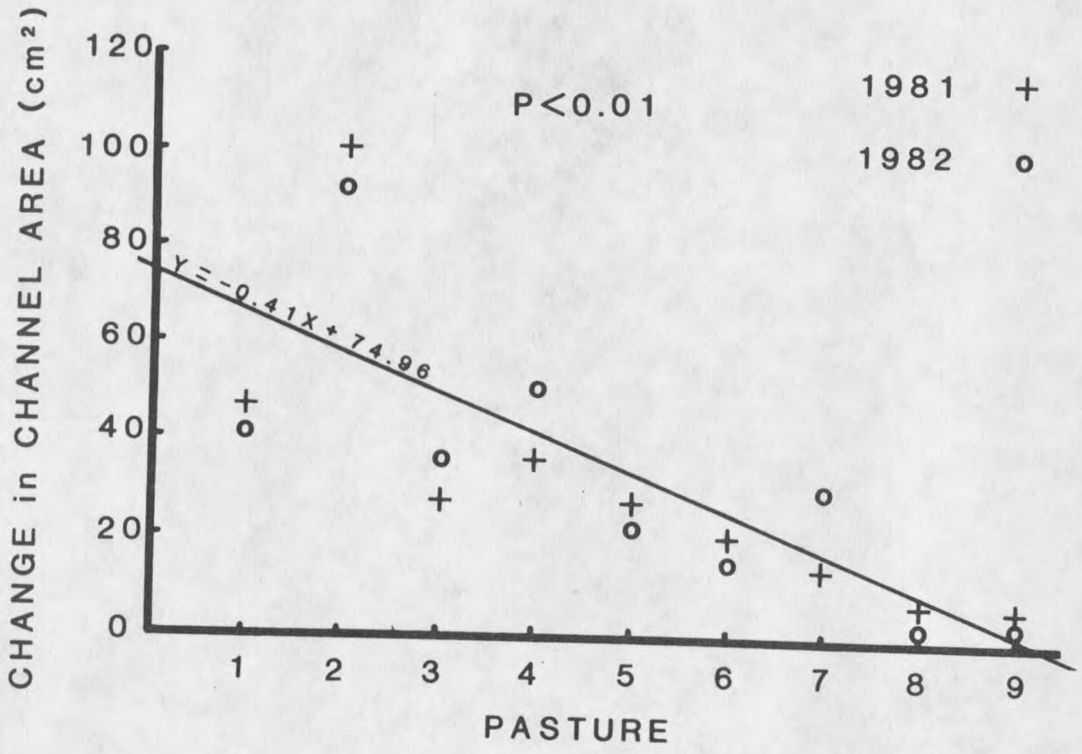
Stream Channel Stability

Changes in stream channel area were found to be either positive or negative values. Positive values corresponded to an increase in channel area, while negative values represented a decrease in area. In compiling total changes incurred by a stream section during a monitoring period, absolute values were used. This procedure was instituted to eliminate the counteracting effects of summing negative and positive values, which could result in an underestimation of total stream channel alterations.

Total stream channel alterations derived for each pasture during a respective monitoring period are illustrated in Figures 15, 16, and 17. Pasture numbers are represented on the horizontal axis and stream channel changes in square centimeters are displayed on the vertical axis.

Stream channel alterations which occurred during the 1981 and 1982 grazing season monitoring periods are presented in Figure 15. During both the 1981 and 1982 grazing seasons, stream channel alterations were significantly greater ($P < 0.01$) during the first half of the grazing season (June 14 - August 9) than during the last half of the season (August 9 - October 4). Pasture 2 (June 28 - July 12) exhibited the greatest level of relative change during both the

Figure 15. Change in Stream Channel Area (cm^2) Observed During the 1981 and 1982 Grazing Seasons.



1981 and 1982 grazing seasons and was significantly different from all other pastures.

Pasture 8 (September 20 - October 4) represented the grazing period showing the least amount of stream channel alteration. It was significantly different from pastures 1 through 4, yet channel alterations in pasture 8 were approximately equal to (1981) or slightly lower (1982) than the channel alterations recorded in the ungrazed control pasture 9.

The relative amount of stream channel alterations expressed within each pasture appears to be consistent from year to year. Channel alterations from 1981 were not significantly different from those recorded for the same pasture during the 1982 grazing season.

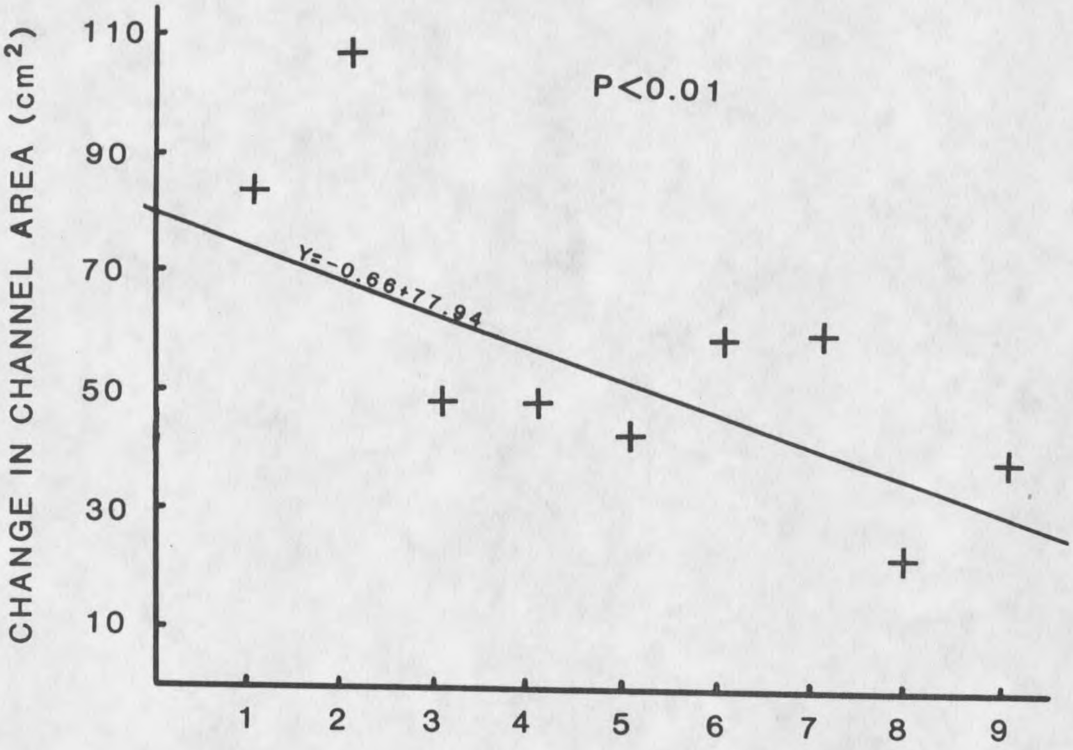
The 1981 and 1982 stream channel alteration data were collectively analyzed using a linear regression to determine if a trend in channel alterations exists. Calculations produced a negative slope:

$$Y = -0.41 X + 74.96$$

indicating a decreasing trend in channel alterations from early to late in the season.

