

# Grazing Practices: A Review of the Literature

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*Technical Bulletin 325-W  
April 2007*

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**This literature review presents numeric information in the original measurement system in which they were presented. Thus, there are both metric and English units.**

**Citation of this document should be as follows: Osmond, D.L., D.M. Butler, N.N. Ranells, M.H. Poore, A. Wossink, J. T. Green. 2007. *Grazing Practices: A Review of the Literature*. North Carolina Agricultural Research Service, Technical Bulletin 325-W. North Carolina State University. Raleigh, NC.**

**Acknowledgements: We would like to thank Janet Young for layout. This document would not have been possible without her help.**

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# 1. Introduction

## *1.1 Livestock production and environmental management*

Traditionally the greatest concern of livestock producers who primarily graze their animals has been maintaining high levels of productivity to maximize profits. Recent interest by the general public and government agencies in conserving the environment has mandated reevaluation of production systems to minimize environmental impacts while maintaining farm viability and profitability.

Surface water quality is a concern in most watersheds in the United States. Since 1972, with the passage of the Clean Water Act by Congress, great strides have been made in controlling point sources of pollutants, and currently there is an increased emphasis on nonpoint sources (NPS). A small portion of NPS pollution is a result of natural ecosystem processes. Most NPS pollution, however, is caused by human activities. According to the U.S. Environmental Protection Agency (2000), agriculture is the primary source of pollution for 50% of the impaired river and stream miles and 40% of the impaired lake and reservoir areas. Agricultural sources of pollution include both cropland and livestock production. In North Carolina, more than 1.7 million acres (a), or 0.69 million hectares (ha), were used as pasturelands in 1997 (U.S. Department of Agriculture, 1997), which makes riparian grazing a critical issue for the state.

Farmers and producers of livestock are often major participants in plans to reduce NPS impacts on surface waters. The need for improved management strategies with regard to grazing livestock has been examined (Morse, 1995). On a national level, the agricultural community has made efforts to respond to increasing scrutiny (Clawson, 1993). A 1998 “Cattlemen’s Information Guide to Water Quality” published by the National Cattlemen’s Association encouraged involvement of livestock producers in water quality planning at both farm and watershed levels. This guide also recognized the site-specific nature of management practices targeted at improving water quality. Although this resource provides significant value to farmers by giving production guidelines and contact information for every state, it does not set a performance objective or provide standards to be reached. Martin (1997) evaluated the Clean Water Act and its impact on animal agriculture. The report noted the increasingly broad powers to regulate confined animal feeding operations (CAFOs) given to the U.S. Environmental Protection Agency (EPA) and the complexity of regulation. Martin noted that land applications of CAFO waste have recently been considered as point sources, though traditionally considered as nonpoint in nature. However, pasture and rangeland operations were not specifically mentioned.

In the late 1990s, North Carolina poultry, swine, dairy, and beef producers were surveyed to assess farmer adoption of waste management practices (Hoban et al., 1997). An average of 88% of the 200 beef and dairy producers surveyed had tested soil in the past 5 years, and 65% of all dairy and nonconfined beef operators had installed best management practices (BMPs) to minimize the impact of livestock on water quality. Beef producers had the most decentralized system for animal waste management with most cow-calf operations pasture-based and livestock stocking rates of generally less than 1 animal unit (AU) per acre (a<sup>-1</sup>). A variety of water sources were available on

farms: streams (55%), ponds (30%), tanks (25%), wells (16%), or a combination of these. Of the 78% who reported streams in or near their pasture, approximately half managed a buffer or filter area and fenced cattle out of streams.

In North Carolina, financial incentives made available through the state's Agriculture Cost Share Program encourage farmer adoption of BMPs to protect water quality (N.C. Department of Environment and Natural Resources, 2003). Although not all BMPs approved for this program relate directly to riparian grazing, they included riparian buffers, streambank stabilization, controlled livestock lounging areas, heavy use area protection, livestock exclusion systems, stream crossings, and off-stream water sources.

In this bulletin, we review the research that evaluates the influence of grazing livestock, primarily beef cattle, on water quality. Our purpose is to help producers and government agencies make informed choices as they consider strategies to protect water quality and maintain productive pasture-based livestock operations. We also present information on grazing issues for pasture-based livestock operations.

### **1.2 Previous literature reviews**

We reviewed many literature sources in our examination of riparian grazing literature. Similar to the findings of Larsen et al. (1998), we found that many of the articles did not include information on original research but instead anecdotally addressed the issue of riparian grazing management. For this effort, we have focused on a few previous literature reviews. A geographical focus indicates that very few directly relate to the climate or physiographic regions of North Carolina.

In the United States, one of the primary reviews that addressed livestock impacts on riparian ecosystems summarized the impacts on streamside management (Kauffman, 1984). Although the focus of Kauffman's work was the public grazing lands of the western U.S., it provided a solid summary of the research and management of riparian areas. Kauffman and Krueger (1984) also pointed out that not much "scientific method" is utilized in this area of work due to the complex nature of the ecosystem. Yet, these authors compiled the "accepted facts and management theories" on the impact of trampling and herbage removal by livestock on in-stream ecology, terrestrial wildlife, and riparian vegetation.

A field survey and literature review for effective cattle management in riparian zones was prepared in Montana by the Bureau of Land Management (Ehrhart, 1997). This review indicated that fisheries biologists reported most of the early work on livestock impacts to watercourses and these reports generally condemned grazing livestock in riparian areas. Early research involved comparing long-term continuous grazing with total livestock exclusion from the riparian area and ignored other access management options that may reduce impacts. In a more recent report, Larsen et al. (1998) made an effort to classify the literature on riparian zones and fish habitat and to separate the reports of original scientific data from secondary commentary. After reviewing 428 reports, these authors reported that 89 of the reports described research that involved replication and statistics. Of these 89 experiments, many were of limited value due to inadequate description of grazing management practices, weak study designs, and lack of pre-treatment baseline data. The report presented a few broad generalizations: (1) Livestock can exist within sustainable riparian systems with or without undesirable

changes in vegetation; (2) responses to management are very site specific; and (3) ecosystems are highly variable in space and time and result from interactions of long-term forces.

Mosley et al. (1997) provided a summary of the available research and recommended management options for the state of Idaho. A key aspect of the summary divided research by management strategy for cattle in riparian areas rather than by cattle impacts. Management strategies presented included changes in grazing timing, frequency, intensity, and distribution. Platts (1979) also summarized data available for Idaho and noted that one recent advance was time-managed livestock access to utilize forage and prevent stream degradation. Utah scientists summarized grazing systems and watershed management and stated that only nine references specifically examined the impacts of grazing systems on plant or litter cover (Gifford, 1976). Furthermore, the site-specific nature of grazing management precluded any general conclusions.

