AN ABSTRACT OF THE THESIS OF

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Title: THE RESPONSE OF SOILS, STREAMBANKS AND INSTREAM COLIFORM BACTERIA LEVELS TO GRAZING MANAGEMENT IN A RIPARIAN AREA

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This thesis describes a case study of the effects of five systems of grazing on watershed values in a deteriorated riparian area. Soil infiltration, bulk density and penetrability, streambank edge movement and coliform bacteria were monitored for seven years along a stream in the Blue Mountains of northeastern Oregon. For five consecutive years, no grazing, four pasture rest rotation, deferred rotation, season-long and late season systems of grazing were applied to small streamside pastures stocked with yearling heifers from June-October at the moderate rate of 3.2 ha/AUM. Infiltration and sediment production were monitored with Rocky Mountain and ring infiltrometers. Measurements with a proving ring penetrometer and bulk density cores indexed compaction. Soil and hydrologic data from ungrazed areas suggested that a process of recovery from the historical heavy use period was occurring. Although season-long grazing for five years did not promote the recovery of soil infiltration, sediment production and soil density and penetrability, the soil response to rest rotation and season-long grazing for one or two years (with four or three years of prior rest) usually corresponded to the ungrazed areas. Generally, soil properties appeared

to fluctuate seasonally, showing greater soil infiltration and penetrability and lower bulk density when measured at the end of winter and the opposite conditions after the grazing season. Ungrazed areas fluctuated less than did grazed areas.

Streambank movement was monitored by change in distance from the bank edges to permanent reference stakes. Bank movement tended to increase with amount of use---use in terms of number of animals and number of years. No grazing and occasional season-long use appeared to be associated with the least bank loss, while season-long grazing for four or five years and deferred rotation grazing were associated with the most bank loss. Rest rotation results were intermediate and variable, but generally low. Late season grazing treatments did not differ between September and October grazing and were not compared to the other systems due to differences in grazing pressure. Although winter processes and livestock grazing exerted a similar amount of pressure per week on streambanks, livestock were present for a relatively short period. Consequently, there was greater total bank loss in the winter on four of the sixteen treatments. These four treatments were season-long grazing for three, four or five years with big game access. The other twelve treatments did not demonstrate significant seasonal differences.

Escherichia coli were monitored by the membrane filter technique to indicate the level of fecal contamination in the stream. Although large numerical differences were sometimes seen, coliform concentrations seldom changed significantly across the 400 meter long pastures. Large numerical reductions in coliform counts were also seen in the first year after livestock removal, but the changes were not statistically significant at the .05 level, either. The bacteria concentrations typically responded to changes in stream discharge due to storms by peaking with the hydrograph and again on the recession limb.

The Response of Soils, Streambanks and Instream Coliform Bacteria Levels to Grazing Management in a Riparian Area

by

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Introduction and Objectives

Riparian areas on rangelands are unique, highly productive units which stand out from the surrounding ecosystems. In the past, floodplains and riparian areas were regarded primarily as convenient locations for roads, logging, and livestock watering and loafing. Today, livestock is still one of the major economic concerns, but the special value that wildland riparian areas and streams have for fisheries, wildlife and downstream agriculture and domestic water supplies is also recognized (Cummins 1974, Jahn 1978, Stevens et al. 1977, Thomas et al. 1979). The paucity of surface water on many rangeland areas emphasizes the importance of all these values. Responsible management of these resources depends on understanding the impacts, benefits and interrelationships of each use. A growing body of literature points to conflicts between livestock and other interests (Behnke and Raleigh 1978, Meehan and Platts 1978, Moore et al. 1979, Platts 1981a). Although much of the literature relates observational or statistically inadequate work, Platts (1978, p. 500) points out that:

> "...it would be unreasonable to claim that a direct relationship between improper livestock grazing of streamsides and aquatic habitat degradation has yet to be proven. The solution to the environmental issue is certainly not to argue whether or not livestock grazing degrades riparian and aquatic systems, but to identify and develop grazing systems compatible with fishery and riparian habitats."

A grazing system is a schedule of the pattern of grazing periods and intensities. Continuous grazing is use by a specific unit of livestock throughout the growing and grazing season; this may also be known as season-long grazing. Deferred rotation grazing refers to a plan in which grazing in one range unit among a set is delayed part of the season, and the deferment is rotated among the range units in the set in succeeding years. Under rest rotation grazing, one range unit of a set is left ungrazed for at least one year, and the period of rest is rotated among the units in succeeding years (Gifford and Hawkins 1976). Rest rotation often also includes a season of deferred use. Late season, high intensity-short duration grazing refers to stocking with enough livestock to remove the available forage in a short period, that period being at the end of the grazing season. Although some studies relate grazing systems to upland watershed conditions, very few report the effects in riparian areas. Neither season-long nor rest rotation appear to be satisfactory for riparian areas (Meehan and Platts 1978).

In 1975 the Forest Service Pacific Northwest Forest and Range Experiment Station undertook a comprehensive case study of grazing in a riparian area in northeast Oregon. The study was conducted through the Range and Wildlife Habitat Laboratory in La Grande, Oregon, and examined the effects of five grazing options on fisheries, cattle production and behavior, riparian vegetation, riparian soil condition, streambamk stability and water quality. This thesis dealt with the soils, banks and bacterial water pollution aspects of the study. The overall objectives of the Meadow Creek Study were to: (1) determine the effects of streamside grazing on the above topics, and (2) develop methods to more accurately monitor grazing effects on the riparian zone (Skovlin and Meehan 1975). The data would also be useful in determining if depleted streamside communities can be restored through grazing management systems.

General Site Description and Methods

Although the study area and methods are described in each chapter with details specific to the topic of the chapter, a few general comments are appropriate here. Meadow Creek is a second order stream coursing a Ponderosa Pine-Douglas Fir forest on the Starkey Experimental Forest and Range in the Blue Mountains, about 48 km. (30 mi.) southwest of La Grande, Oregon (T. 35 R. 34 E. Williamette Prime Meridian). It is a main tributary of the Grande Ronde River, with an average flow between .03 and 5.66 CMS (cubic meters per second) (2 and 200 cubic feet per second). The elevation ranges from 1122 to 1373 meters.

Approximately 8 kilometers were fenced into seventeen small, contiguous pastures. Pasture size averaged about 4 hectares, but one set of pastures ranged between 50 and 80 hectares. Although the pastures were stocked at the moderate rate used on the Starkey Forest as a whole (3.2 ha/animal-unit-month, or, 8 ac/AUM), the use in the riparian areas was probably less than in large managed pastures where more animals per pasture (and per unit stream-frontage) daily trail to water and loaf in the shade. Likewise, the set of larger pastures on Meadow Creek held more animals, relative to the smaller pastures, but had equivalent stream frontage and therefore probably experienced more trailing.

Grazing systems of four pasture rest rotation, deferred rotation, season-long grazing and no grazing were applied to two sets of pastures with one set open to deer and elk use and one set fenced to exclude big game. A third set was used for late season, high intensity-short duration grazing. In the fourth set, one to five years of season-long grazing were applied to test the annual effects of cattle grazing. However, this set of pastures was grazed intermittently throughout the season to achieve 70% utilization, rather than continuously, and therefore may have been inaccurately designated as season-long. Yearling heifers were used for all treatments, and the grazing season extended from approximately 15 June to 15 October.

The Meadow Creek Study was designed as a case study and as such, was not replicated. The statistical analysis in this thesis was performed on multiple samples within a treatment as a guide in interpreting trends and processes specific to the conditions on Meadow Creek, and absolute values are not intended.

Role of This Thesis

The work in this thesis is indicative of a recent direction in stream research and management---integrating of life and earth sciences in rangeland riparian areas. This integration of sciences brings new perspectives to traditionally biological questions (Cummins 1980, Swanson 1980). For instance, as fishery biologists recognize the influence of streambanks on aquatic habitat, they are turning to earth scientists to understand streambank processes and restoration. Although bacterial water pollution is a biological process and problem, monitoring and interpretation requires an understanding of the physical watershed and stream characteristics. A complex relationship between soil properties, climate, vegetation and fauna determines soil condition. All three of these topic areas respond to livestock grazing, which is the basis of this thesis---the response of streambanks, water quality and soils to livestock management in a riparian area, and the biological implications of those responses.

CHAPTER II RESPONSE OF INFILTRATION, SOIL COMPACTION AND SEDIMENT PRODUCTION TO GRAZING MANAGEMENT

Introduction

The rate at which a soil accepts water largely determines the amount of soil water available for plant growth, spring and stream baseflow and groundwater recharge. Soil moisture is often a limiting factor in plant growth on rangelands. Precipitation that does not enter the soil will run off the surface, possibly transporting soil particles and nutrients, or pond on the surface and thus reduce root-zone aeration. Since a stream's hydrograph responds differently to runoff and groundwater flow, aquatic habitat and water supplies are also affected by infiltration rates. Furthermore, the concentration of dissolved salts may depend on whether the streamflow is fed by groundwater or by surface runoff (Morisawa 1968).

A variety of human activities influence infiltration rates. Activities that compact the soil decrease the size of pore spaces and modify soil aggregates. This affects root growth, infiltration and soil water movement (Lull 1959, Chancellor 1977). Soils in riparian areas probably respond to human activities as readily as do upland soils. Flat, moist floodplains may be particularly subject to compaction and ponding and the attendant impacts on vegetation. In addition, the riparian zone's function as a stream source area may be affected by altering the soil's physical properties (Harr 1976).

A number of factors affect infiltration and can be classified into three main categories: (1) soil characteristics (texture, porosity, antecedent moisture, depth and organic content), (2) storm characteristics (intensity, duration and frequency), and (3) vegetation characteristics (type and quantity of cover and litter) (Bertrand 1965, Thompson 1968, Hewlett and Nutter 1969, Chancellor 1977, McGinty et al. 1979, Branson et al. 1981, Brock et al. 1982). Soil frost or ice, surface wettability and surface slope may also influence infiltration (Hewlett and Nutter 1969, Branson et al. 1981). In summary, rate of infiltration results from a complex feedback system involving many soil and vegetation characteristics that determine the hydraulic and capillary conductivity at a given time. Therefore, infiltration rates vary naturally in time and space. However, land uses that alter any of these factors also affect infiltration.

Several studies have linked cattle grazing with changes in soil properties. Livestock grazing on uplands affects infiltration by removing protective plant cover and soil organic matter and by compacting the soil surface. Both alterations result in depressed infiltration rates (Gifford and Hawkins 1978, Moore et al. 1979, Branson et al. 1981, Gifford 1981). Light to moderate grazing intensities on unsaturated soils have a small and similar impact; heavy grazing significantly lowers infiltration rates (Gifford and Hawkins 1978, Moore et al. 1979). However, heavy trampling may be insignificant on fine-textured soils where undisturbed infiltration rates are already low and compaction potential is minimal (Moore et al. 1979). Branson et al. (1981) noted that the impact of grazing on infiltration also varies with range condition, but did not specify how.

Several studies in Texas examined the effect of particular grazing systems on infiltration. In one study, a Merrill system (four pasture, three herd, deferred rotation) yielded infiltration rates nearly as high as ungrazed areas. Short duration grazing decreased infiltration but the continously grazed pastures reported the lowest rates of all

(Wood et al. 1978). In another Texas study, continuously grazed, heavily stocked pastures had one-half the infiltration rates of ungrazed pastures, but the rates in one pasture of a four pasture deferred rotation system were similar to the ungrazed rates (McGintry et al. 1979). Wood and Blackburn (1981) also found that in a mid-grass community, rates on a deferred rotation pasture approached those in ungrazed areas. However, high intensity-low frequency stocking and moderately and heavily stocked, continuously grazed pastures all exhibited lower infiltration rates. Rates did not differ among grazing systems in shrub canopy or short grass communities (Wood and Blackburn (1981).

Some researchers report an improvement in infiltration rates on uplands due to natural processes such as freeze-thaw and build-up of soil organic matter during grazing rest or laboratory experiments, (Garner and Telfair 1954, Orr 1975). Recovery time varies with soil texture, cover and specific grazing system and it appears to be a function of length of rest from grazing. As little as one year may be sufficient rest, but most studies suggest at least three to four years (Gifford and Hawkins 1978, Moore et al. 1979, Branson et al. 1981, Gifford 1981).

Reduced infiltration rates caused by grazing are often a result of compacted soil. Compaction increases soil density by decreasing pore size which in turn reduces infiltration capacity and slows water movement through the soil (Lull 1959, Chancellor 1977). Water pools on the soil surface more readily, reducing or eliminating soil aeration. Not only does water enter and move through compacted soil more slowly, but some of the smaller pores may hold the moisture more tightly so that plants must exert greater stress to remove it (Chancellor 1977). Furthermore, compacted soil impedes root development because lower air and water content or higher bulk densities and soil strength increase the resistance to penetration and by restriction of oxygen diffusion in the seed zone.

Soil resistance to compaction depends upon moisture content, texture, structure, density and organic matter content which are related to the concept of soil strength. Dry soils resist particle rearrangement more than moist soils and medium-textured soils generally compact to the greatest densities because the finer particles fill the voids between the coarser particles. Organic matter improves resistance to compaction (Lull 1959, Chancellor 1977).

It is important to differentiate grazing impacts from naturally varying soil conditions. Bulk density increases naturally as soils dry and shrink (Laycock and Conrad 1967). When soil frost breaks down water-stable aggregates, soils will compact (Lull 1959, Chancellor 1977), and raindrop impact compacts bare soil (Lull 1959). Grazing compacts soil directly through trampling or indirectly by removing organic matter and the vegetation which softens raindrop and trampling impacts (Moore et al. 1979, Branson et al. 1981, Gifford 1981). Compaction is difficult to measure and is usually defined as an increase in bulk density or resistance to penetration. Although the results of bulk density studies are diverse, bulk density tends to increase with grazing, particularly heavy grazing. Grazing compacts the soil to varying depths, but the compaction seems to be confined to within 15 cm. of the surface (Lull 1959, Orr 1960).

Very little of the literature describes the effects of different grazing systems on soil compaction. Bulk density did not differ between season-long and deferred rotation pastures on forest or grassland pastures in northeastern Oregon (Skovlin et al. 1976). Orr (1960 and 1975) investigated the relationship of grazing and bulk density in a _Poa pratensis_ community in the stream bottoms of the Black Hills National Forest.

when pastures were stocked heavily from June through October, bulk densities were significantly higher than in the ungrazed areas. However, the amount of compaction varied directly with the silt and clay content of the soil---sandy soils did not readily compact. Sandy soils compacted 0-5 cm while other soils compacted up to 10 cm. Orr also noted that the large pore space varied more in protected areas than on the grazed range.