Figure 16 represents the stream channel alterations which occurred during the winter of 1981-1982 monitoring period. Relative changes in channel area were greatest in pastures 1 and 2 and lowest in pastures 8 and 9. However, there was no significant difference in channel alterations among the pastures.

Figure 16. Change in Stream Channel Area (cm^2) Observed Following the Winter of 1981-1982.



Linear regression analyses of winter data produced a negative slope:

$$\hat{Y} = -0.66 X + 77.94$$

indicating a decline in damage from early to late grazed pastures.

Channel alterations recorded during the winter of 1981-1982 monitoring period were found to be 10 to 800 percent greater than the stream channel changes recorded during the grazing seasons of 1981 and 1982.

The total stream channel changes which occurred during the two-year study were determined by comparing the channel areas recorded before the 1981 grazing season to the channel areas recorded at the end of the 1982 grazing season. These results are presented in Figure 17. The graph shows that the degree of stream channel alterations gradually decreases as the season progresses in a pattern similar to the yearly grazing season changes.

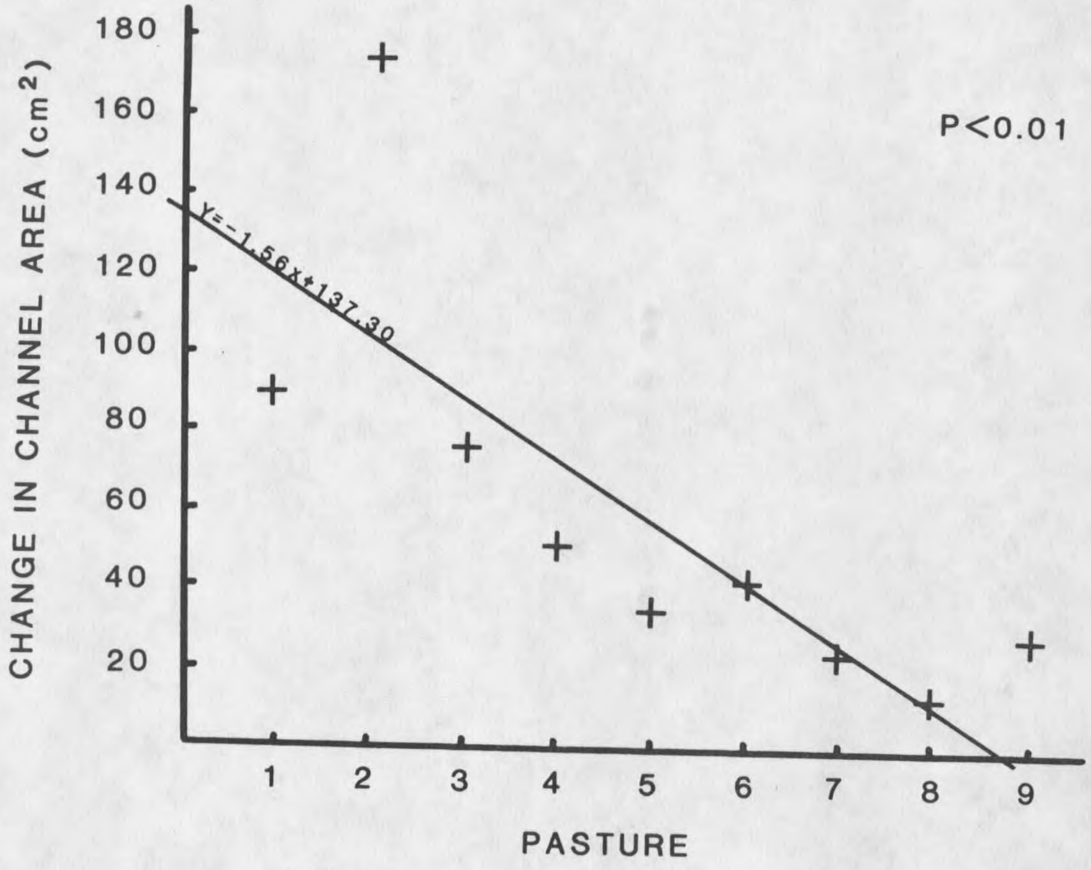
Pasture 2 again showed the greatest levels of channel alterations and was significantly different from all the other pastures. Pastures 7 and 8 both indicated less channel alterations than did the ungrazed control pasture, 9. A linear regression test of total channel alterations produces the equation:

$$Y = -1.56 X + 137.30$$

indicating a decreasing trend in changes of channel area from pasture 1 through pasture 9.

As previously mentioned, changes in channel area are denoted by positive or negative values indicating either an increase or decrease in channel area. Analysis of the direction of change shows little

Figure 17. Total Change in Stream Channel Area (cm^2) Observed From the Spring of 1981 Until the Fall of 1982.



consistency between the 1981 and 1982 grazing periods (Table 1). Comparison of the two grazing seasons reveals that 9 transects increased in area and 9 transects decreased in area during both grazing seasons. Yet, during both years, 27 transects increased in area one year and decreased in area the other revealing an inconsistency in the type of changes being recorded at these transects. Channel alterations which occurred during the winter of 1981-1982 show 32 transects increasing in area and 13 transects decreasing in area. There was no similarity between which transects increased in area and which decreased when comparing the 1981 and 1982 grazing periods to the over-winter alterations.

Total stream channel alterations over the two-year study show 34 transects increased in area while only 11 decreased in area. Transect 9, located in pasture 2, exhibited the greatest degree of increase in channel area (144.39 cm^2), and transect 19, in pasture 4 showed the greatest decrease (24.54 cm^2). Transects 4 through 6 and 30 through 33 appear to be two areas of deposition within the stream channel. These deposition areas contain two thirds of the transects which consistently decreased in area.

Soil Moisture

Soil moisture data were analyzed for the top 45 cm of soil. This depth was selected due to its greater potential susceptibility to livestock impacts and because soil moisture varies little below 45 cm (Papendick, Cochran and Woody 1971). The average soil moisture of the top 45 cm of soil for all streambank access tubes is presented in

Table 1. Direction of change exhibited by stream channel cross-sections during the 1981 and 1982 grazing seasons and the total change from pre-1981 to post-1982. Increases in channel are designated by (+) and decreases in channel are designated by (-).

Pasture	Transect	Grazing Season 1981	1982	Pre-1981 to Post-1982
1	1	+	+	+
	2	+	-	+
	3	+	+	+
	4	-	+	-
	5	-	-	-
2	6	+	-	-
	7	+	-	+
	8	+	-	+
	9	+	+	+
	10	-	-	-
3	11	+	+	+
	12	-	-	-
	13	+	-	+
	14	+	+	+
	15	-	+	+
4	16	+	+	+
	17	+	-	+
	18	+	+	+
	19	+	-	-
	20	-	+	+
5	21	-	+	+
	22	-	+	+
	23	-	+	+
	24	+	-	+
	25	+	+	+
6	26	-	+	+
	27	+	-	+
	28	-	+	+
	29	-	+	+
	30	-	+	+
7	31	+	-	+
	32	-	+	-
	33	-	-	-
	34	+	-	+
	35	-	+	+
8	36	-	-	+
	37	-	-	+
	38	-	+	+
	39	-	-	+
	40	+	-	+
9 Control	41	-	+	+
	42	+	+	-
	43	+	-	+
	44	-	-	-
	45	-	-	+

Figure 18. Soil moisture was sampled at the end of each grazing period and presented here as pasture numbers.