A report by Clark (1996) focused on alternative watering systems for Ontario, Canada, as a means to minimize the perceived conflict between livestock and recreational or tourism industries. The report concluded that direct livestock access to watercourses was a minor contributor to downstream phosphorus pollution and noted that the multiple sources of contamination in this NPS pollution assessment confounded a simple determination of cause and effect. The general impacts included sediment loading related to streambank destabilization and sediment resuspension, nutrient loading into the watercourse from urine and fecal pathogen input, and thermal impacts on water due to vegetation alteration. While the Ontario provincial policy provides economic incentives for complete exclusion of livestock from watercourses, Clark summarized approaches other than fencing, such as biophysical features of the access point, placement of salt and mineral feeders, and provision of alternative watering systems.

A review of literature for the prairie grasslands of the Canadian Great Plains discussed opportunities for grazing management to increase grassland productivity (Vaisey and Strankman, 1999). Species protection, biodiversity, greenhouse gas regulations and incentives, carbon sequestration opportunities, and economic diversification will affect future livestock production in this region. Vaisey's report mentions manure management with respect to surface water contamination and riparian management. In the prairie region, trampling and use of riparian areas by large numbers of livestock for extended periods of time can damage shorelines and result in erosion, which in turn degrades aquatic habitat and may cause species shifts in vegetation.

Drewry reviewed the natural recovery of soil physical properties due to livestock in New Zealand and Australia (2006). He divided the review into short-term (1 year or less) soil physical property recovery and longer-term physical recovery. Depending on the soil physical property measured (i.e. bulk density, Ksat, macroporosity, etc.), improvement ranged from as little as 10% change to more than 100%. Rate of change in soil physical property characteristics depended on the measured trait, soil type, duration that livestock were excluded, weather conditions, and other factors. Most changes occurred, however, within the top 10 to 15 centimeters (cm). Drewry concluded that managing pastures in rotational grazing schemes and removing livestock during wet weather is important in reducing soil compaction from livestock grazing.

Robbins (1979) reviewed grazing literature and found a low impact by grazing animals except for fecal coliform as long as pastures were not overgrazed. In addition, his

review demonstrated elevated nutrient concentrations in impoundments within pastures. More recent information, particularly information coming from more humid regions such as England and New Zealand, has documented phosphorus (P) and nitrogen (N) losses into water resources from pastures.

Although these past reviews provide a wealth of information regarding cattle in riparian areas, the importance of this issue to North Carolina and the Southeast calls for a review more applicable to environmental conditions typical of the region and a more specific focus on research relating to riparian grazing issues.

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## 2. Animal health and production

### 2.1 Water quality

Previous research has demonstrated that water with very high levels of dissolved salts depresses feed intake and animal performance (Saul, 1985; Solomon, 1995). However, limited research is available that indicates giving cattle high-quality water sources instead of letting them drink from any water source they can find will improve animal performance. In southwestern Virginia, improved animal performance is a common justification for installing improved watering systems for cattle (Johnson, 1993).

In research conducted in Alberta, Canada, Willms et al. (1996) compared “fresh” water pumped from wells, springs, or a river to water from dugout ponds with direct access or pumped to troughs for beef cattle. The research was conducted at three locations for a 5-year period. In general, the cattle given fresh water outperformed the cattle given the dugout water. Yearling cattle gained better on fresh water at two sites: 0.12 kilogram (kg) per day ( $\text{day}^{-1}$ ) and 0.25 kg  $\text{day}^{-1}$ . At the third site, no difference was detected in weight gain of yearling cattle for a 3-year period. Water analysis did not provide clear reasons for the reduced gain on dugout water at two sites, although the dugout water was very high in sulfates at one of those sites.

Similar work in Missouri compared well water to water hauled from earthen ponds that had a high level of animal impact (Crawford and Cole, 1999; Crawford et al., 1997). These studies were conducted with either endophyte-infected or endophyte-free fescue pastures. Yearling cattle were grazed in the first 2 years, while cow-calf pairs were grazed on the pastures in the second 2 years. Cattle on endophyte-infected pastures consumed more water than those on endophyte-free pastures, regardless of water source. Endophyte-infected fescue tended to depress performance. But over the 4 years, no significant impact of water source on animal performance was detected. Water analyses indicated that the pond water did have poor quality, with especially high iron levels early in the grazing period and very high fecal coliform levels late in the grazing season. However, the researchers concluded that their results did not support the widespread idea that drinking surface water degraded by high animal impact depresses animal performance.

### 2.2 Waterborne animal pathogens

One potential benefit of excluding animals from surface water is the influence on animal health. Feces and urine from infected cattle can carry pathogens that may enter water, either through direct deposition or runoff, and these could be passed to other animals. Most concern has been with pathogens that can potentially infect humans, such as *Cryptosporidium*, *Giardia*, *E. coli* 0157:H7, *Salmonella*, *Campylobacter*, and *Leptospirosis* (Rosen, 2000). Other diseases, such as bovine viral diarrhea (BVD), Johne’s disease, and footrot, can also be transmitted by water (Clark, 1996). Mastitis can also be a problem in beef herds (Watts et al., 1986) and lounging in water has been suggested as a possible cause (Crawford and Cole, 1999). The USDA’s Watershed Science Institute (WSSI), in a February 2000 publication entitled “Waterborne Pathogens in Agricultural Watersheds,” suggested entry of pathogens into surface

waters could be minimized by these strategies: (1) improve grazing management to better distribute manure, (2) avoid overgrazing to minimize runoff from pastures, and (3) implement management practices, such as alternative water, supplement placement or stream fencing to avoid direct deposition of manure into water (Rosen, 2000). It seems obvious that water access is a risk factor for water-transmissible diseases, but no studies were found showing that exclusion of cattle from surface waters reduced the incidence of any disease. This is an important area for future research.

### 3. Nonpoint source pollution from grazing

#### 3.1 Buffer strips

Vegetative buffers are widely considered to be a useful tool for controlling NPS pollution from agriculture (Wenger, 1999). Working in North Carolina, Bingham et al. (1980) reported that tall fescue buffer widths (expressed in a ratio of buffer area to waste length area) were effective in reducing nutrients from applied chicken litter; total phosphorus (TP) was reduced by 85%, total organic carbon (OC) by approximately 50%, total Kjeldahl nitrogen (TKN) by approximately 60%, and nitrate ( $\text{NO}_3\text{-N}$ ) by more than 90%. Most of the reductions occurred at a buffer area length to waste area length ratio of 1.0, but the researchers caution that NPS reductions are a function of loading rate. In Arkansas, Chaubey et al. (1995) examined the effectiveness of grass buffer strips and found that 3.1-meter (m) buffers reduced mass transport of total TKN by 39.2%, ammonia-nitrogen ( $\text{NH}_3\text{-N}$ ) by 46.6%, TP by 39.6%, and ortho-phosphorus ( $\text{PO}_4\text{-P}$ ) by 38.8%. Buffers that were 21.4 m long reduced transport of TKN by 80.5%,  $\text{NH}_3\text{-N}$  by 98.0%, TP by 91.2%, and  $\text{PO}_4\text{-P}$  by 89.5%.