Soils may "recover" naturally from compaction through the action of freeze-thaw, shrink-swell, and root penetration and decay (Garner and Telfair 1954, Lull 1959, Chancellor 1977). In stream bottoms on the Black Hills National Forest, at least two to four years were necessary for significant recovery from trampling compaction (Orr 1975). When needle frost forms in dense soil, frost-heaving can help relieve the compaction. The likelihood of frost-heaving increases as bulk density increases due to capillary flow to the freezing front. If the water does not move through the soil, concrete frost can form (Heidmann and Throud 1975, Heidmann 1976). Type and depth of the insulating litter layer, depth of snow layer, soil density and amount of litter water influence the formation of soil frost (Throud and Anderson 1969). Livestock grazing could increase the probability of soil frost by reducing or changing the litter layer or increasing soil density. Needle ice lifts soil particles perpendicular to the slope surface. When the ice melts, the particles tumble downslope and are readily available for further transport (Swanston 1980). Thus, sediment production potential on compacted soil loosened by frost-heaving may be increased, at least for a season on steeper slopes, even though bulk densities may be comparable to that of undisturbed areas.

Infiltration and animal trampling also relate to sediment production. Sediment production is strongly influenced by soil organic matter content and the amount of soil cover (Brock et al. 1982). The physical disturbance and removal of protective vegetation by grazing animals may dislodge soil particles. Low infiltration rates may produce overland flow which can transport the loosened soil particles. Light and moderate grazing does not significantly impact sediment production, but heavy, continuous grazing will increase it (Blackburn et al. 1980, Gifford 1981). Heavily stocked, continuous grazing systems in Texas produced higher sediment yields than ungrazed pastures (McGinty et al. 1979).

Although there is little documentation of the effects of cattle grazing on soil properties in a riparian zone, the close linkage between grazing, soil-water relations and plant communities on the uplands suggests that a similar pattern in the stream bottoms may exist. Historically, riparian areas have been heavily grazed by livestock. The moist soils may be vulnerable to trampling and grazing may remove protective vegetation and reduce soil organic matter. Furthermore, compaction and low infiltration rates may interfere with the riparian zone's function as a stream source area. These areas supply streamflow and "expand and contract according to rainfall characteristics and the capability of the soil mantle to store and transmit water" (Hewlett and Nutter 1970, as in Harr 1976). In many areas, however, livestock production currently depends on access to streams for drinking water. Consequently, manipulation of soil condition through the use of a particular grazing system would be economically preferable to livestock exclusion.

In 1975, the Forest Service Pacific Northwest Forest and Range Experiment Station initiated a multidisciplinary case study at Meadow

Creek on the Starkey Experimental Forest and Range in northeastern Oregon. The study was conducted through the Range and Wildlife Habitat Lab in La Grande, Oregon and spanned seven years. One of the objectives was to compare infiltration rates, sediment production and compaction associated with different systems of grazing cattle in a deteriorated riparian zone. The results of these comparisons could be used to prescribe grazing systems which would encourage an improvement in soil conditions on similar sites and to evaluate methods and problems for further riparian research.

Site Description

The Starkey Experimental Forest and Range is located in the Blue Mountains about 48 km southwest of La Grande, Oregon. The study area includes approximately 8 km of stream coursing an open Ponderosa Pine - Douglas Fir forest. The floodplain rises about 1 meter above mean water level and averages 23 meters wide. Soil data is sketchy, but preliminary soil maps on file at the Range and Wildlife Habitat Lab in La Grande generally describe interspersed patches of well-drained Veezie gravelly loam (coarse-loamy over sandy or sandy-skeletal, mixed, mesic cumulic haploxerolls) and Voats sandy loam (sandy-skeletal, mixed, mesic fluventic haploxerolls). Areas of unvegetated riverwash also exist, as well as an occasional boggy patch. Soil frost is believed to occur, at least in spots. Average annual precipitation is 30.5 to 63.5 cm, occurring primarily as winter snowfall, with some contribution from spring and fall rain.

In the first part of the century, the study area was subjected to logging operations which included roads and a splash dam, and heavy livestock grazing. In 1940, the Starkey Forest was dedicated to research which regulated the various activities and reduced grazing pressure (Skovlin et al. 1976). Although the pastures as a whole gradually improved, the stream bottoms still suffered as cattle concentrated there for water and succulent forage (Strickler per. comm. 1980). Rocky Mountain elk (Cervus elaphus nelsoni) use the Forest for spring and fall range, and mule deer (Odocoileus hemionus hemionus) are found year-round.

Methods

The area immediately adjacent to Meadow Creek was fenced into several small, contiguous pastures, and stocked June - October with yearling heifers at the moderate rate used on the Starkey Forest as a whole (3.2 ha/AUM, or, 8 ac/AUM). These pastures held two to twenty heifers, depending on the pasture size and grazing system (Table II-1).

The following grazing systems were applied to the Meadow Creek pastures: four pasture rest rotation, deferred rotation, season-long, and no grazing. Big game were allowed access to all treatments in one area and excluded from the same treatments in another area. In addition, late season, high intensity-short duration grazing was tested in September and in October. Finally, season-long grazing on pastures which had been rested one to four years was examined. All pastures contained a small control exclosure.

Sampling Routine

Infiltration rates were estimated with a Rocky Mountain infiltrometer (Dortignac 1951) and a ring infiltrometer (Haise et al. 1956, Bertrand 1965) on paired treatment-exclosure plots in each grazing systems. All plots were wet down and left to drain prior to testing to alleviate differences due to antecedent moisture. Ocular estimates of vegetative cover were made and broad soil classifications were available. The Rocky Mt. infiltrometer plots received 28-minute applications of simulated rainfall at a rate of approximately 7 cm/hour. This was the lowest application rate of the machine and simulated severe storm conditions for the area.

TABLE II-1 MEADOW CREEK STOCKING SCHEDULE

Grazing Treatment	Approx. Pasture Size (ha.)	No. of Animals	Stocking Rate[1]	Approx. Stream Frontage	Meters of Stream/Animal/Season
Season-long					
1 year	2.8	Ten yearling heifers		523	52
2 years	1.1	stocked intermittently		382	38
3 years	3.2	throughout season until		318	32
4 years	4.0	70% utilization was		397	40
5 years	2.8	achieved (approx.		381	38
		3.2ha/AUM=8ac/AUM)			
Big Game Access					
rest rotation	73.8	20 or 0	3.2ha/AUM	544	27
deferred rota.	82.0	20	3.2ha/AUM	444	22
season-long(5)	56.6	10	3.2ha/AUM	409	41
rest rotation	61.2	0 or 20	3.2ha/AUM	538	27
no grazing	49.0	0	---	352	---
Big Game-Proof					
rest rotation	5.7	4 or 0	3.2ha/AUM	238	60
season-long(5)	4.7	2	3.2ha/AUM	206	103
deferred rota.	4.7	4	3.2ha/AUM	174	44
rest rotation	4.1	0 or 4	3.2ha/AUM	257	64
no grazing	4.0	0	---	248	---
Late Season					
September	6.2	12	.85ha/AUM	648	54
October	5.7	12	.77ha/AUM	397	33

1. stocking rate to acheive 70% utilization

Infiltration rates usually approach a near constant rate within 20 to 30 minutes of the storm inception (Dortignac 1951, Branson et al. 1981, Gifford 1981). Three 76.2 x 30.5 cm subplots were sampled at every plot early in the grazing season each year. The average infiltration rate from five minute intervals for times 3-28 minutes, and the final rate on all treatments were calculated and used in separate ANOVA and LSD tests. Tests were made in 1975, 1976, 1980 and 1981. 1975 and 1981 were calibration years when the pastures were not stocked with cattle. Sediment production was estimated from runoff produced on the Rocky Mt. infiltrometer plots. Although sprinkler-type infiltrometers attempt to simulate natural rainfall conditions for a particular storm, they tend to overestimate actual infiltration rates. Therefore, the data were useful for comparative studies but did not represent absolute values (Hewlett and Nutter 1969).

Fifteen-centimeter diameter cylinders were used as single ring infiltrometers in early summer 1980, late summer 1980 and early summer 1981. Not all pastures were suitable for use with the ring infiltrometer, but pastures where soils were not too stony were tested in exclosure-treatment pairs. Mean and final infiltration rates were calculated from the time needed to drain ten centimeters of water, and used in separate ANOVA and LSD tests. Rate measurements were attempted nine times at each plot in each season, but the actual sample size varied somewhat due to problems with rocks and animal burrows. As with sprinkler infiltrometers, the numerical estimates from ring infiltrometers were useful for establishing trends, but should not be considered absolute values. The rate of intake in ring infiltrometers varies inversely with the size of the cylinder used, increasing greatly in diameters of 30 centimeters or less.

Ring infiltrometers also tend to overestimate infiltration and do not simulate actual precipitation conditions (Hewlett and Nutter 1969, Gifford 1981). Furthermore, soil disturbance while placing the cylinders may significantly affect the results (Bertrand 1965).

Soil bulk density and penetrability were also estimated concurrently at the ring infiltrometer plots, although pastures located on stony soil were dismissed as unsuitable for some tests. All plots were moistened and drained prior to testing to remove differences due to antecedent moisture. Eighteen measurements to a depth of about 3 cm were collected from each plot with a proving ring penetrometer in early summer 1980, late summer 1980 and early summer 1981. Three gravimetric soil cores per plot were collected through the duff layer into the upper 3.8 cm of soil in early summer 1981 and analyzed for bulk density. Differences between treatments and their paired exclosures were tested by one-way ANOVA and LSD.

The proving ring penetrometer is useful to characterize and compare the penetration resistance of soils (A.S.A.E. 1975). It correlates well with bulk density and so it is used as a secondary indicator of compaction (Chancellor 1977, Gifford et al. 1977). However, it is influenced by soil moisture, presence of small gravel and root and animal channels as well as bulk density (Gifford et al. 1977).

Soil core samples are the standard method of estimating bulk density since they disturb the soil sample relatively little (Chancellor 1977). However, the method may be unsatisfactory if stones are present or the soil is very wet or dry (Blake 1965). Compaction may be difficult to detect from core samples if the affected layers are thin (Lull 1959). Furthermore, bulk density will vary across a season due to soil shrink-swell action as soil moisture changes (Laycock and Conrad 1967).

Analysis

The Meadow Creek Study was designed as a case study and as such, was not replicated. Statistical analysis was performed on multiple samples within a treatment as a guide in interpreting trends and processes specific to the conditions on Meadow Creek. The infiltration analysis examined patterns between treatment-exclosure pairs rather than comparing absolute values. Data of this natureare usually analyzed one of two ways: either for changes over time at a particular site or for differences between a treated area and a control. Neither of these approaches was entirely appropriate for these data because analysis for changes over time did not account for environmental influences other than the treatment and treatment-control comparisons were invalid unless both plots were identical at the first measurement. Therefore, an analysis was devised which employed part of each technique and examined trends. First, each plot was analyzed for a statistically significant change over time. Then, significant changes for each treatment plot were graphically compared with the response on its paired exclosure plot to, in effect, remove any environmental influences which would have affected both plots equally. Treatment response was indicated when significant changes on the treatment differed from those found on the paired exclosure. Several treatment-exclosure combinations were possible and each combination was coded as "plus", "minus" or "zero" based on the treatment's response relative to its paired exclosure as an index of the trend (Table II-2).

When long-term data were not available, (ring infiltration, bulk density and penetrability), treatment-exclosure pairs were assumed to be comparable and tested directly with the t-test, ANOVA and LSD statistical tests. These results were also coded (Table II-3).

TABLE II-2

TREATMENT RESPONSE TREND INDEX FOR TRENDS IN SOIL INFILTRATION

Exclosure	Treatment		Trend Index
↑	↑	=	+
↑	no change	=	-
↑	↓	=	-
no change	no change	=	0
no change	↑	=	+
no change	↓	=	-
↓	↓	=	0
↓	no change	=	+
↓	↑	=	+

↑ = rate increase between 1975 and 1981

↓ = rate decrease between 1975 and 1981

TABLE II-3

TREATMENT RESPONSE TREND INDEX FOR RING INFILTRATION, SOIL PENETRABILITY AND BULK DENSITY

Soil Attribute	Response	Trend Index
Ring Infiltration	increase	+
	decrease	-
Penetrability	increase	+
	decrease	-
Bulk Density	increase	-
	decrease	+
Infiltration, penetrability or bulk density	no change	0

Results

Long-term effects on infiltration were estimated from comparison of the Rocky Mt. infiltrometer infiltration rates at 28 minutes in 1975 and 1981. Infiltration increased in several control exclosures, suggesting a process of recovery from the previous heavy grazing. Infiltration patterns on pastures grazed with the rest rotation system was similar to the patterns found in the paired control exclosures, while infiltration on deferred and continuously grazed (for five years) pastures declined relative to their paired control exclosures, regardless of big game accessibility. Late season grazing had a plus response in September but minus in October. If oonditions are assumed to have been similar within each treatment-exclosure pair in 1975, then long-term change can be estimated by comparing 1981 treatment-exclosure ring infiltrometer results. Although these comparisons are not as well defined as the "sprinkler" results, they suggest that rest rotation plots showed a plus response between 1975 and 1981 while season-long (five years) did not (Table II-4). Deferred rotation showed a minus response where big game had access but had no effect on the game-proof pasture. October grazing produced a minus ring infiltration response, but September grazing had no effect. Sediment production, as estimated from "sprinkler" runoff, followed the same pattern as infiltration; the response of rest rotation and no grazing treatments corresponded to their paired exclosures, while season-long (five years) and October grazing had a minus response relative to their paired exclosures. Unfortunately, these were the only treatments with complete data sets (Table II-4).