During both the 1981 and 1982 seasons, soil moisture values were found to be highest in the early grazing periods followed by a rapid decrease through grazing periods 1 and 2 and a gradual decrease until periods 6 (1982) and 7 (1981) when fall precipitation increased soil and moisture levels.

Overall soil moisture levels were higher in 1982 than in 1981. This is especially evident during the fall soil moisture recharge period. Fall recharge occurred earlier and was of a greater magnitude than in 1981.

Stream Flow Discharge

Figure 19 represents water flow data from 1981 and 1982 as the average flow from all five sampling stations at the end of a grazing period. Flow data are presented on a m^3/day basis.

During both 1981 and 1982, peak flow occurred approximately June 1 through 10, thus ending approximately four days before the initiation of any grazing treatments. Flow levels rapidly decreased during the first four grazing periods and stabilized during the remainder of the grazing season. Little fall recharge was noted. Flow levels during 1982 were generally greater than during the 1981 season.

Figure 18. Streambank Soil Moisture (%) Recorded During the 1981 and 1982 Grazing Seasons Using a Troxler Neutron Probe.

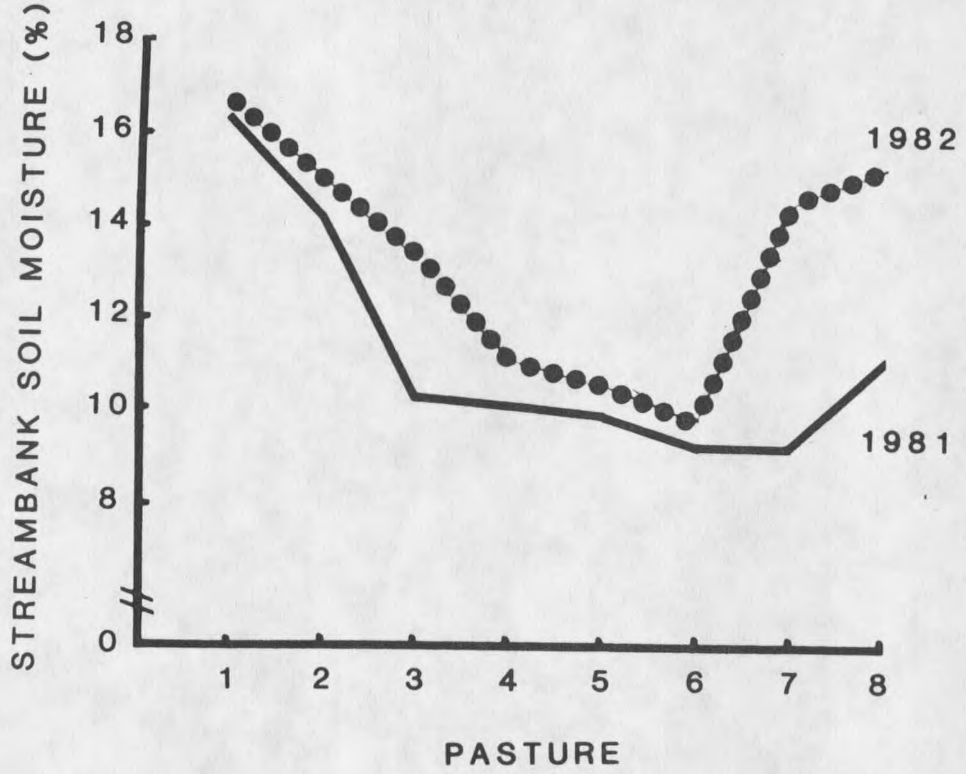
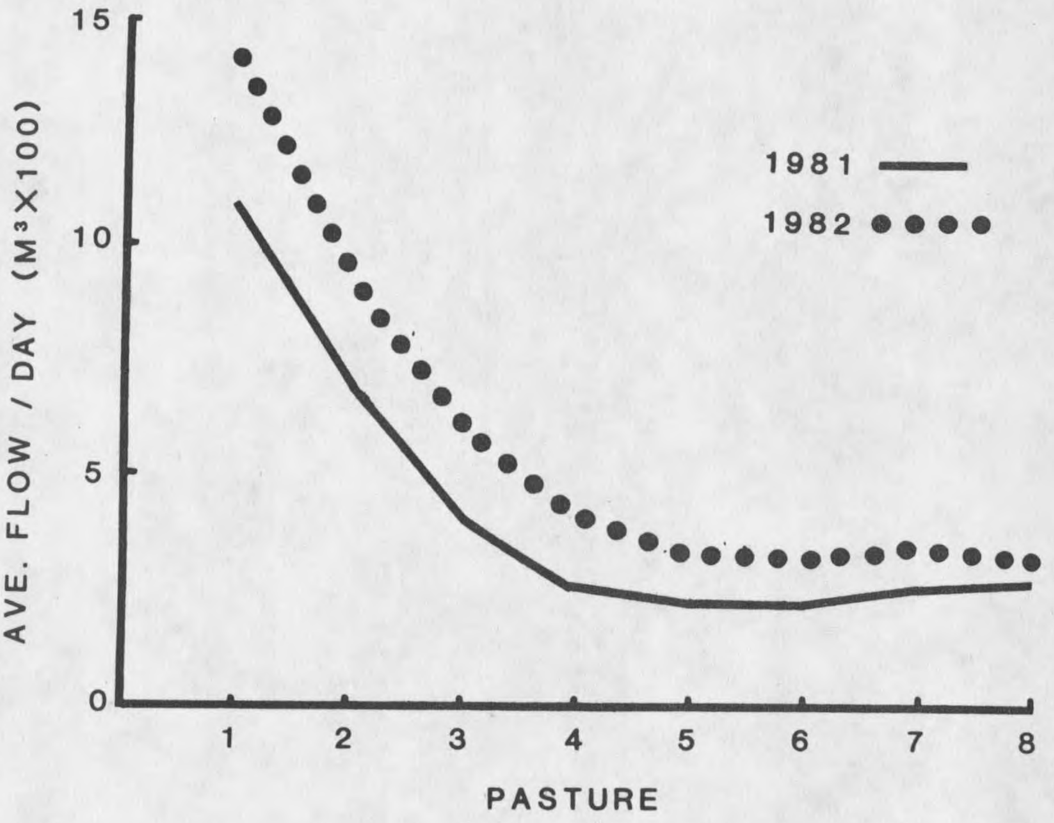


Figure 19. Water Volume Recorded for Cottonwood Creek During the 1981 and 1982 Grazing Seasons (m^3/day).



Suspended Sediment

Suspended sediment data are presented in Figures 20 and 21. The graphs present the amount of suspended sediment collected during a grazing period at each sampling station. Sampling stations are designated A, B, C, D and E on the right-hand axis of the graph. The foreground axis represents the pasture number or grazing period during which sediment was collected. The vertical axis displays the amount of sediment collected during each grazing period in g/m^3 of water flow.