Lim et al. (2000) examined varying widths of vegetated filter strips and found that the buffers removed a significant portion of the nutrient load from cattle manure during an experiment where heavy grazing conditions were imposed (Table 1).

**Table 1. Percent reduction of surface-delivered pollutants by vegetative filter strips**

Variable	Vegetative Filter Strip Width (ft)		
	20	40	60
Total N	78%	90%	95%
Ortho-P	75%	88%	93%
Total P	76%	90%	94%
Total suspended sediments	70%	90%	98%
Total solids	24%	41%	70%

Source: Adapted from Lim et al. (2000)

Daniels and Gilliam (1996) reported that if flow passing through buffers was concentrated then the buffers were much less effective in minimizing NPS losses. Water must be dispersed uniformly throughout the buffer in sheet flow to ensure effective treatment of pollutants. Similarly, Dickey and Vanderholm (1981) reported that the effectiveness of vegetative filters in treating feedlot runoff increased with width (up to 500 m) and with sheet flow conditions for N and total solids, but not for fecal coliform;  $\text{NH}_3\text{-N}$  was reduced by 85%, TKN by 89%, total solids by 79%, and chemical oxygen demands by 92.2%.

Heathwaite et al. (1998) compared the effectiveness of riparian grass buffers when fertilizer, cattle slurry, or cattle manure was applied. The researchers reported that 68% of the N from manure and 62% of the N from slurry were exported in an organic form. Phosphorus had a different response, with 74% of manure P and 39% of slurry P in a particulate or dissolved organic form. Crop buffers (oats, corn, or sudangrass)

have also been studied for potential to reduce runoff from feedlots (Young et al., 1980). The researchers found that these cropped buffer strips on a 4% slope reduced runoff by 67%, solids by 79%, TN by 84%, and TP by 83%. A width of 36 m seemed sufficient for the feedlot examined, which contained 350 head of cattle.

Mersie et al. (2003) compared the effectiveness of tall fescue (*Festuca arundinacea* Schreb.) and switchgrass (*Panicum virgatum* L.) at removing the insecticide endosulfan (1,4,5,6,7,7-hexachloro-5-nobornene-2,3-dimethanol cyclic sulfite). Simulated runoff was applied to the 2 m plots, and surface runoff, leachate, and soil samples were analyzed. At a slower flow rate of 2.7 liters (L) per minute ( $\text{min}^{-1}$ ), tall fescue was more effective than switchgrass at removing endosulfan from runoff. At a faster flow rate of 6.0  $\text{L min}^{-1}$ , the vegetative strips were less effective and no statistically significant differences were detected between the tall fescue and switchgrass. However, both were more effective than bare ground. Generally, the researchers stated that the first third of the filter strip and the 0 to 10 cm soil layer were most effective at retaining endosulfan.

### 3.2 Nutrients and bacteria

Nutrient and bacterial pollutants, along with sediment, are three classes of contaminants often associated with cattle grazing. Harmel et al. (2006) compiled data from 40 watershed studies across the United States and Canada, representing more than 300 watershed years for pasture and rangeland. Median nutrient loads (total TN, dissolved N, particulate N, TP, dissolved P, and particulate P) measured in kilograms (kg) per hectare ( $\text{ha}^{-1}$ ) were always less for pasture or rangeland conditions than for cropped land (Table 2). It is important to note that the applied nutrient levels were also much lower for pasture and hay systems than for cropland, which probably explains at least some of the nutrient loading differences.

**Table 2. Median annual total N and P load value by land use**

Treatment	Total N ( $\text{kg ha}^{-1}$ )	Diss. N ( $\text{kg ha}^{-1}$ )	Part. N ( $\text{kg ha}^{-1}$ )	Total P ( $\text{kg ha}^{-1}$ )	Diss. P ( $\text{kg ha}^{-1}$ )	Part. P ( $\text{kg ha}^{-1}$ )
<b>Land Use</b>						
Corn	18.70	3.02	7.27	1.29	0.22	0.85
Cotton	7.88	2.47	9.13	5.01	0.68	5.60
Oats/Wheat	6.61	1.31	5.90	2.20	0.30	3.45
Soybeans	—	2.70	21.90	0.45	0.60	9.60
Pasture/Range	0.97	0.32	0.62	0.24	0.15	0.00

Source: Adapted from Harmel et al., 2006

Dierberg (1991) monitored three different land uses for water quality in Florida by sampling a series of locations in existing drainage canals. An agricultural watershed that consisted of grazing land with unimproved pasture lost 6.38  $\text{kg ha}^{-1}$  per year ( $\text{yr}^{-1}$ ) of N. This was more than twice as much N lost than from low and moderately developed residential land uses, which lost an average of 2.96  $\text{kg ha}^{-1} \text{yr}^{-1}$ . Phosphorus losses were similar at approximately 0.2  $\text{kg ha}^{-1} \text{yr}^{-1}$  for both land uses.

In New Zealand on Tuapo sandy loam soils, Cooper et al. (1995) compared a native riparian zone, a grazed pasture, and a set-aside pasture for their ability to reduce pollutants. The set-aside pasture had been fenced for 12 years, and during that time the vegetation had shifted from pasture grasses to native tussock. The grazed pasture had the lowest ability and the set-aside pasture the highest ability to transmit water through the soil profile. This indicates that the grazed pasture setting would be more vulnerable to surface losses of soil, sediment-attached P, and TKN.

Kilmer et al. (1974) reported nitrate ( $\text{NO}_3\text{-N}$ ) runoff losses between 2 and 10 milligrams (mg) per liter ( $\text{L}^{-1}$ ) from Kentucky bluegrass (*Poa pratensis* L.) pastures fertilized with  $448 \text{ kg N ha}^{-1}$  over a 4-year period in the mountains of North Carolina. At a fertilizer rate of  $112 \text{ kg N ha}^{-1} \text{ yr}^{-1}$  for 4 years, the  $\text{NO}_3\text{-N}$  concentration of runoff ranged from 0 to  $3 \text{ mg L}^{-1}$ , with  $\text{NO}_3\text{-N}$  runoff losses for both pastures representing 6 to 10% of the total fertilizer applied.