Because soil compaction tests were not initiated until 1980, long-term changes were estimated by comparing conditions on treatment-exclosure pairs in 1981. This approach assumed that conditions in each half of a

TABLE II-4 EFFECTS OF GRAZING MANAGEMENT ON SOIL PROPERTIES, A SUMMARY OF THE TREND INDICES 1975 to 1981 (0.05 SIGNIFICANCE)[1]

Grazing Treatment	Rocky Mt.[2] Infiltrometer	Ring[3] Infiltrometer	Penetrability[3] Penetrometer	Bulk Density[3] (soil cores)	Sediment[2] Production
Game Access					
rest rotation	+	0	-	-	no data
deferred rota.	-	-	-	0[5]	no data
season-long (5yrs)	-	-	-	0	no data
rest rotation	0	no data	no data	no data	0
no grazing	+	0	-	0	+
Game-Proof					
rest rotation	+	+	0	0	no data
season-long (5yrs)	-	-	-[4]	-	-
deferred rota.	-	0	0	0	no data
rest rotation	0	no data	no data	no data	no data
no grazing	+	no data	0	no data	no data
Season-long					
1 year	no data	0	0	0	no data
2 years	no data	no data	0	0	no data
3 years	no data	no data	-	0	no data
4 years	no data	no data	-	0	no data
5 years	no data	0	-	0	no data
Late Season					
September	+	0	0	0	no data
October	-	-	-	0	no data

1. See Tables II-2 and II-3 for further explanation of response symbols
2. Treatment response trend, relative to exclosure
3. Compares treatment to exclosure statistically
4. Plot located on trail
5. At 0.10 significance, minus trend

pair were equivalent at the onset in 1975. Compaction, as indexed by a proving ring penetrometer, increased significantly on all treatments with big game access. Where big game were excluded, the rest rotation, deferred rotation, season-long (five years) and no grazing treatments did not compact significantly (Table II-4). Season-long grazing for one or two years with four or three years of prior rest had no effect on penetration resistance, but a minus trend from three, four or five years of season-long grazing (two, one or no years of prior rest) was evident. October grazing had a minus trend again, but September grazing had no effect. Bulk density increased significantly only on one of the two rest rotation pastures which allowed big game access, and on the season-long grazing (five years) which excluded big game. No other grazing systems affected bulk density.

Final rates from the ring infiltration tests in 1980 and 1981 were examined for patterns of seasonal changes. Generally, the infiltration response in the summer on grazed areas tended to be minus relative to the paired exclosures, or there was no effect. Spring infiltration rates increased over winter on treatments that had been rested the previous season, while on several unrested pastures, there was no effect. However, this data only spans one year (Table II-5).

Seasonal effects on compaction were not clearly evident. Results of summer penetrometer measurements varied but suggested that compaction lessened somewhat over the winter (Table II-5). The results were based on treatment response relative to paired exclosures and were not definitive in that only one year of data was collected. Generally, exclosures and ungrazed pastures showed fewer seasonal variations than grazed areas.

TABLE II-5 SEASONAL FLUCTUATION IN TREND INDICES OF SOIL INFILTRATION AND PENETRABILITY[1,2]

Grazing Treatment	Ring Infiltrometer oversummer	Ring Infiltrometer overwinter	Penetrability oversummer	Penetrability overwinter
Big Game Access				
rest rotation	-	+	0	-
deferred rotation	0	0	+	-
season-long (5)	-	0	-	+
rest rotation	no data	no data	no data	no data
no grazing	-	+	+	-
Big Game-Proof				
rest rotation	0	+	0	+
season-long (5)	0	-	0	+
deferred rotation	+	0	0	+
rest rotation	no data	no data	no data	no data
no grazing	no data	no data	+	-
Season-long				
1 year	0	0	-	0
2 years	no data	no data	-	+
3 years	no data	no data	-	+
4 years	no data	no data	0	+
5 years	0	-	+	0
Late Season				
September	0	0	+	+
October	-	0	0	+

1. See Tables II-2 and II-3 for further explanation of response symbols.
2. Treatment response, relative to exclosure, based on changes of 0.05 significance.

Discussion

Infiltration rates improved in several of the exclosures and between 1975 and 1981, implying that a process of recovery from historical abuses was occurring. "Recovery" is somewhat of an abstract term when applied to a system with very few pristine examples, but may be defined for management purposes as an increase in infiltration rate and decrease in compaction and sediment production. "Full recovery" or the degree of deterioration must remain undefined until the system is better understood. The process of recovery has been recognized in other studies and is usually linked with a period of rest (Gifford and Hawkins 1978, Moore et al. 1979, Branson et al. 1981, Gifford 1981).

On Meadow Creek, the infiltration trend, as measured by the ring infiltrometer, did not differ between the pasture that received four years of rest prior to one year of season-long grazing and the pasture that received no rest and five years of season-long grazing; neither treatment differed significantly from its paired exclosure. However, results from treatment-exclosure comparisons of ring infiltrometer data are not as reliable as over-time comparisons for detecting long-term changes and these "season-long" treatments actually received intermittent grazing. Rest rotation appeared to favor recovery while deferred rotation and season-long (five years) hindered it. The plus infiltration response to the high intensity-short duration grazing scheme in September and minus response to the same application in October may reflect altered soil conditions in October due to the onset of fall rains.

A period of non-use is often a component of compaction recovery also. On Meadow Creek, the penetrometer data showed as association between recovery and rest from grazing. Although penetrometer results from pastures that were rested three or four years and then grazed season-long for one or two years did not differ significantly from their paired exclosures, penetrability decreased on pastures with less rest and more grazing.

Although big game use appeared to contribute to compaction regardless of the grazing system, comparisons between big game pastures and game-proof pastures were not valid. The big game pastures extended onto the uplands and were larger than those which excluded game, and therefore required approximately five times more livestock than the smaller pastures to maintain the prescribed stocking rate. Thus, standardizing the stocking rate resulted in a great disparity in the number of cattle trailing to water on big game exclosure and access pastures. Stream frontage remained approximately constant for all pastures so cows per unit of streamside area were greater on big game pastures; data may therefore reflect greater livestock use of the riparian area rather that big game use. This emphasizes the need for caution in interpreting the data and comparing grazing treatments. Furthermore, topography and roads may have directed big game traffic regardless of grazing system. However, this was not tested.

Seasonal cycles of soil bulk density, penetrability and infiltration rates apparently exist on the Meadow Creek pastures. Although one year is not a definitive sampling period, infiltration and penetrability tended to increase and bulk density decrease by the end of winter. Seasonal variations were more pronounced in the grazed pastures than in the ungrazed pastures, probably reflecting the yearly impact of livestock; ungrazed pastures are not as severely compacted in the summer and so have less to loosen.

Summary

1. The effective stocking rate was lighter than usually found on large, managed pastures.

2. Season-long grazing for five years reduced the recovery of soil infiltration, bulk density and penetrability and sediment production.

3. The soil response to rest rotation grazing and season-long grazing for one or two years (with four or three years prior rest) usually corresponded to ungrazed areas.

4. Soil and hydrologic data from ungrazed areas suggested a process of recovery from the historical heavy use period was occurring.

5. Generally, soil properties appeared to fluctuate seasonally. Infiltration and penetrability were increased and bulk density was decreased at the end of winter. The trends were reversed at the end of the grazing season. Soil properties in ungrazed areas fluctuated less than did grazed areas.

Technical Recommendations

1. Pastures should be equal in size, stocking rate and carrying capacity for comparative studies. Variable numbers of animals per unit stream frontage may bias data on soil effects when animals congregate in the riparian areas.
2. Proper interpretation is difficult when pasture size and stocking rate result in very small animal numbers. The effect on soils from as few as two animals may not be detectable among the variability produced by environmental factors. However, the break-off point of sufficient animals is not known.
3. Small experimental riparian pastures do not simulate conditions found on large, managed pastures because fewer animals trail through the area to the stream. Soil response to grazing systems may differ when the livestock use found on large, pastures is applied.
4. Data collected on the same plots over years were more reliable indicators of long-term change than comparisons of exclosures and treatments, due to the small scale of sampling and large variation in soil surface conditions. Soil classification specific to each study plot is necessary in riparian areas.
5. Soils with river cobbles, gravel or pebbles are not well-suited for use of the ring infiltrometer, penetrometer or gravimetric bulk density cores.
6. The penetrometer is fast and easy, which facilitates large sample sizes. In suitable soils and with large enough sample sizes, it is a useful tool in riparian areas. Although the soil cores were sometimes difficult to extract satisfactorily and sampled destructively, they provided both soil moisture data and bulk density data.

7. Infiltration in a riparian zone is affected by saturated soil conditions and high water tables. Since both situations can vary frequently by space and time in a riparian area, specific conditions at each site should be monitored. A better understanding of the role of infiltration in riparian zones and sub-irrigated areas is needed. The infiltration rate at the end of a test produced the same trends as average rates, and is more convenient to collect and calculate.

8. The Rocky Mt. infiltrometer produces relatively precise and accurate data. It is self-contained but cumbersome and cannot be taken into roadless riparian areas with wet, highly compactable soils. The primary advantage of ring infiltrometers is their convenience---they can be carried into areas where large infiltrometer systems cannot go, as long as water is available. Experience on Meadow Creek suggests sample sizes large enough to reduce the sampling error associated with ring infiltrometers may be possible on rangeland soils only when relatively few stones, roots, moss or animal burrows are present.

9. Runoff must be produced to examine potential sediment production with the Rocky Mt. infiltrometer method. This is not always realistic in riparian soils on flat floodplains.

10. Suggested sample size for similar soil and site conditions, as determined by Steins Two-Step test: Rocky Mt. Infiltrometer: 6 samples for 10% of the mean 80% of the time (sample size actually varied dramatically by plot and ranged from 1-189 samples).

Ring Infiltrometer: 40-60 samples for 10% of the mean 80% of the time.

Penetrometer: 20 samples for 10% of the mean 90% of the time.

Bulk Density of Soil Cores: between 2 and 36 samples (clustered around 10 samples) for 10% of the mean 95% of the time.

CHAPTER III STREAMBANK RESPONSE TO GRAZING MANAGEMENT

Introduction

As the interface between terrestrial and aquatic habitats, streambanks are a unique form in the riparian landscape. Bank and channel profiles largely determine the amount of water surface exposed to solar radiation, which affects stream temperature and photosynthesis (Brown 1980). Sloping banks with wide shallow channels expose more water surface to the sun, and have relatively larger wetted perimeters, which means a slower, warmer flow. Streambank shape also helps determine water depth and velocities (Platts 1981a) and sediment imput (Berry 1979). The equation, Q=WDV represents the direct relationship between stream discharge (Q) and stream width, depth and velocity. When one factor changes for any reason, the others must adjust (Morisawa 1968). Stream width partially determines fish habitat, particularily as it relates to reduction of depth and total suitable water space (Platts 1976), and warming water temperatures inhibit trout survival and reproduction (Reiser and Bjornn 1979). Overhanging banks and stream velocities also contribute to aquatic habitat (Reiser and Bjornn 1979). Experiments which artificially altered bank configuration demonstrated a positive correlation between pounds of fish and overhanging banks (Boussu 1954). However, Platts (1976) could not correlate his streambank condition rating with total fish populations. The vegetation which is found on stable banks provides cover, food and shade for the aquatic environment (Cummins 1974, Platts 1979, Platts 1981a). Bank stability and height also affect the amount of land occupied by stream meandering and flooding.

In recent years, several authors have recognized the impact of cattle grazing on bank shape, stability and vegetation. Behnke and Raleigh (1978) and Platts (1981c) summarized some of the effects of overgrazing on stream habitat: (1) a widening and shallowing of the streambed, (2) channel trenching or braiding, depending on soils and substrate, (3) elevated stream temperatures. It appears that when cattle bagin to graze a riparian area which is in good condition, the impacts show up first on the banks and riparian vegetation (Platts 1981b). Streambank sloughing and collapse from improper livestock grazing may be the greatest effect of livestock on fish populations (Platts 1981a). Although several studies have related bank instability to overgrazing, most studies used subjective rating schemes (Meehan and Platts 1978, Berry 1979). However, grazing often causes subtle changes over many decades that are difficult to detect on a shortened time perspective; natural "catastrophies" are much easier to document (Platts 1981a).

Cattle grazing effects on streambanks fall into two related categories: (1) removal of bank vegetation, and (2) trampling bank edges. Although there is little definitive research on the subject, several authors agree that the roots of streamside vegetation help stabilize banks and that the stems dissipate some of the energy of streamflows directed at the banks and physically protect the banks from ice floes, water-borne debris and trampling (Pfankuch 1978, Berry 1979, Heede 1980, Platts 1981a). Gunderson (1968) investigated cattle trampling by comparing a stream reach that had been burned and then heavily grazed continuously to a reach which had been lightly grazed for a period and then rested for ten years. The ungrazed segment was deeper and narrower than the burned and grazed reach and had more brown trout over six inches as well as 31% more pounds/stream-acre of brown trout. Hayes (1978) related bank sloughoff during the grazing season to livestock use, but found more erosion in the ungrazed areas than the grazed during spring discharge. Two years of non-use improved bank stability and channel depth on a Nevada stream and also a east central Idaho stream (Dahlem 1979, Keller et al. 1979). After four years of non-use, banks on an eastern Oregon stream stabilized and remained stable through six years of special-use grazing in mid-August at an unspecified stocking intensity (Storch 1979).

As an alternative to livestock exclusion, Storch (1979) also examined the effects of different grazing systems. Season-long grazing did not meet the streamside management objectives. The success of rest rotation grazing depended upon the composition, density and variation of age-classes of the vegetation at the initiation of the grazing system; rest rotation maintained or improved an initially good condition. Stocking rates for these systems were not specified. Platts (1981b) found that after two years of the grazing phases of a rest rotation cycle, habitat alteration occurred on pastures with at least 65% utilization, but not on pastures utilized 25% or less. The time period was too short for the alterations to be significant. In northeastern Oregon, two grazing seasons on a late season grazing system significantly increased bank erosion compared to ungrazed areas. Grazing also reduced the number of bank overhangs (Kauffman 1982).

A large part of the literature addressing livestock effects in riparian zones is either speculative or suffers from ill-defined terms such as "unstable banks" or "streambank alteration." Although "stability" involves a bank's resistance to change and resilence after change, it is often used to simply describe the rate of bank movement. Since streambanks are part of a dynamic system, geologic erosion must be distinguished from grazing impacts. There are two aspects of bank erosion to examine. The first relates to the lateral movement of the channel and the second is bank shape as it relates to the channel cross-section. Most streams work back and forth across floodplains in response to erosion-deposition processes. Steeper streams have the velocity to attack banks forcefully and the competence to carry the ensuing sediment load (Heede 1980). An accompanying deposition process may occur where velocity changes around obstacles or at the inside of meander bends (Morisawa 1968). Banks must have erodible materials for erosion to occur. Most bank failures are either by scaling (loss of thin flakes, usually from the bank toe upward) or from slip failures, which are induced by piping or horizontal stratification of bank materials (Heede 1980).