The shaded portions of each graph represent the location of the cattle during that grazing period and help to identify which collection station is downstream of that location (e.g. collection station A is downstream of pastures 1 and 2, collection station E is downstream of the ungrazed pasture, 9, and represents the control).

For the 1981 grazing season (Figure 20), peak suspended sediment flow was found to occur during the second grazing period at each of the five sampling stations. Sediment levels sharply decreased following the peak loading period at stations B through E. Sediment concentrations then stabilized during the fourth grazing period and remained constant throughout the remainder of the grazing season. A gradual decrease in sediment concentrations was noted at station A following the peak loading period, and continued until the termination of the grazing season.

Station B recorded the highest concentration of suspended sediment at peak sediment flow during the second grazing period. During the second and third grazing periods, station B collected

Figure 20. Suspended Sediment Concentrations (g/m^3) Collected During the 1981 Grazing Season Using a Modified Single Stage Sediment Sampler. The Shaded Portion of the Figure Represents the Location of the Cattle in Relation to the Sampling Stations.

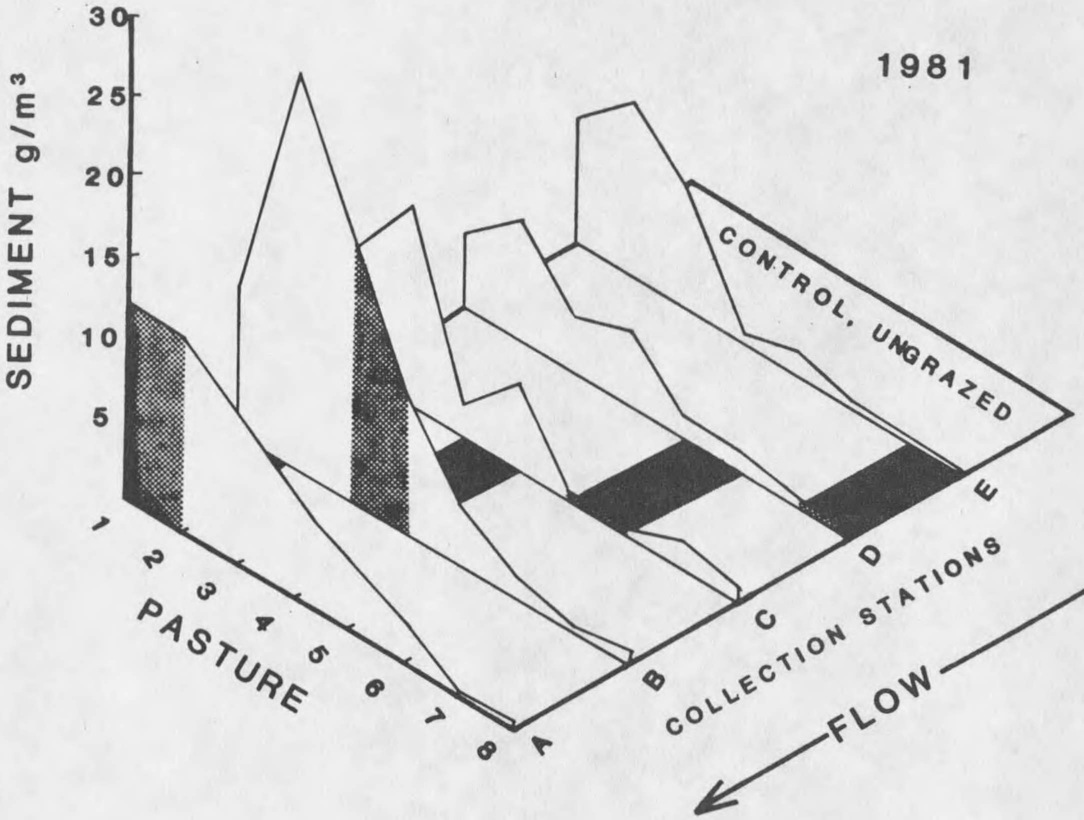
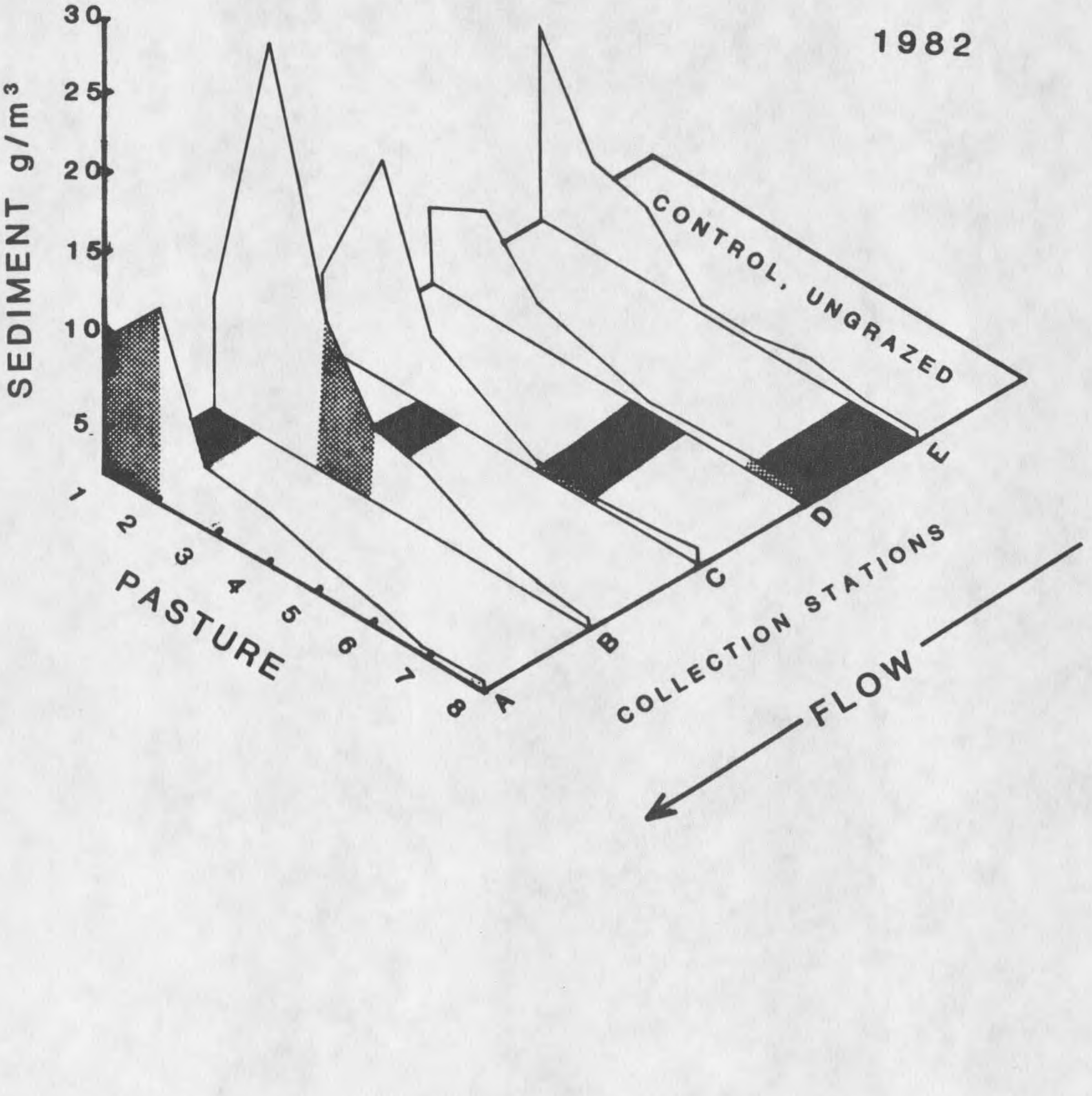