Livestock exclusion (fencing and 30 to 50 ft riparian buffer establishment) was found to be effective in reducing nutrient losses to a piedmont North Carolina stream (Line et al., 2000) in a heavily stocked dairy loafing pasture. The nutrient reduction after dairy cattle were fenced out of the riparian area was 55% for TKN, 79% for TP, and 33% for  $\text{NO}_3\text{-}/\text{NO}_2\text{-N}$ . Although the reductions in  $\text{NO}_3\text{-}/\text{NO}_2\text{-N}$  were not statistically significant, the reductions of the other nutrients were significant.

Watersheds with different land uses were studied in the coastal plain, piedmont, and Appalachian regions of the Chesapeake Bay watershed (Correll et al., 1995). Results from the piedmont and Appalachian regions where cattle were not fenced out of streams were reported (Table 3).

**Table 3. Dissolved nutrient concentrations of streams draining the Chesapeake Bay**

Nutrient	Piedmont and Appalachian Regions		
	Cropland (17 streams)	Pasture (13 streams)	Forest (17 streams)
Organic C (mg C L <sup>-1</sup> )	9.78	15.8	8.13
Nitrate (mg N L <sup>-1</sup> )	2.33	1.86	1.54
Ammonium ( $\mu\text{g N L}^{-1}$ )	5.58	7.99	0.54
Organic N ( $\mu\text{g N L}^{-1}$ )	79.4	117	21.3
Phosphate ( $\mu\text{g P L}^{-1}$ )	25.3	55.1	6.32
Organic P ( $\mu\text{g P L}^{-1}$ )	10.6	15.4	16.1

Source: Adapted from Correll et al. (1995)

Sheffield et al. (1997) demonstrated that pollutants from cattle using streams as water sources were significantly reduced when alternative water systems were provided. Cattle preferred to drink from a trough 92% of the time when alternative water systems were installed on commercial cow-calf operations in Virginia. At one farm, stocking density was 200 cows and 170 calves on 136 ha (8 pastures). On this farm, installation of alternative water sources reduced average concentrations of total P by 81%, fecal coliform by 51%, and fecal streptococci by 77% at stream sampling stations. Soluble nutrients ( $\text{NO}_3\text{-N}$  and  $\text{PO}_4\text{-P}$ ) increased slightly due to the installation of

the water trough. The authors note that seasonal variation was a limiting factor in conclusions drawn from this study due to its relatively short 14-month duration.

Researchers in Virginia correlated water quality data with land use and hydrologic delivery (Brenner and Mondok, 1995). They found a relationship between the watershed delivery, animal numbers, manure management, and contaminant (fecal coliform and P) levels found in the streams. Nitrate level was related more strongly to groundwater delivery than to the other factors. The authors concluded that the management of livestock is critical to reducing NPS pollution.

A paired watershed study in Ohio demonstrated little difference in surface nutrient losses between a grazed pasture and a wooded area (Owens et al., 1997). A wooded area within the pasture surrounded the stream, so little runoff drained directly from the pasture into the stream without first passing through a forested area.

In another Ohio study, both surface and subsurface N losses were compared in pastures with summer grazing only and summer grazing plus winter feeding (Owens et al., 1982). Annual subsurface N losses were similar between the two systems (~18 kg N ha<sup>-1</sup>). However, annual surface and sediment-attached N losses were negligible under the summer grazing system but substantial under the winter-feeding situation: 14 kg N ha<sup>-1</sup> (dissolved surface losses) and 8 kg N ha<sup>-1</sup> (sediment-attached losses). The winter-feeding situation lost more than twice as much total N as did the grazed-only pasture. In another feeding study from Ohio, summer-grazed pastures lost less N in surface runoff than the winter-feeding pastures (Chichester et al., 1979). However, 2 to 3 times greater N leached into the shallow groundwater under the summer-grazed pastures than under the winter-feeding pasture. Another study from Montana showed little effect on stream nutrient concentrations due to winter feeding but did show large increases in fecal coliform (Milne, 1976).

Owens et al. (1994) evaluated groundwater NO<sub>3</sub>-N levels upon conversion of a fertilized grass pasture to a grass-and-legume pasture with the legume supplying the N source. They reported that fertilized grazed pastures of orchardgrass (*Dactylis glomerata* L.) had an average shallow groundwater NO<sub>3</sub>-N concentration of 9.7 mg N L<sup>-1</sup> compared to tall fescue at 17.7 mg N L<sup>-1</sup> during the 5-year fertilization period. Fertilization was then stopped, and the pastures were seeded with alfalfa (*Medicago sativa* L.). Groundwater was sampled for the next 10 years, and the average NO<sub>3</sub>-N concentration for the orchardgrass-alfalfa pasture was 3.0 mg N L<sup>-1</sup> compared to 9.3 mg N L<sup>-1</sup> for the mixture of tall fescue and alfalfa. In these systems, most N was lost through subsurface flow, even when a legume was used rather than N fertilizer. The majority of the N lost in surface runoff from fertilized pastures occurred shortly after fertilization (Owens, 1984). Shallow groundwater NO<sub>3</sub>-N concentrations were ~5 mg L<sup>-1</sup> when pastures were fertilized at a rate of 56 kg ha<sup>-1</sup>. When fertilization was increased to 168 kg N ha<sup>-1</sup> as either methylene urea (slow-release fertilizer) or ammonium nitrate, groundwater NO<sub>3</sub>-N increased to 16 mg L<sup>-1</sup>.

Arkland and Langers (1994) reviewed N loss pathways in pasture systems. They reported gaseous and leachate losses from grazed systems may be 6 times greater than from a hay system because yearling steers remove less than 30 lb N yr<sup>-1</sup>. Researchers in New Zealand found that under grazed pasture conditions, NO<sub>3</sub>-N leaching into shallow groundwater was 5.6 times greater than when the grassland was harvested as hay. The amount leached was even greater than losses under cultivated fields (Ryden et al., 1984). Researchers acknowledged that as much as 90% of the N consumed by the

cattle is returned to the pasture system whereas 75% of the N is removed when pastures are hayed.

A Texas study of different agricultural land uses showed low  $\text{NO}_3\text{-N}$  concentrations in shallow groundwater under native grasses ( $0.08$  to  $1.1 \text{ mg L}^{-1}$ ) but higher levels under improved grasses and alfalfa ( $0.8$  to  $16 \text{ mg L}^{-1}$ ), perhaps partly due to surface flow into wells (Smith et al., 1985). In a longleaf pine forest in Louisiana, N losses were greater when cattle were grazed than when no cattle were present and also under intensively managed forest systems compared to less intensively managed systems (Wood et al., 1989). This was likely due to more bare soil being exposed by grazing and intensive silviculture.