As stream meanders migrate laterally, the outer bank often assumes a concave form, worn by erosion while aggradation at the inner part of the bank forms a more or less convex bank (Leopold and Langbein 1966). Vigorous corrasion against banks during floods may widen the stream, as could water from a tributary (Morisawa 1968). The predominant determinants of channel shape appear to be quantity of water, type of sediment load and type of bank material (Zimmerman et al. 1967, Dunne and Leopold 1978, Heede 1980). The channel adjusts to changes in one of these factors, although some conditions apparently create more variability than others (Zimmerman et al. 1967). Because of the relationship, Q=WDV, velocity and channel changes also reflect upstream activity (slides and slumps) and upslope erosion, as well as on-site impacts (Morisawa 1968).

Bank composition may predispose channels to a particular configuration. Banks with a high silt-clay composition form narrow and deep channels because the cohesiveness of the material resists erosion. As sand and coarser material content increases, channels tend toward wide and flat forms (Morisawa 1968, Heede 1980). Sod-roots apparently act more like cohesive sediments than tree roots, because channels tend to be wider in forests and more narrow through sod (Zimmerman et al. 1967).

In 1975 the Forest Service Pacific Forest and Range Experiment Station initiated a case study to examine the affects of various cattle grazing systems on bank movement and to assess the method used in this bank study. The study was conducted through the Range and Wildlife Habitat Lab in La Grande, Oregon, spanned seven years, five of which were grazing years, and compared season-long, deferred rotation, rest rotation, late season and no grazing systems.

Site Description

Meadow Creek is located on the Starkey Experimental Forest and Range in the Blue Mountains about 48 km southwest of La Grande, Oregon. The study area included approximately 8 km of stream through a Ponderosa Pine-Douglas Fir forest. On average, the floodplain is about 23 meters wide and about 1 meter above the mean water level at low flow. Meadow Creek is a second order stream, draining approximately 98 km^2 and dropping an average of 15 meters/1.6 km (50 ft./mile). Flow ranges between .03 and 5.66 CMS (cubic meters per second) (1 and 200 cubic feet per second), usually peaking in March, but sometimes in January. Ice floes do occur. Average annual precipitation is 30.5-63.5 cm falling primarily as winter snow, but with some contribution from fall and spring rains. Both cutbanks and sloping, gravel banks are found.

In the first part of the century, Meadow Creek was subjected to logging operations which included a splash dam and roads, and heavy grazing. In 1940, the Starkey Forest was dedicated to research which regulated the various activities and reduced the grazing pressure (Skovlin et al. 1976). Although the pastures as a whole gradually improved, the stream bottoms still suffered as cattle concentrated there for water and forage (Strickler, per. comm. 1980). Rocky Mt. elk (*Cervus elaphus* nelsoni) use the Forest as spring and fall range, and mule deer (*Odocoileus hemionus* hemionus) are found year-round.

Methods

Small, contiguous pastures were fenced along Meadow Creek and stocked June-October with yearling heifers at the moderate rate used on Starkey Forest as a whole (3.2 ha/AUM, or, 8 ac/AUM). These pastures held two to twenty cows depending on pasture size and grazing system (Table III-1). The pastures were stocked to represent the following grazing systems: four pasture rest rotation, deferred rotation, season-long, and no grazing. Big game had access to all these treatments in one area and were excluded from the same treatments in another area. In addition, late season short duration-high intensity grazing was tested in September and October. Finally, season-long grazing on pastures that had been rested one to four years was studied.

Permanent reference stakes were set at 16 sites along the streambank in each pasture. The distance from each permanent reference point to the closest bank edge was recorded before and after every grazing season. Most stakes monitored reasonably straight, representative stream reaches, but some were on curves. The mean total bank loss and its accompanying confidence interval for each pasture were used to compare treatments. This technique is a conservative method of comparison, chosen because of the wide range of variability present in the data. However, an ANOVA with a randomized block design (years=blocks) and a year x season error term was used to compare seasonal differences in bank movement.

In 1980, several bank characteristics were recorded at each reference stake by ocular reconnaissance. The following characteristics were evaluated:

TABLE III-1 MEADOW CREEK STOCKING SCHEDULE

Grazing Treatment	Approx. Pasture Size (ha.)	No. of Animals	Stocking[1] Rate	Approx. Stream Frontage (m.)	Meters of Stream/Animal/Season
Season-long					
1 year	2.8	Ten yearling heifers		523	52
2 years	1.1	stocked intermittently		382	38
3 years	3.2	throughout season until		318	32
4 years	4.0	70% utilization was		397	40
5 years	2.8	achieved (approx.		381	38
		3.2ha/AUM=8ac/AUM			
Big Game Access					
rest rotation	73.8	20 or 0	3.2ha/AUM	544	27
deferred rota.	82.0	20	3.2ha/AUM	444	22
season-long (5)	56.6	10	3.2ha/AUM	409	41
rest rotation	61.2	0 or 20	3.2ha/AUM	538	27
no grazing	49.0	0	---	352	---
Big Game-Proof					
rest rotation	5.7	4 or 0	3.2ha/AUM	238	60
season-long (5)	4.7	2	3.2ha/AUM	206	103
deferred rota.	4.7	4	3.2ha/AUM	174	44
rest rotation	4.1	0 or 4	3.2ha/AUM	257	64
no grazing	4.0	0	---	248	---
Late Season					
September	6.2	12	.85ha/AUM	648	54
October	5.7	12	.77ha/AUM	397	33

1. stocking rate to achieve 70% utilization

Characteristic	Descriptions Used
Final bank shape	Sloped, straight, undercut, trampled or slumping in 1980
Stones	Present or absent in upper profile
Percent stones	0-4%, 5-19%, 20-39%, 40-59%, 60-79%, 80-100%
Grass roots (fine roots)	Present or absent
Other roots (coarser roots)	Present or absent
Ground cover	0-4%, 5-19%, 20-39%, 40-59%, 60-79%, 80-100%
Stake position	Stake located at inside of curve, outside of curve, or straight stretch
Grazing treatment	Twenty pastures, subjected to various grazing treatments

A stepwise regression was applied to these data to select the major determinants of bank loss. The characteristics were tested against total bank loss over the length of the study.

Results and Discussion

Treatment Effects

The regression analysis of bank characteristics suggests that the type of grazing system, stake position and stones significantly related to total bank loss at the .05 level:

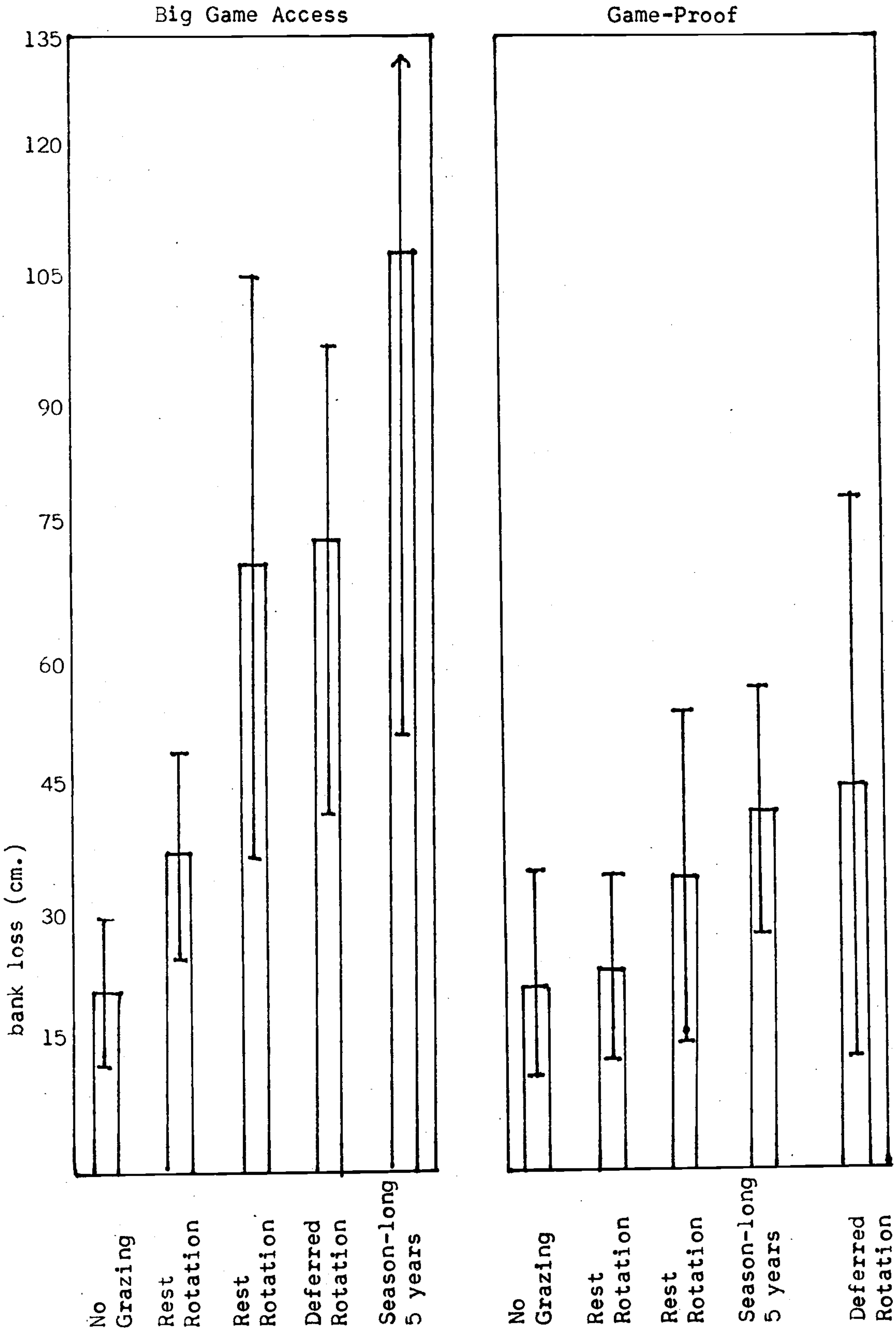
Characteristic	Relation to Bank Loss	P Value
grazing treatment	signif.	.0001
stake position	signif.	.0019
stones	signif.	.0062
percent stones	signif.	.0334
other roots	non-signif.	.0751
grass roots	non-signif.	.1430
final bank shape	non-signif.	.5476

Grazing treatment was placed first into a stepwise regression and showed a R^2=0.23. The addition of stake position to the model raised the R^2 to 0.25; no other factor significantly raised the R^2. On a similar stream in northeastern Oregon, position of the sample points was not significantly related to bank loss (Kauffman 1982). More detailed hydrological data are needed to establish a relationship. The lack of predictive ability does not necessarily discredit any of the factors but suggests the need for more detailed data. Observations made during the course of this study indicated soil texture and beginning bank shape may be important keys. Bank shape at the onset of the study may have an important influence on bank loss in short-term comparative studies since the collapse of an overhanging bank registers a dramatic loss compared to movement on an outsloped bank. Therefore, reference points must sample bank types equally in all areas. Because the position of the sample points affected bank loss, the loss among all grazing treatments was compared by analyzing only reference points on straight stream reaches.

Figure III-1 shows the mean bank loss between 1975 and 1981 for each pasture, and the confidence intervals about those means. In both the game-proof and the game access pastures, ungrazed pastures sustained the least bank loss while deferred rotation and season-long treatments lost the most. The differences between most grazed and ungrazed pastures were significant in the game access area. The bank loss means on rest rotation pastures fell between the low and high mean losses found on the other treatments, but differed significantly from these other treatments only once. Generally bank losses were higher where big game had access, but not significantly. However, pastures with big game access extended further upslope than did the game-proof pastures and therefore were stocked with up to five times more cattle to achieve the 3.2 ha/AUM stocking rate. Although the stocking rate was constant, the number of livestock trailing to water and concentrating along the banks was greater in the game access pastures. While no conclusions regarding big game access can be drawn, the data imply an apparent trend associating bank loss with the amount of domestic and/or wild animal use.

Although season-long grazing for five years increased bank loss numerically more than other treatments and significantly more than ungrazed pastures, season-long grazing for shorter periods following a period of rest may have less effect. A series of pastures were stocked one to five years intermittently throughout the grazing season, for enough days to achieve 70% utilization. The number of actual grazing days varied each year. This stocking schedule was termed "season-long" although most managed pastures are stocked continously for season-long grazing. Pastures grazed season-long for one year and three consecutive years (two years was not tested due to stream sinuosity) sustained significantly less bank loss

FIGURE III-1 MEAN BANK LOSS, 1975-1981



than the pasture that was grazed for five years, season-long. (Figure III-2). These pastures had been previously rested four, two and zero years, respectively. Loss from four years of season-long use was greater than from one or three years of use but less than five years of use and in no case was it significantly different (Figure III-2). Bank loss from late season, high intensity-short duration use did not differ significantly between late season-September and late season-October (Figure III-3).

The confidence intervals were quite large in the treatments with the greatest bank losses, probably due to at least one large bank collapse among the routinely smaller losses. This means that bank shape at the reference points could be an important factor affecting the variability in bank loss because the collapse of overhangs will be much more pronounced than the wearing away of outsloped banks.