Figure 21. Suspended Sediment Concentrations (g/m^3) Collected During the 1982 Grazing Season Using a Modified Single Stage Sediment Sampler. The Shaded Portion of the Figure Represents the Location of the Cattle in Relation to the Sampling Stations.



greater amounts of sediment than any other station ($P < 0.01$). No other significant differences were noted between the sampling stations during any other grazing period. Also, sediment concentrations during the first three grazing periods were found to be significantly greater than the last five grazing periods for stations B through E and for grazing periods 7 and 8 for station A.

The 1982 suspended sediment data displays trends similar to those expressed in 1981 (Figure 21). Peak sediment concentrations were recorded during the second grazing period for all sampling stations except E, where peak sediment loading occurred during the first grazing period. A rapid decrease in sediment concentrations was recorded following the peak concentration period. Sediment concentrations stabilized during the fourth grazing period and remained constant throughout the remainder of the grazing season.

As with 1981, station B recorded the highest sediment concentrations during the second grazing period. Sediment concentrations for station B were significantly greater than the other stations. No other significant differences were noted between stations during the remaining grazing periods except that suspended sediment concentrations during the first two grazing periods were significantly greater than the last six grazing periods at all five sampling stations.

No increase in suspended sediment concentrations was observed due to the presence of cattle. In most cases, a general reduction in collected suspended sediment was recorded in 1981 during all grazing periods and in 1982 during grazing periods 3 through 8. An increase in suspended sediment concentrations was observed downstream of the cattle at station A during grazing periods 1 and 2, however, this same increase was also noted upstream of the cattle at stations B, C, D and E during the same period.

Figure 22 represents the grams of suspended organic matter collected at each sampling station during the 8 grazing periods from the 1982 grazing season. No data are available for 1981. Although organic matter levels were greatest during the early grazing periods, 1 through 3, there was no significant difference between early and late periods. Sampling stations A, B, C and D recorded peak organic material loading during the third grazing period, while station E recorded its peak levels during the second grazing period. Subsequent peaks were observed at stations A, C, D and E at various times during the grazing season. No increase in organic matter loading was evident due to cattle activity upstream of any recording station.

Vegetation Utilization

During the 1981 grazing season utilization rates in the riparian area were consistently higher than in the upland communities (Figure 23). Utilization rates in the riparian communities averaged 59 percent with a high of 71 percent during grazing period 2 and a low of 49 percent during period 5. Upland communities averaged 46 percent utilization over the grazing season with a high of 73 percent during grazing period 7 and a low of 27 percent during period 4.

Figure 22. Suspended Organic Matter (g) Collected During the 1982 Grazing Season Using a Modified Single Stage Sediment Sampler. The Shaded Portion of the Figure Represents the Location of the Cattle in Relation to the Sampling Stations.

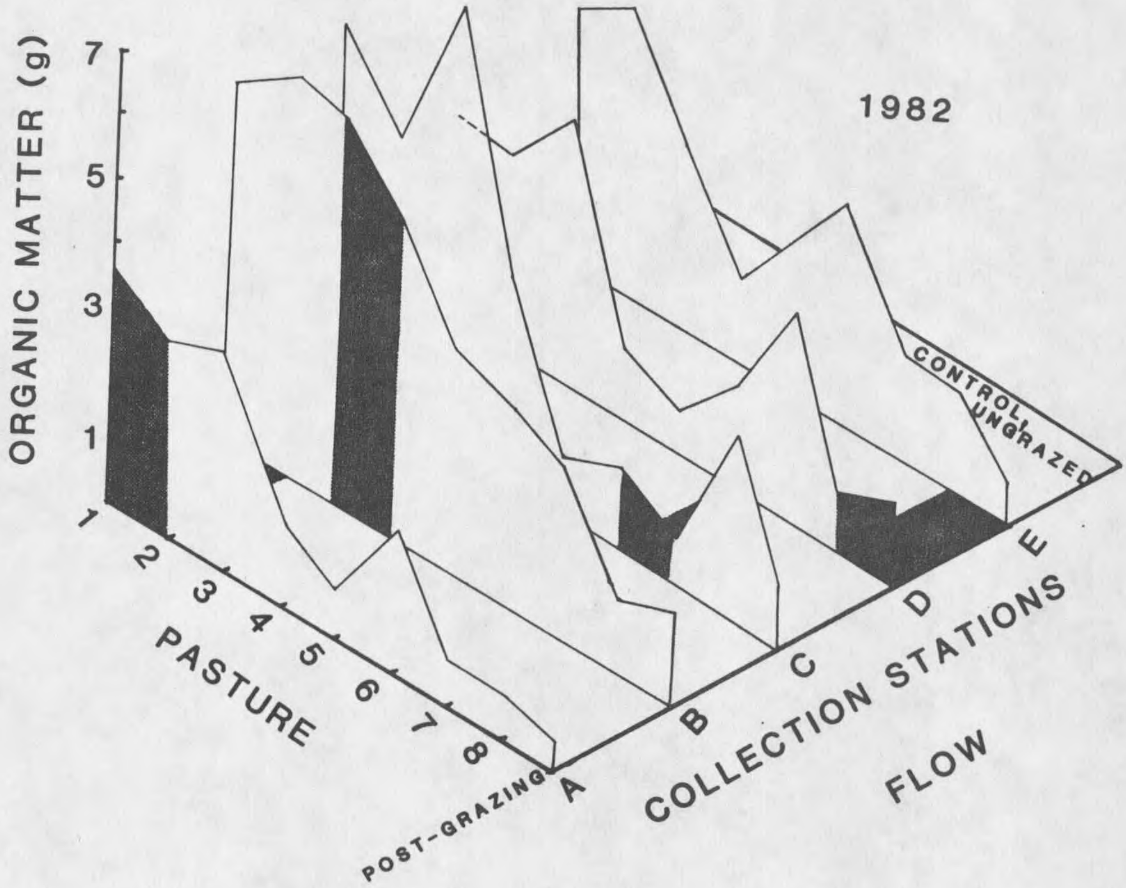
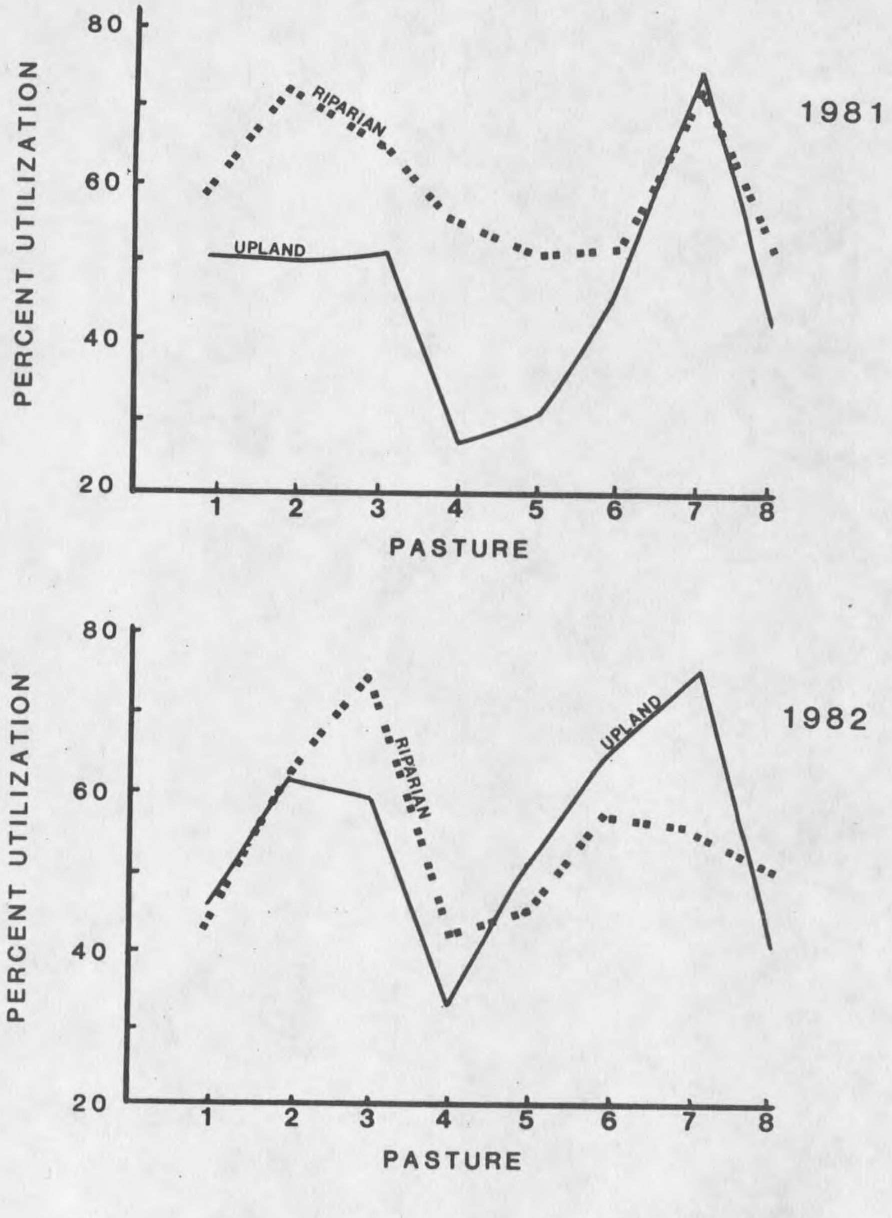