Phosphorus losses from pastures can also be a problem. Grazing lands on the coastal sands of western Australia have caused eutrophication in streams from P leaching losses. In a very early study on P losses from fertilized pastures in southwestern Virginia, researchers found that P fertilizer increased vegetative cover but the P losses associated with soil doubled (Dickerson and Rogers, 1941). Based on observing pastured dairy cows in New York state, Gburek (2005) found that 13% of manure from pastured cows was deposited in the stream and 46% within 40 m of the stream. Based on the P concentration of cow manure, each cow deposited  $0.34 \text{ kg P ha}^{-1} \text{ yr}^{-1}$  into the stream and  $1.25 \text{ kg P ha}^{-1} \text{ yr}^{-1}$  near the stream. The amount of P delivered due to direct access by the cows was much greater than from other agricultural land uses ( $0.13 \text{ kg P ha}^{-1} \text{ yr}^{-1}$ ). The author suggested that cattle exclusion would dramatically decrease the P loading into the reservoir.

During a paired watershed experiment, researchers in the Pacific Northwest reported that delivery of N and P into water resources was low for both grazed and ungrazed watersheds (Jawson et al., 1982). However, total N and P losses were 8 to ~12 times greater from the grazed watershed than the ungrazed. The authors noted that depending on the quality of downstream surface waters, grazing did not present much of a nutrient pollution hazard, though phosphorus contributions were at a level that might lead to enrichment of certain waters. Rainfall in the studied region is generally around 25 inches (in), and runoff occurs in late fall and winter when pastures are not actively growing and the cattle are not grazing.

In Arizona, ungrazed brush-covered rangeland, recently subdivided rangeland, and grazed brush-covered rangeland were compared for surface water quality (Schreiber and Renard, 1978).  $\text{NO}_3\text{-N}$  concentration was about twice as high in the recently subdivided watershed ( $0.62 \text{ mg L}^{-1}$ ) than in the grazed and ungrazed watersheds. However,  $\text{PO}_4\text{-P}$  was about 4 times greater ( $0.22 \text{ mg L}^{-1}$ ) in the grazed watershed than in the ungrazed and subdivided watersheds. This may have been a function of the parent material rather than the actual land uses.

In Oregon, Wigington et al. (2003) studied the effectiveness of riparian buffers at removing  $\text{NO}_3\text{-N}$  from shallow groundwater and reported that riparian buffers strips reduced  $\text{NO}_3\text{-N}$  concentration in drainage water from grass seed fields. However, the researchers noted that the percentage of streamflow through riparian soils at their site was limited. Most stream water came directly from flowing ephemeral swales in the grass seed fields.

During a 3-year study in the Pacific Northwest, Gary et al. (1983) observed cattle behavior and monitored stream water quality. Grazing pressure was moderate, 40 to

150 cattle on about 80 ha, during the experiment. These researchers found that cattle spent more than 65% of their time within 328 ft of the stream and 5% of their time in or immediately next to the stream. Approximately 8.6% of all feces and 7.7% of the total urine production were directly discharged into the stream. Rainfall was so low during the study that no surface runoff was ever observed, and at one point the stream went dry. It is expected that rainfall would have significantly changed water quality in this experiment.

In the piedmont of Georgia, Byers et al. (2005) studied two side-by-side unfenced streams grazed by beef cattle. Pastures surrounding each stream were composed of endophyte-infected fescue and bermudagrass typical of many southern cattle pastures. Each pasture differed in the amount of nonriparian shade present, and both storm and base flow were monitored entering and exiting the pastures. Each pasture involved different watering practices. In some pastures, cattle had access to the stream and a period of access to an off-stream watering trough. In other pastures, cattle had water only from the stream. Cows in each pasture were fitted with GPS (global positioning system) collars to determine animal location constantly throughout the study. Cattle caused increases in TP, dissolved P and *E. coli*, but the level of contamination was less from pastures with both nonriparian shade and access to a water trough.

In a study of three watersheds in northern Utah, Coltharp and Darling (1975) assessed bacterial, chemical, and physical indicators to detect the impact of range grazing, by either cattle or sheep, on water quality. The watersheds grazed by cattle and sheep both had significantly higher total coliform, fecal coliform, and fecal streptococcus counts than did the ungrazed watershed. Mean total coliform counts were elevated to 240 counts ml<sup>-1</sup> (per milliliter) in the watershed grazed by cattle and 103 counts ml<sup>-1</sup> in the sheep-grazed watershed, but counts were just 17.7 counts ml<sup>-1</sup> in the ungrazed watershed. In general, livestock grazing did not significantly affect levels of nitrates and phosphates or physical parameters such as temperature, pH, and turbidity.

Another possible contribution from grazing livestock to surface waters is *Cryptosporidium* oocysts, which have been found in association with wild and domestic animals. Calves consistently shed greater numbers of oocysts than do older animals (Atwill, 1996). By 4 months of age, calves develop a resistance and the number of oocysts shed is dramatically reduced. An alternative to livestock exclusion in areas where *Cryptosporidium* may be a concern is to graze livestock that are older than 4 months in the watershed. In a review of the impacts of domestic grazing on water quality, Buckhouse (2000) reported that further studies on *Cryptosporidium* and pathogenic *E. coli* in livestock under range conditions are needed.

### 3.3 Sediments

Sediment loss is an important concern in grazing situations because it can carry nutrients and pathogens into watercourses and increase turbidity, which creates poor conditions for aquatic life. Sediment export from pastures, however, is generally much lower than that from other agricultural fields. Berg et al. (1988) reported that conventionally tilled fields lost 30 tons a<sup>-1</sup> yr<sup>-1</sup> of sediment, whereas no-till fields lost 1.3 tons a<sup>-1</sup> yr<sup>-1</sup>. Pasture losses were even lower at 0.13 tons a<sup>-1</sup> yr<sup>-1</sup>. Grazing has been shown to impact sediment losses from grasslands, though often not at levels that would threaten water quality. In a paired watershed experiment in the Pacific Northwest, researchers

found that sediment loss averaged over 3 years was 382 kg ha<sup>-1</sup> for the grazed pasture versus only 19 kg ha<sup>-1</sup> from the ungrazed pasture (Jawson et al., 1982). In a 2-year 25-site study, researchers in Oklahoma determined that rangeland had less impact on water quality than land devoted to other uses (Powell et al., 1983). Sediment was the major pollutant from rangeland, primarily from drainage channels.