Seasonal Effects

Ice floes can be a formidable force which skins shrubs and bends rebar reference stakes and metal fenceposts along Meadow Creek. Most research relating to fluvial ice has been on navigable rivers, where channel icing is most likely on shallow or braided reaches and the major effects are flooding and channel erosion and abandonment (Smith 1980). However, ice formation and breakup may result in flooding and mechanical bank and channel erosion and redistribution of bottom gravels on smaller streams also (Swanston 1980). Kauffman (1982) found more bank erosion during the winter than the summer on both grazed and ungrazed stream reaches. Hayes (1978) found seasonal differences in bank loss due to spring discharge caused more erosion in ungrazed areas than in

FIGURE III-2 MEAN BANK LOSSES FROM SEASON-LONG GRAZING

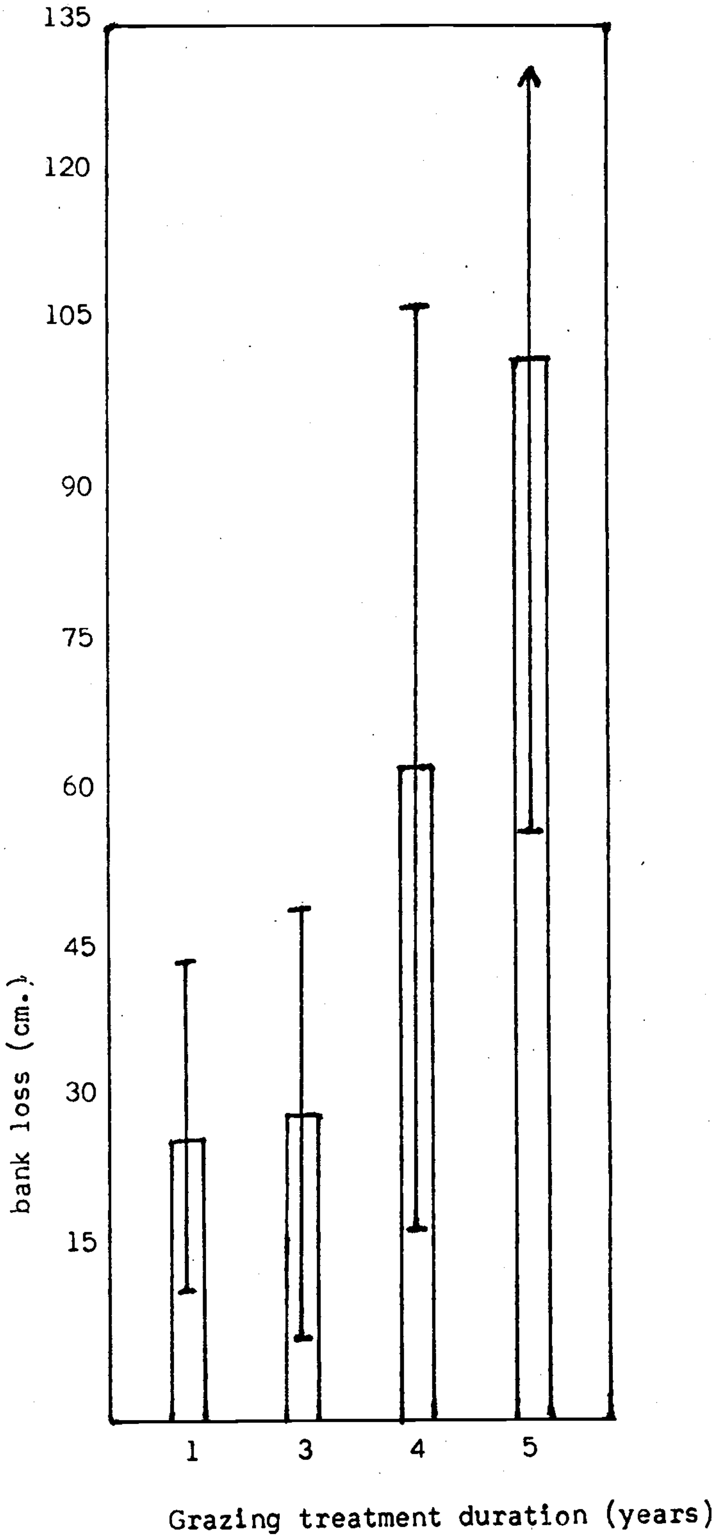
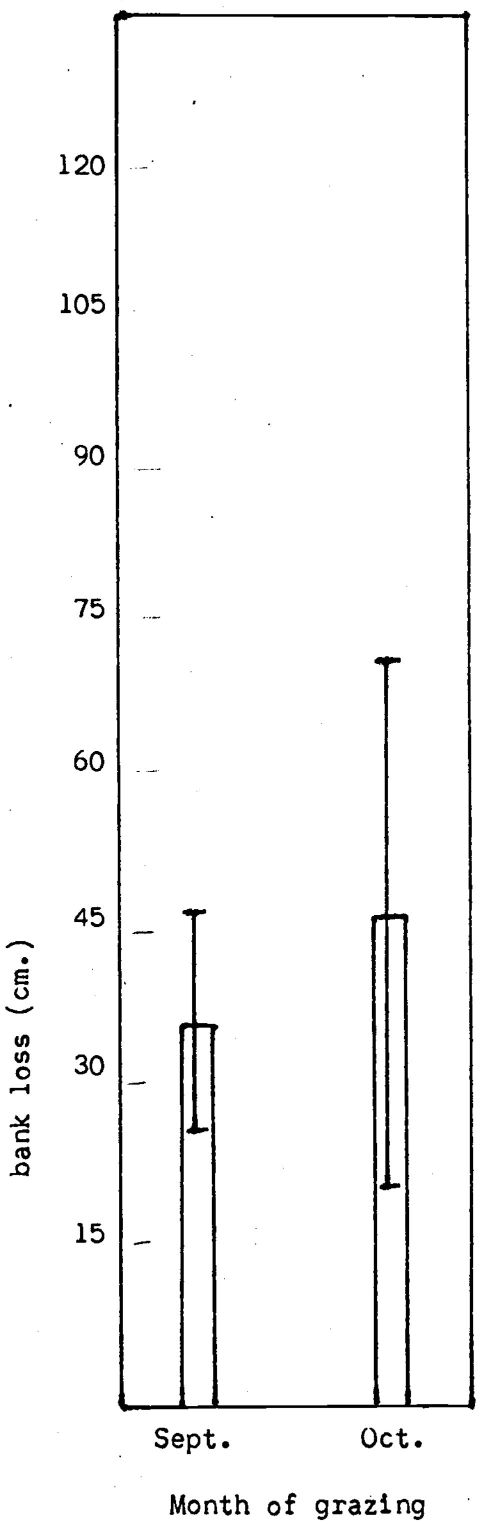


FIGURE III-3 MEAN BANK LOSS FROM LATE SEASON GRAZING



grazed areas. After the first two grazing seasons of the Meadow Creek Study, Buckhouse et al. (1981) summarized the data. Although there was no relationship between bank erosion and grazing treatment evident at that time, significantly more erosion was occurring in the winter than the summer. On a per week basis, however, grazing is apparently as powerful a force on streambanks as the overwintering processes of ice and spring discharge (Table III-2).

Although livestock grazing and overwinter processes were equally powerful in generating streambank loss, grazing occurs only about four months a year. The longer overwinter period resulted in significantly greater bank loss in the winter than in the summer on four of the sixteen pastures (Table III-2). These four pastures were all stocked season-long for three, four or five years and had big game access. The only season-long pastures which did not show significant winter losses experienced comparatively less animal use: season-long grazing for only one year, and, season-long with few livestock and no big game. If grazing and winter conditions are equal in force, as the first analysis suggested, and the winter period lasts three times longer than the grazing period, then it would seem reasonable to expect significant winter losses on most of the treatments. On Meadow Creek, only four of the sixteen pastures experienced significantly higher winter losses, either because a large sampling variation masked significant differences or because there was an interaction between grazing and the magnitude of winter processes. The other twelve pastures did not show significant seasonal differences. It would also seem reasonable to expect most of the bank loss in ungrazed pastures to occur in the winter. Again, this was not the case on Meadow Creek. Bank loss appears to be a complex process which was not fully addressed in this experimental design.

TABLE III-2 SEASONAL MEAN BANK LOSSES

Grazing Treatment	Mean Bank Loss (cm/week) Winter	Summer	Overall Bank Loss (cm/week) Winter	Summer
Big Game Access				
rest rotation	0.34cm	0.24cm	10.88cm	3.84cm
deferred rotation	0.39	0.34	12.48	5.44
season-long (5)	0.45	0.33	14.40**	5.28
rest rotation	0.16	0.28	5.12	4.48
no grazing	0.14	0.13	4.48	2.08
Big Game-Proof				
rest rotation	0.10	0.19	3.20	3.04
season-long (5)	0.19	0.38*	6.08	6.08
deferred rotation	0.24	0.19	7.68	3.04
rest rotation	0.47	0.16	15.04	2.56
no grazing	0.14	0.07	4.48	1.12
Season-long				
1 year	0.13	0.11	4.16	1.76
3 years	0.49	0.21	15.68*	3.36
4 years	0.50*	0.25	16.00**	4.00
5 years	0.68	0.41	21.76*	6.56
Late Season				
September	0.11	0.20	3.52	3.20
October	0.18	0.20	5.76	3.20

*significantly more loss this season than other season at 0.10 level
**significantly more loss this season than other season at 0.05 level

Summary

1. The specific causes of bankcutting and variation in bankcutting were largely unaccounted for. Of the factors examined, different grazing treatment best explained total bank loss. Position of the sample points was also significant, though secondary in importance. Stones in the bank were also related to bank loss. Other factors should not be ruled out until submitted to more vigorous examination. Bankcutting on Meadow Creek during the study period apparently resulted from a very complex interaction of bank vegetation and soils, historical condition and shape, ice floes, spring discharge, channel hydrology and animal use.

2. Bank loss tended to increase with amount of use---use in terms of number of animals and number of years.

3. No grazing and occasional season-long use appeared to be associated with the least bank loss; season-long grazing for four or five years and deferred rotation grazing were associated with the most bank loss. Rest rotation results were intermediate and variable, but generally low. Late season grazing treatments did not differ between September and October grazing.

4. Livestock grazing and winter processes removed approximately equal amounts of streambank, averaged over several years, but any one year may have experienced seasonal differences. Because winter processes worked over a larger portion of the year than summer grazing, there was more total bank loss in winter on four treatments. All four of these treatments were season-long grazing with big game access, for 3, 4 or 5 years. The other twelve treatments did not demonstrate significant seasonal differences.

Biological Implications

The biological relationship of streambanks to the aquatic system is the basis for the growing interest in streambank condition on low-order streams. Although "stability" is the bank attribute most commonly sought, it is often an ill-defined characteristic and may involve resistance to change or resilience after change. Bank shape appears to be an important influence on stream temperature (Brown 1980), velocity (Morisawa 1968) and cover (Platts 1981a). It may be that the most important impact on a streambank is altering its shape, and that cannot be determined by simple edge-movement measurements; the bank profile or a shape classification must be employed. In areas where the use history may have previously altered the shape, bank soils, stream hydrology and ice dynamics must be considered to understand the affects of current management.

Another important aspect of potential impacts on banks is the sediment loading of the stream as banks erode. Both the amount of sediment and the timing of the input may affect the aquatic system. High sediment loads hinder feeding and reproduction of fish and other aquatic organisms and clog gills (Platts 1979, Reiser and Bjornn 1979, Brown 1980). The amount of input from bank erosion may be indexed by edge-movement monitoring. However, the timing of the input and the fate of the sediment may be critical. Sediments loaded into the stream from bank failure in the winter may be flushed out of the gravels and transported to deposition areas by spring discharge. Low summer flows may not be able to move sediment loaded in the summer, which would then settle out uniformly across the streambottom or remain suspended, depending on particle size. Consequently, summer sediment-loading could further stress aquatic organisms already contending with warm water temperatures and limited water volume, whereas winter sediment-loading may result in minimal aquatic organism stress. Furthermore, aquatic organisms normally cope with adverse conditions in the winter. However, increased stress in the summer may interfere with important growth processes (Gregory, per. comm. 1982).

The interaction of bank shape and bank stability is a complex but important matter. When an overhang collapses, there is a large bank loss, but a straight wall results from which flowing water can carve another overhang. Outsloping banks may be very stable and particularly resistant to trampling, but do not shade the water, and form wide, shallow, warm channels. Although the outsloping of a bank may occur slowly and less dramatically than the collapse of overhangs, the outsloped bank is not particularly beneficial biologically. However, some sloping banks may be natural (as on a gravel bar) while others are induced by trampling. In terms of aquatic impacts, a bank loss of 100 cm change from an overhang collapse is not equivalent to a 100 cm change from straight to outsloping which represents a fundamental change in channel form. On the other hand, accelerated overhang collapse and undercutting may increase the sediment load.

Although bank failure apparently corresponds to different types and amounts of animal use, it is not known at what point bank loss begins to affect aquatic habitat, or to what degree the timing of bank loss and resultant sediment loading is important. As research into streambank condition branches away from the engineering perspective into the biological significance, studies should be tailored toward these problems.

Technical Recommendations

1. Use of Bank Stakes to evaluate streambank erosion: This method is easy, inexpensive and fast. There is a problem with measuring to the nearest edge rather than a set point, however, and this problem can be eliminated by simply setting two stakes perpendicular to the bank to line up the measurements each time. Reference stakes should be carefully mapped on streams where they may be removed by ice floes or vandalism. Also, this method does not determine changes in bank shape. The distance measurement is a rough field technique and on occasion, growing vegetation or difficulty in measuring rounded bank edges produced an apparent bank increase.

2. Length of Study Period: Preliminary analysis of the first two years of the Meadow Creek Study provided results significantly different from the analysis of seven years of data. Even at seven years, streambank response in ungrazed areas were apparently just beginning to diverge. Geomorphic processes such as bank and channel form require a long-term perspective.

3. Importance of Bank Shape: Aquatic habitat quality may be related to bank shape as much or more than bank movement. Repeated bank profiling will document both shape change and amount of bank loss, but is very time consuming. An alternative may be to classify bank shape yearly or seasonally, with slope and height measurements at the beginning and end of the study. Coupled with distance measurements, this classification system provided the vital information for relatively little time or money. The width-depth ratio wetted perimeter and bankfull width may also be a useful indices.

4. Bank Descriptions: Accurate soil and surface vegetation descriptions

be vital keys to understanding bank vulnerability. Soil textures and horizons of the banks should be carefully described.

5. Selecting Sample Points: Studies which compare pastures should be designed to avoid sampling banks which may be more responsive to stream processes than to grazing management, and attempt to hold general vegetation class, soil texture and bank shape constant. Dense vegetation or topography may influence animal access to the bank.

6. Sample Size: Sample size was calculated for each pasture using the Stein's Two-Step Method on total bankcutting at straight stream stretches only. In this type of research, being within 20% of the mean 80% of the time is often reasonable accuracy. The sample size necessary to meet those criteria on Meadow Creek clustered between 20 and 60 samples (varying by pasture) and averaged at 44 samples. An average of 317 samples would be necessary to be within 10% of the mean 90% of the time.