Figure 23. Percent Utilization of Upland and Riparian Vegetation Determined Using the Cage Comparison Method.



Utilization rates during the 1982 season show riparian utilization higher in early season (pastures 2, 3 and 4) while upland utilization rates were higher during the latter (pastures 5, 6 and 7).

Riparian utilization rates averaged 52 percent with a high of 74 percent during grazing period 3 and a low of 42 percent during 4. Upland communities averaged 54 percent with a high of 74 percent during grazing period 7 and a low of 35 during period 4.

During both the 1981 and 1982 seasons, peak utilization in the upland communities occurred during grazing period 7, while peak riparian utilization occurred during grazing period 2 in 1981 and period 3 in 1982. The period of lowest utilization for both years for upland communities was during period 4, while for riparian communities it occurred in grazing period 5 in 1981 and period 4 in 1982. During both seasons, utilization rates in the spring were high for riparian and upland communities dropping to a low during mid-season and then increasing again during late season.

DISCUSSION

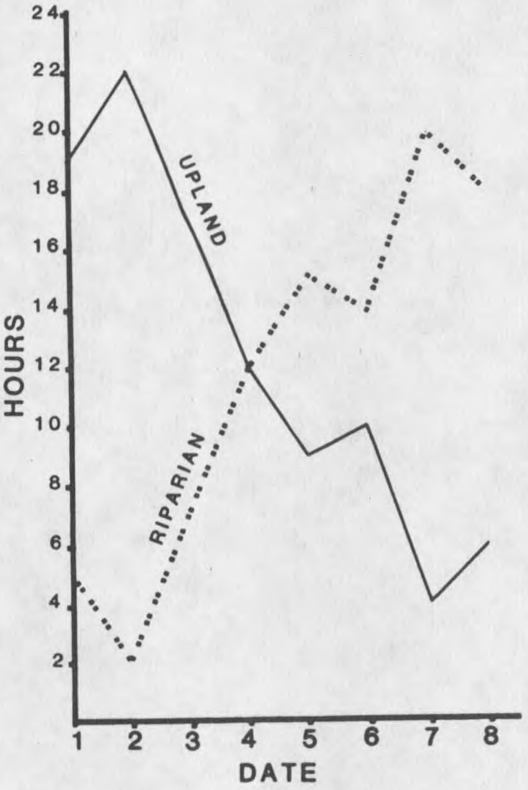
Time of grazing was found to be fundamental in evaluating the effects of livestock-induced streambank instability along Cottonwood Creek. Alterations of streambanks attributable to livestock grazing were found to be greatest during early grazing periods (periods 1 to 4) and significantly less in the latter periods (periods 5 to 8) ($P < 0.01$). The second grazing period in late June and early July was found to have significantly greater streambank alterations than any other grazing period during both years of monitoring. Alterations were observed to be consistent from one year to the next, indicating the banks were receiving approximately the same impacts each season. Streambank alterations during the latter part of the season were not significantly different than those displayed within the ungrazed control.

Qualitative observations indicate considerably more exposed banks and hoof damage during the early periods, especially at creek crossing locations, and at points where the cattle entered the creek channel to graze on streambank vegetation. Vegetation utilization studies by Platts (1982) and Hayes (1978) indicate that decreased streambank stability is likely to result when utilization levels become excessive. Platts (1982) reported that streambank alterations were probable when riparian vegetation utilization exceeds 65 percent with Hayes (1978) reporting similar findings of damage occurring above 60 percent use. Utilization of riparian vegetation on the Cottonwood study site averaged 62 and 63 percent for 1981 and 1982 respectively during the first half of the grazing season and 55 and 52 percent during the second half of the season.

The periods of greatest streambank alterations coincide with high utilization rates supporting Platts' (1982) and Hayes' (1978) conclusions that high utilization is a good indicator of decreased streambank stability. This concept did not hold true in 1981 during grazing period 7, however, when riparian vegetation utilization levels exceeded 70 percent and streambank alterations were minimal, followed in 1982 by utilization levels of 55 percent and a marked increase in alterations. Cooper (1979) and Duff (1979) both noted that heavy utilization was not necessary to impart damage upon the streambanks that the amount of animal activity and the sensitivity of the banks were a more critical factor.