Time of grazing has been shown to be an important factor in sediment losses. A 20-year study in Ohio showed the importance of seasonal grazing (Owens et al., 1997). For 12 years, a spring-calving herd grazed May through October and received hay during the dormant season. Total sediment losses were 2,259 kg ha<sup>-1</sup>, with 1,442 kg ha<sup>-1</sup> lost during the winter-feeding period and 817 kg ha<sup>-1</sup> lost during the grazing period. Summer-only grazing yielded a total sediment loss of 146 kg ha<sup>-1</sup>, and the ungrazed losses were 13 kg ha<sup>-1</sup>. In another seasonal feeding study in eastern Ohio, 7 times as much sediment was lost to streams in a winter-feeding situation as during summer grazing due to increased runoff (Chichester et al., 1979; Van Keuren et al., 1979). Surface runoff in the summer-grazing pastures was less than in the winter-feeding pastures. There are, however, limitations to concluding cause-and-effect relationships between season of use and sediment loss in most studies because of many confounding factors. These include pasture groundcover and compaction, livestock lounging area occurrence, infiltration rate of soils, and regional climate variability.

Stream fencing is one method to control sediments from livestock. Water quality in a wooded, unfenced stream that flowed through a 26 ha unimproved grazed pasture was monitored for 7 years (Owens et al., 1996). The stream was then fenced and monitored for an additional 5 years, during which sediment concentration decreased by 50%, sediment loss by 40%, and annual soil loss decreased from 2.5 to 1.4 mg ha<sup>-1</sup> yr<sup>-1</sup>, even though precipitation levels were similar during both periods. This sediment reduction was attributed to a reduction in streambank cutting rather than a retardation of sediment from the pasture. Line et al. (2000) found an 82% reduction in total suspended sediment and total sediment after fencing and a riparian buffer were established on a heavily stocked dairy loafing pasture in piedmont North Carolina.

In Idaho, Yankey et al. (1991) found that eroded streambanks in the grazed portion of the watershed were a major source of sediment after sediment from irrigation activities had been controlled through best management practices (BMPs). After BMPs were installed, sediment losses from grazed areas were 2 to 5 times greater than from cropland. A paired watershed study in this same area showed that most sediment loss in grazed pastures was from cattle paths that over time became drainage channels and even small gullies (Fortier et al., 1980). In a three-way paired study conducted in New Zealand, researchers monitored three watersheds for 18 years. All watersheds were pastured for 9 years. Then the riparian areas in two of the three pastures were planted (Smith, 1992). Although peak flow decreased during small rainfall events in the pastures where riparian areas were forested, sediment increased. The researchers believe the decline in water quality was due to the lack of riparian wetlands.

Analyzing the movement of fallout cesium-137 (a fission byproduct of past atomic weapons testing), researchers in Illinois demonstrated that the majority of soil losses were from floodplain soils, not uplands (Wilkin and Hebel, 1982). Under forested vegetation, the floodplain soils became a sink for sediment rather than a source. This is a particularly important consideration with cattle grazing in riparian areas because they can stir the sediments and disrupt the cesium-137 signal.

Alternative water sources can help to reduce the time livestock spend in a riparian area, thus reducing overall impact. Sheffield et al. (1997) demonstrated, although with limited monitoring, that pollutants from cattle using streams as water sources were significantly reduced when alternative water systems were provided. Streambank erosion was reduced by 77%, and total suspended solid concentrations in grab samples were reduced by 54%. In contrast, Line et al. (2000) reported that an alternative watering supply placed in a pasture of young dairy cows did not significantly change sediment export. Cattle access to unfenced streams in Georgia resulted in increased sediments in stream water, while access to off-stream water decreased base flow loads of sediments (Byers et al., 2005). Allowing access to nonriparian shade also reduced storm flow loads of sediments.

The effect of forage groundcover on sediment loss is important. Lang (1979) conducted a groundcover versus runoff study for grazing lands and found that the storm yield was 85% at 0% cover and 30% for 100% cover. The author concluded that if groundcover drops below 75%, bare areas start to connect, which greatly increases sediment loss. A researcher in Australia determined that when groundcover dropped below 70%, the rate of runoff and soil loss changed rapidly (Costin, 1980). These studies were conducted with moderately to heavily grazed (12 to 30 sheep ha<sup>-1</sup>) canarygrass (*Phalaris* spp.) and subterranean clover (*Trifolium subterraneum*) pasture. Sediment losses for both native and improved pasture were composed of suspended sediments.

The amount of pasture vegetation significantly affected runoff and soil erosion in a study conducted in Pakistan under both dry and wet conditions (Bari et al., 1995). During the 2-year study, erosion increased when vegetative cover decreased by varying amounts. When vegetative cover was approximately 50% of nongrazed conditions, sediment concentration was 1.5 times greater. When vegetative cover was 35% of nongrazed conditions, erosion was 2 times greater. And when vegetative cover was 22%, erosion was 2.5 times greater. In New York, researchers found that soil loss from a lightly grazed, fertilized pasture was 26 lb a<sup>-1</sup>, compared to 163 lb a<sup>-1</sup> for a heavily grazed, nonfertilized pasture and 67 lb a<sup>-1</sup> for a heavily grazed, fertilized pasture (Johnstone-Wallace et al., 1942).

In North Dakota, Hofmann et al. (1983) found that totally covered (or totally bare) areas were better predictors of soil erosion and runoff losses than live surface cover (Table 4).

Ethiopian researchers (Mwendera and Saleem, 1997) found that erosion and runoff increased as grazing rates and slope increased under heavy grazing of 3.0 animal-unit months (AUM) ha<sup>-1</sup> and very heavy grazing (4.2 AUM ha<sup>-1</sup>), indicating the need for slope-specific recommendations for grazing rates. They suggested that the critical level of groundcover is 75% on plots with a 0 to 4% slope and 85% on plots with a 5 to 8% slope.

In a study evaluating runoff from manured riparian plots under simulated rainfall (Butler, 2004; Butler et al., 2007), researchers compared different levels of groundcover and a bare, compacted simulated loafing area. Canopy cover for the low-, medium- and high-cover treatments were 72, 79, and 92%, respectively, while the loafing area had 0% canopy cover. Total runoff from each of the three vegetated plots was similar, but runoff was threefold higher for the bare area. Nutrient runoff data were similar to the total water runoff data, with few differences between the

**Table 4. Soil loss, soil runoff, and cover on grazed, reclaimed, and native pastures**

Treatment	Soil loss (kg ha <sup>-1</sup> )	Runoff (mm)	Cover (%)
Reclaimed, ungrazed	18	2.8	97
Reclaimed, lightly grazed	64	8.4	94
Reclaimed, moderately grazed	155	13.7	72
Reclaimed, heavily grazed	1,054	23.1	54
Reclaimed, burned	2,170	18.5	6
Native, ungrazed	8	1.0	95
Native, closely grazed	28	3.3	94
Burned	1,022	14.2	18

Source: Adapted from Hofmann et al. (1983)

groundcover treatments but dramatically higher values for the bare areas. This supports earlier reports that around 75% groundcover is critical to prevent high losses of nutrients and sediments in runoff, and that much of the impact during runoff events in riparian areas is from the bare compacted areas where cattle lounge and enter and exit a stream.