CHAPTER IV RESPONSE OF COLIFORM BACTERIA CONCENTRATION TO GRAZING MANAGEMENT

Introduction

Bacterial contamination of surface waters may impact human health by transmitting pathogenic organisms. For several decades, the fecal group of *Escherichia coli* have been used to indicate the presence of fecal material which may contain pathogens. State and federal water quality regulations employ fecal coliform counts to monitor point source fecal contamination and to define the sanitary status of urban watercourses. When the 1972 Federal Water Pollution Control Act (PL 92-500, Section 208) required evaluation of non-point source pollutants, the same techniques and similar standards were applied to wildland streams. However, certain aspects of fecal coliform behavior in wildland watersheds require careful interpretation for rangeland monitoring purposes. For example, coliform concentrations in streams readily respond to runoff events (Kittrel and Furfari 1963, Morrison and Fair 1966, Stephenson and Street 1978, Doran and Linn 1979, Hanks et al. 1981). Apparently, cowpies can provide a protective media that allows coliform survival for at least a year, during which time the bacteria could be carried to the stream with overland flow (Buckhouse and Gifford 1976, Clemm 1977). However, only 2-3% of the bacteria theoretically available from an eastern United States pasture actually reached the stream (Kunkle 1970) and runoff carried viable coliform only about one meter on a Utah range (Buckhouse and Gifford 1976). It is possible, though, that when cattle concentrate in a riparian area, the stream would be within transport distance. In addition, on western United States rangelands, high intensity-short duration storms produce conditions which lower infiltration and increase the volume of runoff available to transport bacteria (Hanks et al. 1981).

Once in the streams, the organisms tend to bind to suspended sediments and settle out (Kittrel and Furfari 1963, McSwain and Swank 1977, Speck et al. 1981). In fact, coliform concentrations exhibit an hysteresis loop characteristic of suspended sediment concentrations associated with high flows (Kunkle 1970). Bottom sediments are apparently a significant reservoir for fecal coliform which may be resuspended by streamflow or animal disturbance (Kunkle 1970, Van Donsel and Geldreich 1971, Stephenson and Rychert 1982). However, coliform bacteria may die-off in riffle areas due to increased contact with bacteria predators and good aeration (Kittrel and Furfari 1963). Unfortunately, little is known on the behavior of pathogens in bottom sediments; Salmonellae apparently survive in mud similarly to fecal coliform (VanDonsel and Geldreich 1971). Fecal coliform concentration also vary daily, seasonally and with water temperature (Kittrel and Furfari 1963, Morrison and Fair 1966, Kunkle and Meiman 1968, Skinner et al 1974, McSwain and Swank 1977).

To summarize the literature, fecal coliform concentrations from non-point sources may indicate direct fecal contamination, enter with overland flow, or reflect suspended sediment concentrations. It is not clear if pathogens respond to these situations in the same way as coliform bacteria. There is some evidence, stemming from research related to septic tanks, that coliform bacteria may survive in some soils and move laterally as far as a few hundred feet with subsurface flow under saturated flow conditions. Well-drained colluvium apparently favored bacterial movement (VanDonsel et al. 1967, Hagedorn and McCoy 1979, Moore et al. 1981).

Livestock and wildlife grazing are considered major sources of fecal pollution on wildland streams. Several studies have correlated fecal contamination with livestock grazing (Morrison and Fair 1966, Kunkle and Meiman 1967, Darling and Coltharp 1973, Johnson et al. 1978, Stephenson and Street 1978, Doran and Linn 1979, Dixon et al. 1981, Gifford 1981). Other mammals, such as wildlife, also transmit coliform bacteria. For example, when local big game populations concentrated in a protected watershed in Montana, the water produced higher coliform concentrations than did a comparable watershed open to recreation (Walter and Bottman 1967, Stuart et al. 1971). Therefore, background levels of coliform may vary with wildlife use.

The longevity of livestock effects on water quality remains a controversial problem for managers. Some research suggests one week to several months may be necessary for coliform counts to return to background levels following livestock removal (Johnson et al. 1978, Stephenson and Street 1978). As part of a multi-disciplinary case study on the effects of grazing management in a riparian area, the Forest Service Pacific Northwest Forest and Range Experiment Station briefly examined this question at the conclusion of five years of controlled grazing on several small streamside pastures.

This study was conducted through the Range and Wildlife Habitat Laboratory in La Grande, Oregon in 1980 and 1981 and was located at Meadow Creek on the Starkey Experimental Forest and Range in northeastern Oregon.

Site Description

The Starkey Experimental Forest and Range is located in the Blue Mountains about 48 km southwest of La Grande, Oregon. The study area includes approximately 8 km (5 miles) of stream coursing an open Ponderosa Pine-Douglas Fir forest. Meadow Creek is a second order stream, draining approximately 98 km^2 (38 $miles^2$); flow varies between .03 and 5.66 CMS (cubic meters per second) (1 and 200 cubic feet per second), and peaks usually in March, but sometimes in January. The stream drops an average of 15 meters/1.6 km, on a primarily gravel bottom (interspersed with fines and some sand). Average annual precipitation is 30.5 to 63.5 cm, falling primarily as winter snow, but with some contribution from fall and spring rains.

In the first part of the century, Meadow Creek was subjected to logging operations which included roads and a splash dam, and heavy grazing. In 1940, the Starkey Forest was dedicated to research which regulated the various activities and reduced grazing pressure. Although the pastures as a whole gradually improved, the stream bottoms still suffered from cattle trailing to water and loafing (Skovlin et al. 1976, Strickler, per. comm., 1980). Rocky Mountain elk (*Cervus elaphus nelsoni*) use the Forest for spring and fall range, and mule deer (*Odocoileus hemionus hemionus*) are found year-round.

Methods

The area immediately adjacent to the stream was fenced into small, contiguous pastures, and stocked at the moderate rate used on the Experimental Forest as a whole (3.2 ha/AUM, or 8 ac/AUM). Depending on size, these pastures held from two to twenty yearling heifers. This had the effect of reducing the stocking rate on the riparian zone, since cattle on larger pastures will travel some distance and concentrate along streams.

The pastures were stocked by a variety of grazing treatments from June to October, and most were accessible to big game (elk and deer). All pastures contained approximately 400 meters stream frontage.

Sampling Routine

Two hundred and fifty ml water samples were collected above and below each pasture every three to four weeks in 1980 and 1981 and divided into 50 ml and 100 ml subsamples for filtering and culturing. The two subsamples were averaged for a count representing colonies per 100 ml at each station. Water samples were cultured for fecal coliform bacteria following standard methods described for the membrane filter technique (American Public Health Association 1975). The time of sampling remained constant at each station. In 1980, sampling was conducted monthly from June through October. In 1981, the same areas were sampled on the same dates as the previous year, however, livestock were not present. In 1982, livestock were again on the area, and selected pastures were sampled intensively during the month of September. In addition, some storm samples were collected as the stream hydrograph responded to the onset of fall rains.

Analysis

On the 400 meter stream reaches, water flowing from one pasture into the next confounded sampling in the lower pasture. Therefore, the arithmetic difference in counts as the stream entered and left a pasture was considered representative of the effect from that pasture. The t-test was applied to above and below pasture pairs to determine whether changes were significant. This particular analytical approach created the apparent paradox of negative colony counts when the coliform concentrations decreased across a pasture. Although impossible in absolute terms, negative counts are acceptable and logical to this analysis which examined relative change and not absolute values.

Results

A t-test was applied to determine if fecal coliform counts changed significantly within each treatment. Although large numerical differences in water upstream and downstream of a pasture were sometimes detected, most of the differences were not statistically significant (Table IV-1).

When the pastures were rested in 1981, most of the mean fecal coliform concentrations dropped from counts recorded in the grazed year. The changes were sometimes numerically large but never statistically significant. Counts were fairly uniform throughout the study when cattle were absent, averaging between 13 and 61 colonies/100ml. The upstream pastures which received water from grazed areas above the study recorded the highest counts. In contrast, during the grazed 1980 season, counts showed great variation throughout the study area, ranging between 14 and 111 colonies/100 ml (Figure IV-1).

The data for the fecal coliform response to storm runoff were most complete for a storm series in September 1980 in the game-proof pastures. Bacteria counts recorded in most grazed and ungrazed areas rose and fell with the stream hydrograph, but they peaked a second time on the recession limb. On one area, however, counts fell as discharge peaked, and then climbed as discharge receded (Figures IV-2 and 3).

TABLE IV-1 PASTURES WITH SIGNIFICANT CHANGES IN FECAL COLIFORM CONCENTRATIONS ACROSS TREATED AREA

	Type of Change in Coliform Concentration	Grazing Treatment
1980		
	↓	season-long, 3 years
	↑	season-long, 4 years
	↓	no grazing (game access)
1981	(no livestock this year)	
	↓	no grazing (game access)
	↓	season-long, 3 years
	↓	season-long, 4 years
	↑	rest rotation (game-proof)
1982		
	no significant changes	

↑ =increase in coliform count

↓ =decrease in coliform count

FIGURE IV-1   AVERAGE NUMBER OF COLONIES: GRAZED VS. UNGRAZED YEARS

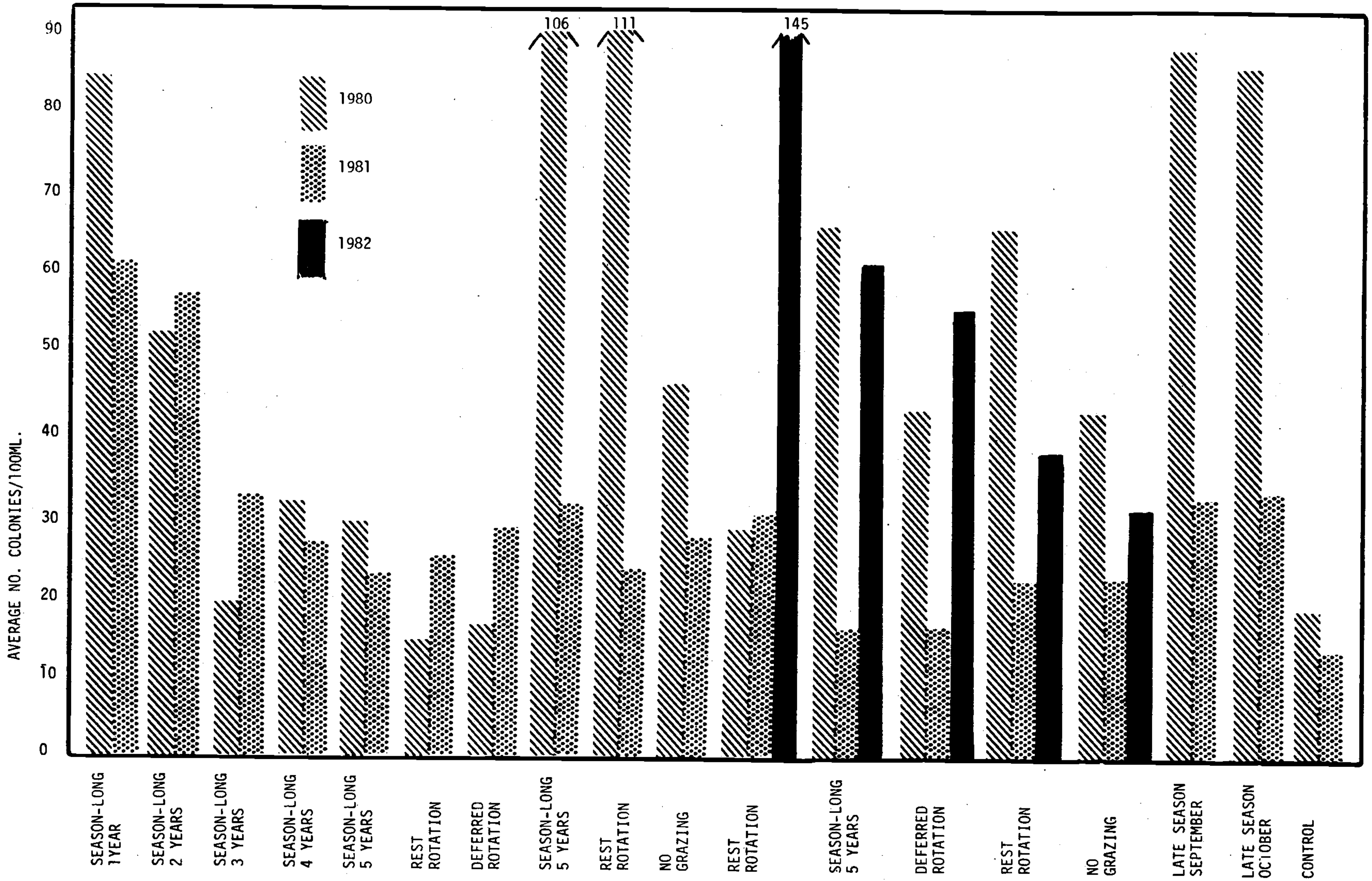


FIGURE IV-2 STORM RESPONSE (game-proof area)