A cattle behavior study conducted by Marlow (1983) on the Cottonwood Creek study site reveals that the cattle are spending significantly less time in the riparian communities during the first half of the grazing season than the last (Figure 24). No correlation between the amount of time cattle spend in the riparian communities and streambank alterations was discernible ($r^2 = 0.04$). The cattle were having a significantly greater impact on the streambanks and doing it in a shorter period of time during the early grazing periods, while having little impact over a long period of time during the latter grazing periods. This leads to the inference that the streambanks may be more vulnerable to livestock impacts in the early part of the grazing season.

Figure 24. Time (Hours) Spent by Cattle Group in Upland and Riparian Habitat Types During the 1982 Grazing Season (Marlow 1983). Dates Along the Horizontal Axis are Synonymous With Grazing Periods.



The direction of streambank changes (increased area due to soil loss or decreased area due to soil gain) was highly variable between monitoring periods. This variability may again be attributed to cattle behavior. During each grazing season a different group of heifers were used. Qualitative observations reveal that the two groups used different creek crossing points which resulted in certain transects receiving more trampling damage while others downstream of such areas received debris and sediment accumulations. The consistency of impact should be noted though. Although differing transects displayed alterations one year to the next, the total alterations within each pasture remained consistent during the two years.

Roath (1980) states the greatest impact livestock have on riparian areas may be trampling damage and that wet soil is the most susceptible to livestock impacts. The periods of greatest streambank alterations were found to be closely correlated to high soil moisture levels ($r^2 = 0.82$) during frost-free grazing periods. Soil moisture was found to be highest early in the season and gradually decreased to the lowest levels in early September. Streambank alterations were also highest early in the season followed by a gradual decrease throughout the remainder of the season. As the streambank dried, it appeared to be less susceptible to trampling damage. During the 1981 season, the dry streambanks showed little impact due to the cattle, yet, increased streambank alterations were noted within pasture 7 during the 1982 season after an early fall snow storm increased soil moisture levels. This increase and damage lasted only one grazing period.

The correlation between soil moisture and streambank alterations dropped ($r^2 = 0.63$) after mid-September during both grazing seasons. During the last two grazing periods, soil moisture increased while streambank alterations decreased even though soil moisture was being recharged by fall precipitation events. During both 1981 and 1982, early fall snowstorms and average daily air temperatures below 2° C. may have combined to freeze the recharge moisture in the upper layer of soil, thus acting to cement the banks in place. The frozen streambanks may then have been strong enough to support the weight of the cattle and not succumb to trampling damage. Similar findings were reported by Cooper (1979), who noted reduced streambank damage associated with livestock grazing late in the fall and winter after the streambanks had become frozen. Kauffman (1982) also reported reduced soil disturbance during late fall grazing.

Although direct livestock impacts to streambank stability may be reduced during the fall and winter, it was over-winter alterations which were found to be greater than livestock-induced damage. Over-winter alterations were 10 to 800 percent greater than the alterations recorded along the same transects during the grazing season. Similar results were reported by Buckhouse (1980) and Hayes (1978). Buckhouse (1980) reported greater streambank alterations occurring during the winter than during the grazing season and concluded that ice floes, high water, and channel physiognomy were critical factors involved in the erosion process. Hayes (1978) also found winter/spring channel alterations to be in excess of alterations attributable to cattle grazing impacts during the grazing season.

Cottonwood Creek characteristically has deep snow drifts lining the channel length over the winter and into late May. The weight of snow and ice may act to loosen the soil and cause streambank slumping on areas impacted by livestock during the previous year's grazing. The degree of livestock impact during the grazing season could influence the amount of over-winter damage. The first two grazing periods in which the greatest degree of streambank alterations occurred during the grazing season also had the greatest amount of over-winter change. The remaining 7 pastures all had statistically similar levels of alterations during the winter period although they were significantly greater than the impacts recorded during the grazing season. However, over-winter alterations in the ungrazed control pasture also averaged 655 percent greater than the alterations recorded during the grazing season. This indicated that naturally occurring factors may have as significant an impact on inducing streambank instability and eventually increased suspended sediment loading as does livestock impacts.

Rosgen (1975) reports that suspended sediment concentrations are correlated to streambank stability and water flow. As streambanks become less stable, more sediment will be contributed to the stream flow and increasing volumes of water can transport a greater volume of sediment. Johnson et al. (1978) also state that high concentrations of suspended sediment are generally an indication of erosion associated with some degree of impact.

Cattle presence appeared to have no effect on the period of peak sediment concentrations as peak suspended sediment concentrations occurred at all recording stations during the second grazing period during both monitoring seasons regardless of cattle presence. The same held true for suspended organic matter. Peak suspended sediment concentrations of 24.04 g/m^3 in 1981 to 25.25 g/m^3 in 1982 were well below the critical level of 80 g/m^3 reported by McKee and Wolf (1963) to be detrimental to aquatic organisms.

The pattern of peak suspended sediment concentrations lasting only for approximately two weeks immediately followed by a rapid decrease and stabilization with low concentrations is consistent with findings by Gary et al. (1983), who found similar peak concentration - stabilization patterns on a small watershed in the Colorado Front Range. In their observations, they noted maximum sediment concentrations occurred during peak stream flow periods. Yet, in this study, maximum suspended sediment concentrations occurred approximately 14 to 21 days after the peak water flow period.

The peak suspended sediment concentration period (June 28 - July 12) coincides with the period of heaviest precipitation for the Cottonwood Creek drainage. The Cottonwood Creek drainage receives an average of 450 mm per year with 110 mm, or 24 percent of the yearly average occurring during late June and early July. The large volumes of water originating from convectional thunderstorms may act to wash loosened soil along damaged streambanks into the water column. Although there was no observable increase in suspended sediment concentrations due to cattle activity as they were moved upstream through the pastures, there may have been an indirect increase during the following spring associated with their residual impacts.

Suspended sediment concentrations were found to be greater below pastures that had considerable streambank alterations. Peak sediment concentrations were found at collection stations A and B, which were downstream of the pastures grazed early in the season and which showed the greatest alterations. The cattle activity of altering the streambanks may be coupled with the destabilizing forces of ice and snow during the winter to loosen the exposed banks and may provide a source of sediment to be flushed into the water column.

It appears that periods of peak suspended sediment concentrations may be magnified by livestock activity on Cottonwood Creek during the previous grazing season.

SUMMARY

Livestock grazing can affect all components of a riparian system. The influence of livestock on riparian areas depends on numerous factors, including the time of grazing. The objective of this study was to ascertain what time during the grazing season streambanks are most susceptible to livestock-generated impacts and whether increases in suspended sediment concentrations occur during periods of cattle activity. Quantitative measurements of stream channel area, soil moisture, stream flow, suspended sediment concentrations, and vegetation utilization were made during each fourteen-day grazing period.

Early-season grazing induced immediate streambank alterations as well as increased suspended sediment concentrations which occurred the following year. Stream channel alterations were found to be greatest during the early grazing periods and were associated with riparian vegetation utilization rates exceeding 60 percent. Pastures receiving less than 60 percent use showed far less streambank instability. Soil moisture was closely correlated with stream channel alterations (r^2 = 0.84) during frost-free grazing periods. This correlation was less evident (r^2 = 0.63) after mid-September when the streambanks began to freeze. Frozen streambanks may be able to withstand livestock activity with very little damage.