An infiltration and erosion study was conducted in Kenya (Mbakaya et al., 1988). The area receives 560 cm yr<sup>-1</sup> of rainfall in a bimodal distribution. Study treatments included moderate continuous grazing, high-intensity/low-frequency grazing, rotational grazing, and exclusion of sheep and cattle. The stocking rate was 17 cows and 20 goats on 37.3 ha for all three grazing treatments. The high-intensity/low-frequency treatment divided into 16 equally sized pastures, and the rotational grazing treatment divided into 3 equally sized pastures. Researchers reported a decrease in infiltration and an increase in erosion with all the grazing treatments. After a rest period, both sediment losses and infiltration rates were similar for all treatments except continuous grazing. The researchers noted that their results do not support the idea that short-term, intensive grazing causes better hydrological functioning of the soils. Rather, rest periods allow soils to recover from the livestock compaction. These researchers also suggested that the ratio of grazing time to rest time is important. Rest periods equal to or greater than grazing periods allow soils to recover from compaction, while shorter rest periods may not.

Alderfer and Robinson (1947) conducted a thorough study of grazing intensity, soil compaction, and runoff in Pennsylvania. They reported a relationship between grazing intensity and runoff. Runoff from heavily grazed pastures was 50 to 80% of the total rainfall applied, whereas moderately to lightly grazed pastures had runoff losses of 1 to 50% and ungrazed pastures just 0 to 2%. In Texas on a silty clay soil, Warren et al. (1986a; 1986b) examined the effect of grazing intensity and soil compaction separate from the effects of vegetation removal through increased grazing. Infiltration rates declined and sediment production increased under high trampling intensities (4.1 and 2.7 ha AU<sup>-1</sup>). The researchers also demonstrated greater bulk densities when soils were trampled wet (~25% moisture content) rather than dry (~5% moisture content) and increased bulk densities as stocking rates increased.

Researchers in New Mexico studied the effects of short-duration and continuous grazing on sediment losses from two watersheds (Weltz and Wood, 1986). Short-duration (3 to 4 days) grazing had the highest sediment losses, followed by heavy continuous, then moderate continuous grazing. Pastures where cattle were excluded had the lowest sediment losses (Table 5).

**Table 5. Sediment losses on two watersheds under varying grazing treatments**

Grazing System	Stocking Rate	Watershed 1	Watershed 2
		Total Suspended Sediment Production (kg ha-1)	
Exclusion	0	90	20
Moderate Continuous	18 ha AU-1	300	100
Heavy Continuous	13.5 ha AU-1	320	—
Grazed Short Duration	14 ha AU-1	580	300

Source: Adapted from Weltz and Wood (1986)

A 2-year grazing-area and watershed study in the central Blue Mountains of eastern Oregon found little impact of grazing animals on soil compaction, erosion, and streambank cutting (Buckhouse et al., 1981). The authors noted, however, that the study’s duration was too short to allow firm conclusions. More applicable to heavily grazed conditions than others, a California fact sheet on soil compaction and grazing listed multiple studies that demonstrated increased bulk density and runoff in grazing areas (George and Menke, 1994). In Arizona, runoff and erosion were significantly greater when rangeland was burned than when it was not (Emmerich and Cox 1994). Paired plots in this experiment showed consistently greater runoff and sediment losses, especially when plots were burned in consecutive years.

In a literature review of the impact of cattle grazing on water quality, Clark (1996) concluded that grazing situations are highly complex and it is difficult to judge the impact of cattle grazing versus other pollutant sources. Evidence suggested that cattle grazing generally had low nutrient pollution impact, although in some cases nutrient loading was significant. However, fecal coliform and sediment were more problematic pollutants.

### 3.4 Channel morphology and aquatic habitat

Several studies have shown that unrestricted livestock access can affect channel morphology. Clifton (1989) studied a stream where the vegetation had been denuded. After cattle were excluded from the stream, vegetation returned and the channel narrowed and deepened, becoming more like ungrazed areas. Similarly, in New Mexico, Sowards and Valett (1996) reported that streams where livestock were excluded had greater benthic biomass and transient hydraulic storage than streams to which livestock had access.

In a paired watershed study from Pennsylvania, Wohl and Carline (1996) demonstrated the impacts on streams from cattle grazing in the riparian area. The ungrazed stream had substantially greater substrate permeability (less silt) than the two streams

with extensive grazing. In addition, fish populations were 5 to 22 times greater and benthic macroinvertebrate population densities were 2 to 4 times higher in the nongrazed stream. In a subsequent study, these researchers implemented streambank fencing, bank stabilization, and installation of rock-lined ramps on the streambanks that allowed cattle to cross (Carline and Spotts, 1998). In one of the streams, the median total solids declined by ~50% and density of macroinvertebrates increased by 70%. In the other stream, macroinvertebrate density increased by 150%. Habitat increases in both streams were attributed to the sediment load reductions.

A three-way paired watershed experiment was conducted in the central Nevada mountains to determine the effects of cattle and roads on stream health as measured by streambank soil stability, vegetation type and amount, and quality of pools (Myers and Swanson, 1995). Initial surveys demonstrated the three streams to have similar conditions prior to establishment of different treatments for a 7-year period. Cattle were removed from one watershed (Marysville), whereas the other two watersheds (San Juan and Washington) were placed under deferred grazing conditions where the cattle grazed alternating watersheds. Between 300 and 430 cow-calf pairs started grazing on one watershed in mid-June and rotated to the other in August. Roads cross the stream in the San Juan watershed. The Marysville stream had the least embeddedness (percent of gravel in channel surrounded by finer material) with a value of 8, whereas the San Juan stream had the highest embeddedness value of 18. Streambank damage due to cattle was least on the Marysville stream. Measurement of stream parameters demonstrated that the Marysville stream was in the best condition and the San Juan was in the poorest. Although deferred grazing helped improve stream quality and habitat conditions (such as pool quality, gravel-cobble percent, and bank stability) in the Marysville and San Juan watersheds, cattle removal in the Marysville watershed produced the greatest improvements in stream health. Roads in the San Juan watershed contributed to poorer stream conditions than in the Washington watershed.