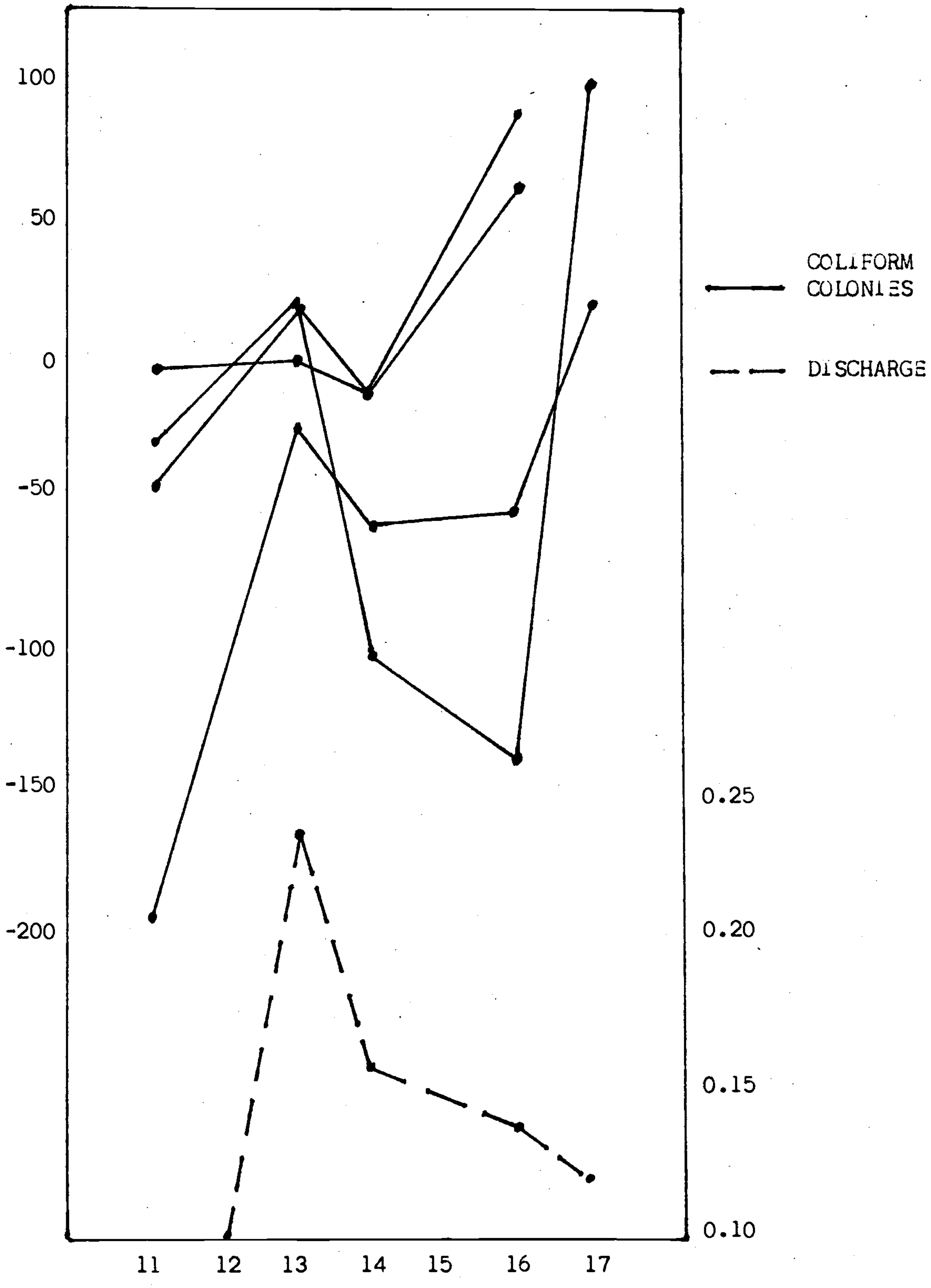
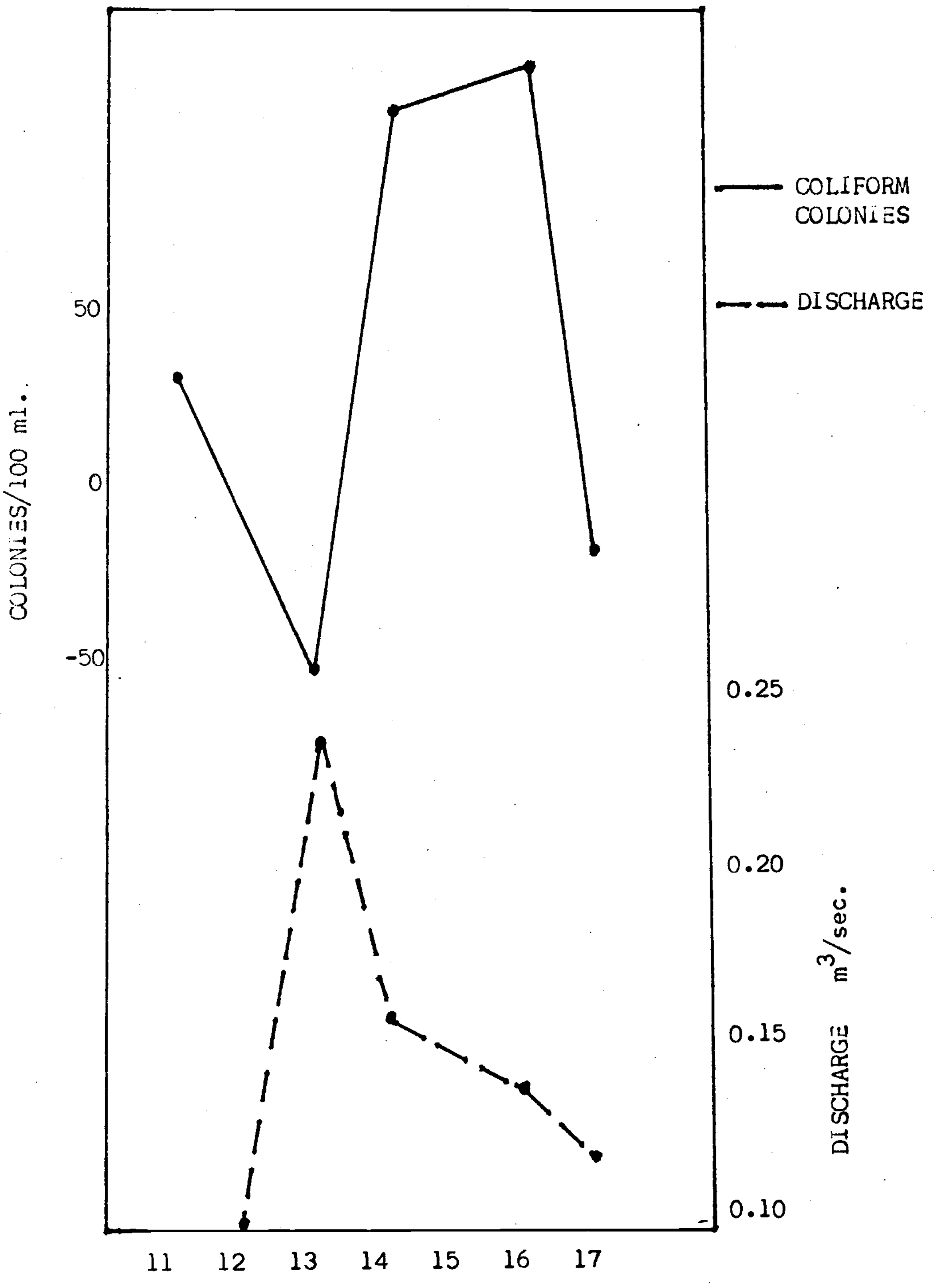


FIGURE IV-3 ATYPICAL STORM RESPONSE (game-proof area)



Discussion

The t-test failed to detect significant changes in fecal coliform concentration across pastures. One explanation is that a 400 meter stream reach is too small an area to produce a significant impact from a non-point source. Another possibility is that the sample variation associated with overland flow, hydrograph changes, groundwater seepage, temperature, disturbance of bottom sediments, and wildlife access statistically masked any effects a grazing treatment may have induced. Either explanation underlines the difficulty in interpreting coliform data from non-point source wildland streams. Although sample variation was large even in the ungrazed year, it appeared to broaden when livestock were present. This may have been caused by animal disturbance of the bottom sediments.

Elevated counts were typically associated with increased discharge from storms on Meadow Creek. The fecal coliform concentrations peaked with the hydrograph and then again on the recession limb of the hydrograph. Suspended sediment rating curves also often display a second peak, and so the fecal coliform bacteria results may be an example of the parallelism between suspended sediment and coliform behavior (Kunkle 1970). This is supported by the atypical coliform response in which the concentration decreased as discharge increased and later peaked during the stream's recession. This response is occasionally seen when suspended sediments are at first diluted by the increased water volume. However, the second peak in bacteria concentration may be associated with the subsurface flow portion of the hydrograph, suggesting bacterial transport with groundwater (Morrison and Fair 1966). However, it is not clear if pathogens also respond to discharge changes.

The membrane filter technique presented some problems; part or all of several samples were discarded due to cultures with irregular growth or color. Irregular colonies were not unique to this study and present a serious obstacle to monitoring wildland streams (Rychert and Stephenson 1981). Fecal coliform bacteria monitoring by land management agencies increases each year in response to legal mandates and a growing awareness and interest in wildland streams. The great majority of monitoring employs the membrane filter technique due to its field adaptability and suitability for use by non-microbiologists. This research suggests, however, that the technique may not be reliable in all wildland situations.

The problems encountered in interpreting the samples from Meadow Creek often resulted from variability associated with non-point sources and therefore have not been thoroughly addressed by the research which established coliform standards and sampling procedures for point sources. Until research is completed for non-point sources, it must be assumed that any presence of fecal coliform indicates the possibility of pathogens.

Summary

1. Non-point source pollution from 400 meter stream reaches did not appear to affect coliform concentrations significantly, though large numerical differences were sometimes seen.

2. The number of colonies and the range of the counts generally decreased the first year livestock were not present. Although the changes were often numerically large, they were statistically insignificant.

3. Coliform bacteria concentrations responded to changes in stream discharge due to storms in much the same way as suspended sediment concentrations typically do. Typically, bacteria concentrations peaked as the hydrograph peaked and then a second time on the hydrograph recession limb. In an atypical response, bacteria concentrations declined as the hydrograph rose and peaked on the hydrograph recession limb. It is not known how pathogens respond to discharge changes.

4. The literature suggests that interpretation of coliform data from non-point sources must be made with caution and must recognize a number of sources of variation from the environment.

CHAPTER V CONCLUDING ESSAY---ANALYSIS OF A PILOT STUDY

The Meadow Creek Study was among pioneering objective investigations of livestock effects on rangeland riparian ecosystems and therefore has valuable lessons to offer. Rangeland riparian areas are distinguished from upland ecosystems by the presence of high water tables and surface water at least part of the year. This characteristic adds a unique dimension to riparian research which must be recognized for productive data collection.

Streams sit in the bottom of notches in the watershed and therefore collect a variety of inputs from the uplands such as water, organic material, and sediment. The quantity, quality and timing of these inputs vary with the watershed characteristics and condition of the uplands. Streams also flow down through the watershed, carrying the "memory" of upstream conditions. There are also on-site influences, and these are the focus of most of the current rangeland riparian research and controversy. However, research that focuses only on streamside influences without considering upslope and upstream conditions may yield rather confusing results. The upstream influence was seen clearly on Meadow Creek in the coliform bacteria analysis. Upslope factors may have affected any of the tests in this thesis, either directly through overland flow or indirectly by influencing patterns of animal traffic.

A stream is the centerpiece of the riparian ecosystem, and may also be one of the strongest and most active influences. However, return intervels on hydrological events are typically much greater than the timespan of a study so it is crucial to know how ordinary or extraordinary the flow behavior was during the study period. Long-term data are also valuable in pinpointing the study's position on the stream's upward, downward or stair-step trend. This information would have been invaluable in the analysis of streambanks, for example, on Meadow Creek. Other stream behavior, such as meandering, flooding and ice floes, shapes an extremely patchy floodplain environment which often defies standard soil and vegetation classification methods and challenges study plot selection. The patchy soils and sensitivity of the water table complicated infiltration analysis over space and time on Meadow Creek.

Many riparian areas appear to be astoundingly resilient. The ungrazed areas on Meadow Creek began recovering vegetative cover in the first year of protection and the soil data reported here indicates an improvement in certain soil characteristics. However, it is difficult to assess the state of a system with few pristine examples for comparison and very long, undisturbed periods are required to simulate a pristine equilibrium. Even then, because a riparian system is an open system, pristine conditions may never be recovered. It is far more efficient to seek to understand the role each component of the system plays, and then see if that component is functioning, than to estimate a "recovered" state. However, an estimation of the pre-disturbance state can be gleaned from recent historical clues such as tree stumps or roots on or above the current streambank or floodplain, the soil profile on the floodplain and even geographical names---there are many streams named "Willow Creek" or "Cottonwood Creek" without a stick or willow or cottonwood today. Geomorphologic processes which shape channels, banks and floodplains work on timescales larger than most biological research, as evidenced by the streambank data in this study. The results of two years of bank data differed from that of seven years, and even at seven years, the banks were only beginning to respond to changes in management. Although the vegetative cover may fill in rapidly, the form structure and function of a riparian system may respond much more slowly.

It is evident the riparian ecosystems are extremely dynamic and the role and behavior of each element must be understood to fully evaluate the effects of management programs. The extreme variability built into the natural system challenges experimental design and demands sample sizes and replication that may be prohibitively expensive unless methods are refined. A case study such as Meadow Creek can shed light on processes and possibilities to pursue, but, as in all case studies, the results must be interpreted with respect to the specific conditions of the study area.

Riparian systems promise a rich story for researchers and managers to unfold. The management problems are complex, expensive and immediate but if sound integrative research continues while state-of-the-art knowledge is applied, the story will unfold and the problems will become more manageable.