Within pastures and between years, the trend of change in channel alterations was inconsistent from one year to the next and may be a result of different crossing point preferences displayed by the

different heifer groups used during the two years of study. Behavior observations of the cattle used in this study (Marlow 1983) indicate the animals are spending less time in riparian areas during the early grazing season while inflicting a greater impact on the streambanks. This lends to the inference that the streambanks are more susceptible to cattle damage early in the grazing season.

Although direct impacts of cattle were greater during the early grazing periods, overall channel alterations were 10 to 800 percent greater during the winter monitoring period than during the grazing season. This increase in damage may have been due to ice and snow collapsing streambanks already altered by cattle the summer before. Cattle-induced alterations, intensified by snow and ice damage, may provide the source of high suspended sediment concentrations in the late spring. Similar increases in alterations were displayed within the control pasture, indicating environmental factors may have as significant a role in impacting streambanks as do livestock.

Peak suspended sediment concentrations were greatest at all sampling stations during the second grazing period (June 28 - July 12) regardless of cattle presence. The highest concentrations occurred 14 to 21 days after peak stream flow discharge in the creek and in conjunction with periods of heavy rainfall. Peak suspended sediment loading may be a function of overland sediment travel from streambanks altered by cattle grazing the season before and damaged by ice and snow during the winter. The greatest sediment concentrations were generally downstream of the pastures that have the greatest streambank instability.

The sampling technique used to estimate stream channel alteration appears accurate and repeatable. Although time-consuming, the method provided a reliable representation of channel movement. The modified single-stage sediment samples also proved to be accurate and reliable in estimating sediment concentration within the water column. A major drawback of the sampler was clogging with ice during the latter part of the season.

Late-season grazing may be a less damaging alternative than grazing at other times in riparian areas deemed critical to fisheries or in areas with sensitive streambanks or areas already exhibiting livestock damage. This could reduce livestock-generated impacts to the environment, while still permitting utilization of the riparian forage base. Proper grazing management, using moderate stocking rates, salting away from the riparian zone, and herding the animals to prevent areas of overgrazing, is a necessary part of any riparian grazing plan.

More intensive research is required concerning the correlation of the physical alteration of riparian areas with the effects of livestock grazing under proper management. Too often, riparian studies have evaluated improper grazing practices resulting in an indictment of livestock grazing in general, yet provided little information as to the ecological principles involved in the interaction. An adequate understanding of the ecological processes and proper livestock management in riparian areas is essential if we are to fully optimize the multiple use of riparian ecosystem resources.

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APPENDICES

Appendix A

Vegetation Types Common to the Cottonwood Creek Study Site

Appendix A

Table 2. Vegetation types common to the Cottonwood Creek study site based on criteria established by the Montana Rural Areas Development Committee (1982), with modification to include adjacent upland vegetation types.

RAD Classification	Vegetation Type	Riparian Predominant Species
I A 4	Aspen	Populus tremuloides michx. Poa compressa L. Bromus inermis Leyss. Phleum pratensis L. Trifolium repens L. Taraxicum officinale Weber Ribes lacustre (Pers.) Poir.
II A 1/99	Aspen/Willow	Populus tremuloides Salix spp. L. Poa compressa Agrostis stolonifera L. Carex rostratea Stokes Carex sprengelii Dewey Juncus balticus Will[. Ribes lacustre Prunus virginianus L.
III E	Bog	Carex rostrata Carex sprengelii Agrostis stolonifera Juncus balticus Ribes lacustre
IV A	Meadow	Bromus inermis Phleum pratensis Poa compressa Agrostis stolonifera Carex rostrata Juncus balticus Achillea millifolium L. Cirsium avarense (L.) Scop.
III B 1	Streambank	Poa compressa Agrostis stolonifera Bromus inermis Carex rostrata Carex sprengelii Juncus balticus Linarea vulgaris Hill

Table 2 (Continued).

RAD Classification	Vegetation Type	Upland Predominant Species
V A 1	Upland/Grassland	*Poa compressa* *Poa sandbergii* Vasey *Poa pratensis* L. *Stipa comata* Trin. & Rupr. *Stipa virigula* Trin. *Agropyron smithii* Rydb. *Agropyronspicatum*(Pursh) Scribn. & Smith *Festuca idahoensis* Elmer *Bromus tectorum* L. *Achillea millifolium*
V B 1	Upland/Sagebrush	*Artemisia tridentata* var. vaseyana (Rydb.) Beetle *Rosa woodsii* Lind. L. *Bromus tectorum* *Poa compressa* *Stipa comata* *Achillea millifolium*
I A 4/99	Aspen Park	*Populus tremuloides* *Poa compressa* *Bromus inermis* *Geranium viscosissimum* F.&M. *Taraxicum officinale*

Appendix B

Description of Computer Program

Appendix B

Description of computer program designed to determine suspended sediment loads for each sampling period based on average water depth, total water flow and total sediment collected (Taylor 1983). Computer is a Texas Instruments TI-58 hand-held calculator mounted on a printout crib.

The program consists of four steps:

1. Initialize the computer to erase existing material and prepare unit to work program.

2. Enter average water depth (stage height) during the collection period. Program calculates the area of water flowing through flume and adjusts for the number of collection tubes which would be filling.

3. Enter total water flow recorded during the collection period. Program measures the length of the water column to give a volumetric value to water flowing into the collection tube.

4. Enter total sediment collected during collection period. Program calculates the grams of sediment per cubic meter of water during the collection period.

Appendix B - Continued

			Step	
000	76	LBL		
001	10	E		
002	47	CMS		
003	25	CLR	1	Initialize
004	58	FIX		
005	09	09		
006	91	R/S		
007	76	LBL		
008	11	A		Enter average water depth
009	99	PRT		
010	65	x		
011	07	7		
012	93	.		
013	06	6		
014	02	2		
015	95	=		
016	55		2	Determine water area
017	01	1		
018	00	0		
019	00	0		
020	00	0		
021	00	0		
022	95	=		
023	42	STD		
024	01	01		
025	91	R/S		
026	76	LBL		
027	12	B		Enter total water flow
028	99	PRT		
029	55			
030	43	RCL	3	Determine water volume
031	01	01		
032	95	=		
033	42	STD		
034	02	02		
035	91	R/S		
036	76	LBL		
037	13	C		Enter total sediment collected

Appendix B - Continued

			Step	
038	99	PRT		
039	42	STD		
040	03	03		
041	43	RCL		
042	02	02		
043	65	x		
044	01	1		
045	93	.		
046	09	9		
047	06	6		
048	03	3		
049	52	EE		
050	05	5		
051	94	+/-		
052	95	=	4	Calculate sediment - g/m^3/collection period
053	22	INV		
054	52	EE		
055	55			
056	43	RCL		
057	03	03		
058	95	=		
059	35	1/x		
060	99	PRT		
061	98	ADV		
062	91	R/S		
063	00	0		
064	00	0		
065	00	0		
066	00	0		