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APPENDICES

APPENDIX A ROCKY MT. INFILTRATION RATES
(final rates in cm/hr)

Pasture	Treatment	1975 Mean Rate	Stand. Dev.	1981 Mean Rate	Stand. Dev.	Response	Trend Index
Game Access							
II-1 exc.	rest	104.33	9.29	146.67*	25.97	↑	
trt.	rotation	42.00	4.58	75.00*	30.12	↑	+
II-2 exc.	deferred	34.00	47.66	132.33*	18.77	↑	
trt.	rotation	96.67	4.73	130.00	22.11	0	-
II-3 exc.	season-	96.67	12.66	144.67*	28.43	↑	
trt.	long	143.33	18.18	60.33*	31.09	↓	-
II-4 exc.	rest	62.00	19.31	78.00	38.11	0	
trt.	rotation	90.00	8.72	98.67	10.79	0	0
II-5 exc.	no	48.33	18.93	126.33*	15.18	↑	
trt.	grazing	47.00	5.57	101.33*	4.73	↑	+
Game-Proof							
III-1 exc.	rest	79.67	10.01	120.33*	8.39	↑	
trt.	rotation	111.00	40.45	150.67*	19.60	↑	+
III-2 exc.	season-	46.00	13.12	122.33*	14.36	↑	
trt.	long	43.33	2.89	42.67	6.81	0	-
III-3 exc.	deferred	93.00	18.68	153.33*	37.85	↑	
trt.	rotation	109.00	10.54	147.67	45.02	0	-
III-4 exc.	rest	128.00	13.00	108.33	19.30	0	
trt.	rotation	69.33	22.28	88.33	13.32	0	0
III-5 exc.	no	52.33	11.93	46.67	18.77	0	
trt.	grazing	81.67	10.26	155.67*	47.29	↑	+
Late Season							
IV-A exc.	Sept.	29.33	23.80	62.33	27.06	0	
trt.		109.33	25.33	174.33*	23.63	↑	+
IV-B exc.	Oct.	50.67	4.04	97.67*	26.35	↑	
trt.		66.67	0.58	80.67	16.62	0	-

* significant change (.05 level) from 1975 (L.S.D. Multiple Range Test)

APPENDIX B RING INFILTRATION RATES (Final rates in cm/hr)

Pasture	Treatment	June '80	Stand.	Oct. '80	Stand.	June '81	Stand
Season-long							
I-1 exc.	1 year	704.33	356.92	496.63	228.78	290.71	132.14
trt.		448.88	204.44	347.67	296.38	368.86	238.20
I-5 exc.	5 years	425.63	228.28	253.88	92.16	400.43	256.58
trt.		532.63	288.92	542.14	462.60	216.25#	89.44
Game Access							
II-1 exc.	rest	1431.17	1100.44	3380.38*	1674.01	1147.71#	621.65
trt.	rotation	469.50	182.74	448.57	325.35	826.43	623.09
II-2 exc.	deferred	1032.89	430.13	955.57	506.48	710.38	533.72
trt.	rotation	129.13	69.06	82.43	21.14	167.43	94.95
II-3 exc.	season-	1964.25	1366.58	3959.75*	2711.96	4351.00	2360.63
trt.	long	319.13	169.18	395.00	242.10	226.80	82.47
II-5 exc.	no	382.89	213.27	537.44	320.36	477.17	116.43
trt.	grazing	555.22	359.52	249.78*	143.28	658.78#	359.88
Game-Proof							
III-1 exc.	rest	201.00	90.31	293.83	115.57	135.38#	67.16
trt.	rotation	258.57	146.58	275.38	191.56	343.71	187.81
III-2 exc.	season-	411.29	169.99	421.29	237.34	916.50#	636.95
trt.	long	283.88	146.01	86.57	42.56	399.67	231.23
III-3 exc.	deferred	2126.44	1891.61	522.14*	246.75	819.00	364.45
trt.	rotation	351.20	72.47	294.13	103.43	543.50	332.66
Late Season							
IV-A exc.	Sept.	2078.00	1305.99	1434.86	382.63	894.67	475.38
trt.		1074.75	268.19	1420.33	583.37	784.13	339.95
IV-B exc.	Oct.	937.75	536.89	1541.44*	576.53	1102.86	511.09
trt.		528.88	218.34	458.33	286.90	541.89	390.14

significant change (.05 level) over summer (L.S.D. Multiple Range Test)

* significant change (.05 level) over winter (L.S.D. Multiple Range Test)

APPENDIX C PENETROMETER AND SOIL CORE RESULTS

Pasture		Treatment	Penetrometer (lbs/in^2)						Soil Core (g/cm^3)	
			June '80 rates	Stand. Dev.	Oct. '80 rates	Stand. Dev.	June '81 rates	Stand. Dev.	June '81 rates	Stand. Dev.
Season-long										
I-1	exc.	1 year	51.44	20.83	53.67	20.64	84.22#	16.83	0.19	0.08
	trt.		57.56	13.22	81.73*	18.73	95.39#	13.63	0.82	0.08
I-2	exc.	2 years	58.00	15.59	66.33	19.32	66.83	18.82	1.03	0.07
	trt.		60.22	16.84	104.67*	25.93	78.17#	12.92	1.15	0.11
I-3	exc.	3 years	35.22	3.87	33.78	12.73	65.44#	10.56	0.90	0.03
	trt.		74.11	17.48	117.61#	22.11	94.39	15.52	0.96	0.06
I-4	exc.	4 years	47.56	9.80	69.11*	23.21	56.28#	10.74	0.89	0.06
	trt.		93.33	24.89	117.22*	12.67	93.61#	13.30	1.00	0.09
I-5	exc.	5 years	119.67	22.14	76.44*	15.23	84.44	13.88	0.95	0.19
	trt.		161.56	15.48	117.39*	21.04	112.67	18.41	0.90	0.01
Game Access										
II-1	exc.	rest	55.33	11.08	70.56	21.09	51.28#	12.18	0.74	0.15
	trt.	rotation	100.33	26.14	104.56	18.66	82.94#	22.04	1.01**	0.08
II-2	exc.	deferred	40.67	12.66	54.17	17.49	54.44	14.92	0.84	0.13
	trt.	rotation	138.11	13.73	117.17*	24.12	133.33#	18.09	1.06**	0.10
II-3	exc.	season-	19.67	8.46	23.56	7.56	38.67#	17.63	0.76	0.17
	trt.	long	107.22	37.83	123.39*	18.11	114.00	16.94	0.81	0.07
II-5	exc.	no	52.56	21.46	81.11*	24.17	47.67#	11.85	0.97	0.13
	trt.	grazing	62.22	13.85	75.56	24.01	76.72	14.35	0.81	0.13
Game-Proof										
III-1	exc.	rest	54.33	14.62	86.06*	29.86	63.94#	10.74	0.89	0.07
	trt.	rotation	87.00	28.14	123.94*	13.76	67.89#	19.71	0.90	0.18
III-2	exc.	season-	44.22	5.33	82.61*	31.23	79.33	18.00	0.84	0.56
	trt.	long	109.33	22.97	144.83*	17.37	104.28#	15.75	0.99**	0.05
III-3	exc.	deferred	59.22	18.91	88.28*	16.17	63.94#	10.74	0.86	0.04
	trt.	rotation	87.67	21.58	114.22*	18.85	67.89#	19.71	0.80	0.03

significant change over winter (L.S.D. Multiple Range Test, .05 level)
* significant change over summer (L.S.D. Multiple Range Test, .05 level)
** differs significantly from paired exclosure at 0.10 level (t-test)

APPENDIX C PENETROMETER AND SOIL CORE RESULTS (cont.)

Pasture		Treatment	Penetrometer (lbs/in^2) June '80 rates	Stand. Dev.	Oct. '80 rates	Stand. Dev.	June '81 rates	Stand. Dev.	Soil Core (g/cm^3) June '81	Stand. Dev.
III-5	exc.	no	69.89	22.85	73.72	17.31	39.78#	14.94	----	---
	trt.	grazing	68.67	15.44	26.94*	7.81	46.78#	9.14	----	---
Late Season										
IV-A	exc.	Sept.	60.00	13.22	113.61*	14.45	78.39#	8.89	1.25	0.37
	trt.		75.22	16.73	83.83	28.96	70.94#	12.81	1.45	0.04
IV-B	exc.	Oct.	55.00	12.03	84.22*	16.89	74.06	16.72	1.04	0.06
	trt.		86.44	22.32	143.89*	17.55	91.56#	12.58	1.09	0.06

* significant change over winter (L.S.D. Multiple Range Test, .05 level)
\# significant change over summer (L.S.D. Multiple Range Test, .05 level)
** differs significantly from paired exclosure at 0.10 level (t-test)

APPENDIX D RATES OF SEDIMENT PRODUCTION (kg/ha/plot)

Pasture		Treatment	1975 Mean	Stand Dev.	1981 Mean	Stand Dev.
Game Access						
II-1	exc.	rest	---	---	---	---
	trt.	rotation	2080.00	766.58	547.33*	339.40
II-2	exc.	deferred	205.00	178.40	---	---
	trt.	rotation	39.50	55.86	16.33	28.29
II-3	exc.	season-	---	---	15.50	21.92
	trt.	long	---	---	17.00	14.80
II-4	exc.	rest	304.67	103.32	102.00	144.25
	trt.	rotation	289.00	288.44	198.00	61.39
II-5	exc.	no	3539.33	1031.41	34.67*	33.23
	trt.	grazing	1589.33	329.12	194.00**	276.02
Game-Proof						
III-1	exc.	rest	498.00	177.42	27.67*	38.79
	trt.	rotation	143.00	0	---	---
III-2	exc.	season-	3247.33	3342.23	7.33*	12.70
	trt.	long	598.33	323.55	526.33	153.49
III-3	exc.	deferred	124.67	95.36	---	---
	trt.	rotation	56.50	79.90	---	---
III-4	exc.	rest	---	---	---	---
	trt.	rotation	94.00	162.81	74.67	88.90
III-5	exc.	no	162.00	143.06	---	---
	trt.	grazing	412.00	582.66	17.00	0
Late Season						
IV-A	exc.	Sept.	287.33	250.30	---	---
	trt.		---	---	---	---
IV-B	exc.	Oct.	9962.33	6252.55	184.67*	310.37
	trt.		60.33	52.54	60.67	62.04

* significant change from 1975 (L.S.D. Multiple Range Test)

APPENDIX E AVERAGE BANK LOSS PER WEEK

Pasture/ Season		Treatment	1976 Mean	Stand Dev.	1977 Mean	Stand Dev.	1978 Mean	Stand Dev.	1979 Mean	Stand Dev.	1980 Mean	Stand Dev.	1981 Mean	Stand Dev.
Season-long														
I-1	sp	1 year	.213	.200	.027	.067	.186	.436	.238	.337	.083	.272	.050	.141
	fa		.083	.105	.086	.169	.121	.172	.063	.083	.168	.317	.152	.377
I-3	sp	3 years	.662	.365	.725	1.09	.092	.155	.710	1.06	.138	.346	.605	.767
	fa		.125	.112	.207	.510	.356	.539	.223	.337	.329	.525	.009	.036
I-4	sp	4 years	.733	.680	.589	.638	.577	.864	.395	1.089	.222	.314	.464	.555
	fa		.153	.154	.266	.478	.246	.392	.524	.633	.168	.252	.121	.208
I-5	sp	5 years	1.14	1.04	.693	1.092	.287	.767	.908	.876	.278	.398	.748	1.128
	fa		.115	.141	1.122	1.413	.231	.394	.235	.679	.461	.568	.321	.472
I-5A	sp	5 years									.033	.048	.397	.356
	fa								.048	.090	.220	.233	.052	.111
Game Access														
II-1	sp	rest	.368	.828	.080	.123	.129	.218	.333	.581	.176	.544	.963	1.415
	fa	rotation	.167	.205	.451	.801	.359	.384	.262	.381	.007	.018	.183	.639
II-2	sp	deferred	.912	1.230	.110	.184	.149	.251	.380	.878	.220	.357	.548	.741
	fa	rotation	.639	.855	.214	.361	.551	.644	.185	.260	.444	.730	.009	.036
II-3	sp	season-	.652	.709	.530	.808	.471	.819	.553	.834	.114	.163	.405	.634
	fa	long	.569	.465	.691	1.227	.258	.378	.122	.203	.161	.395	.170	.421
II-4	sp	rest	.311	.234	.051	.129	.075	.117	.110	.368	.155	.379	.277	.379
	fa	rotation	.774	.907	.181	.277	.106	.184	.321	.384	.257	.293	.013	.029
II-5	sp	no	.385	.427	.063	.156	.057	.136	.178	.285	.095	.224	.082	.160
	fa	grazing												
Game-Proof														
III-1	sp	rest	.294	.462	.021	1.44	.048	.105	.058	.169	.044	.103	.116	.385
	fa	rotation	.556	.586	.135	.206	.266	.740	.173	.433	.020	.047	.013	.054
III-2	sp	season-	.345	.342	.106	.232	.316	.788	.058	.126	.133	.386	.163	.473
	fa	long	.563	.637	.263	.394	.859	1.471	.122	.225	.375	.963	.098	.271

APPENDIX E AVERAGE BANK LOSS PER WEEK, CONT.

Pasture/ Season	Treatment	1976 Mean	Stand Dev.	1977 Mean	Stand Dev.	1978 Mean	Stand Dev.	1979 Mean	Stand Dev.	1980 Mean	Stand Dev.	1981 Mean	Stand Dev.
III-3 sp	deferred	.128	.232	.229	.501	.048	.088	.405	.854	.519	1.216	.121	.351
fa	rotation	.295	.518	.280	.449	.305	.478	.131	.173	.148	.324	.009	.024
III-4 sp	rest	1.400	.979	.208	.291	.222	.485	.408	.637	.053	.173	.539	.699
fa	rotation	.240	.500	.191	.276	.074	.189	.128	.232	.309	.616	.009	.024
III-5 sp	no	.172	.295	.049	.112	.129	.256	.045	.139	.006	.017	.452	.885
fa	grazing	.122	.203	.165	.335	.043	.085	.033	.054	.003	.013	.049	.100
Late Season													
IV-A sp	Sept.	.074	.079	.017	.035	.267	.579	.123	.320	.053	.181	.116	.219
fa		.639	.688	.168	.269	.078	.142	.113	.329	.158	.379	.058	.161
IV-B sp	Oct.	.409	.370	.051	.114	.125	.330	.218	.479	.074	.175	.225	.660
fa		.406	.577	.201	.246	.156	.342	.244	.332	.158	.358	.013	.029
Controls													
A sp	no	.517	.357	.280	.460	.265	.270	.905	1.131	.152	.300	.598	1.425
fa	grazing	.052	.106	.082	.236	.094	.155	.069	.098	.013	.041	.036	.108
B sp	no	.412	.449	.381	.642	.160	.281	.650	.943	.492	.858	.904	1.915
fa	grazing	.076	.153	.273	.506	.188	.543	.268	.594	.102	.165	.954	.139
O sp	no	.446	.356	.275	.300	.125	.292	.540	.919	.174	.317	.279	.380
fa	grazing	.066	.096	.303	.516	.227	.596	.060	.077	.125	.352	.138	.332

APPENDIX F ACTUAL FECAL COLIFORM NUMBERS (per 100 ml.)

Grazing Treatment	1980 (grazed)	Range of Counts as Stream Leaves Trt.	1981 (ungrazed)	
Big Game Access				
rest rotation '80 rest	10-18		13-32	
deferred rotation	8-26		9-49	
season-long (5)	28-247*		10-67	(warm springs enters)
rest rotation '80 grazed	88-157		8-34	
no grazing	37-55		11-36	
Big Game-Proof				
rest rotation '80 rest	13-33		7-62	
season-long (5)	29-172		10-25	
deferred rotation	15-98		10-22	
rest rotation '80 grazed	18-180		17-29	
no grazing	17-80		19-24	
Season-long				
1 year	35-161		16-133	
2 years	13-89		18-121	
3 years	5-26		23-47	
4 years	18-51		8-38	
5 years	14-64		18-27	
Late Season				
September	7-300 *		24-35	
October	10-300 *		23-50	
No Grazing--control	8-30		8-22	

* exceeds "200 count" standard