### **3.5 Conclusion**

The effects of livestock pastures on the water quality of streams draining them are highly variable, depending both on livestock management and stream characteristics. From this review of the literature, unlimited heavy grazing tends to have the greatest impact on sediment, stream habitat, and fecal coliform. Livestock exclusion, alternative water supply, and intermittent resting tend to reduce the impact to varying degrees. Nutrient delivery from moderate grazing tended to be low although greater than from nongrazing situations.

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## 4. Grazing management

### 4.1 Definition of riparian as it is related to grazing

Riparian areas or zones are generally considered to be transition areas between aquatic and upland environments lacking in definitive boundaries (Lowrance et al. 1985). Relating this definition to grazing can be arbitrary. An alternative definition is given by Heady and Child (1994), who suggest this guideline: Soil characteristics and vegetation that either require or tolerate standing water for at least part of the year indicate a riparian area. Most scientists, however, use the Lowrance definition when describing riparian areas.

### 4.2 Definition of grazing management

Grazing management has been defined as “the manipulation of animal grazing in pursuit of a defined objective” (Allen, 1991). The defined objective on most farms and ranches is to provide an economical source of feed for livestock while maintaining stands of forage for many years. Maintaining and properly utilizing persistent stands of forage minimizes the cost of livestock production while minimizing soil erosion and movement of nutrients from surface-applied fertilizer and manure. This level of forage stand management also increases water infiltration and decreases the impact of short-term droughts.

Grazing management involves the complex manipulation of animals, plants, soils, and environmental conditions (Allen, 1991). The impact of grazing on riparian or upland areas will primarily depend on the grazing season, grazing period duration, and days of rest between grazing periods; the type and density of animals being grazed; the soil moisture conditions at time of grazing; the forage morphology and life cycle; and forage density, mass, and height.

The pasture or grazing management unit is the land area used to grow forage for supporting a group of grazing animals for a period of time. It may be a single enclosed area, or it may be divided into several paddocks or pastures (Allen, 1991). The riparian areas within a grazing unit (farm) may or may not be managed separately from adjacent landscapes. Due to landscape position, riparian areas generally produce more forage or browse than adjacent land areas, thereby requiring different use patterns than adjacent upland fields.

### 4.3 Grazing terminology

*Continuous stocking* refers to situations where grazing livestock are given “unrestricted and uninterrupted” access to the unit of land during the grazing period (Allen, 1991). To understand what is occurring on a specific site, one has to recognize the length of the grazing period. *Set stocking* is a method of continuous grazing, but it infers a “fixed number of animals on a fixed area of land” during a grazing period (Allen, 1991). Quite a different practice is *rotational stocking*, which involves utilizing “recurring periods of grazing and rest among two or more paddocks in a grazing management unit” throughout the grazing period (Allen, 1991).

*Stocking rate* is “the relationship between the number of animals and the grazing management unit utilized over a specified time period” (Allen, 1991). It is usually described as the number of AU a<sup>-1</sup> or ha<sup>-1</sup> for the year or season. Proper stocking rates for a farm will be based on the nutrient needs of the animals and the management level needed to maintain persistent stands for protecting soil and water resources. The level of grazing management will strongly influence stocking rates on farms with similar forage, soils, fertilization practices, and environmental resources. Several researchers have researched stocking rates for which observations and responses of grazing lands have been reported. However, few data have been cited that actually compared stocking rates to riparian area observations and responses (Clary and Booth, 1993; Mwendera and Saleem, 1997).

*Stocking density* is “the relationship between the number of animals and area of land at any instant of time” (Allen, 1991). Stocking density, length of graze period, and length of rest period are three aspects of grazing management that can be manipulated to control the amount of forage or plant use, forage regrowth rates, and soil cover. Thus, they are extremely important to proper riparian grazing management.

When livestock graze, they feed on growing herbage throughout the day. Grazing can involve *browsing*, which describes feeding on the tender shoots of trees and shrubs rather than *foraging* on grass and other groundcovers. *Spot grazing* occurs when animals have more forage than is needed and therefore primarily graze areas where high-quality herbage grows with very palatable young, green, leafy growth. *Ruminating* describes chewing of previously swallowed herbage for an extended period.

Other activities occur before and after grazing. *Loitering*, *lounging* and *loafing* describe lazy movement with aimless, idle stops and pauses. *Resting* indicates the cessation of all movement and time spent lying down to sleep. *Sloughing* occurs when animals plod through an area in or near the stream, as though plodding through mud.

#### 4.4 Characteristics of livestock species that potentially impact riparian use

##### 4.4.1 Vegetation preferences and grazing patterns

The grazing behaviors among livestock species differ considerably, and grazing effects on the growing plant can also differ. Because some of the more useful forages store reserve energy in organs above the ground, the grazing characteristics of specific animals can influence plant survival following various defoliation intensities. For the most part, animals do not prefer to bite plants off at the soil surface. But when feed availability is limited, they may graze the plants so close to the soil surface that reserve energy storage is consumed. If sufficient rest time for the plant to replenish reserve energy and leaf area is not provided between defoliations, the plant cannot maintain its vitality. Each successive defoliation increasingly weakens the plant. Under such grazing practices, animals cannot meet their daily nutrient requirement because of limited intake. The plant is being sacrificed to provide very limited feed supply, and the animal is not performing because of underfeeding. If the top growth of a plant is continually defoliated, the root system weakens, thus contributing to less stable soil conditions and potentially subjecting the site to greater surface soil erosion and nutrient movement.

Substantial differences have been observed in how animals graze and how close to the soil they can bite plants. Dietary profiles compiled from world literature sources by

Van Dyne et al. (1980) also suggest differences in vegetation preference among species (Table 6).

**Table 6. Summary of average dietary botanical composition for all seasons**

Species	Diet		
	Grass	Forb	Shrub
Cattle	72%	15%	13%
Horses	69%	15%	16%
Sheep	50%	30%	20%
Goats	29%	12%	59%
Red deer	40%	21%	39%

Source: Adapted from Van Dyne et al. (1980)

The data indicate that cattle and horses prefer grasses, whereas goats prefer shrub vegetation. Sheep and red deer seem to have a more diverse diet; the data do not indicate that they prefer any particular category of vegetation. Gordon (1989) suggests that animal mouth size and shape regulate their ability to graze selectively.

#### 4.4.1.1 Cattle

Cattle can graze herbaceous plants to within 2 cm of soil surface, but they generally do so only when feed availability is limited. Cattle will browse on young woody species and forbs that are found in riparian areas, but if forage supply is adequate on upland sites the severity of defoliation can be controlled. Cattle will “spot graze” certain areas within a pasture, which is an indication that animals have access to more forage than is needed. Plants in those spots will eventually weaken and not produce to their potential because of low leaf area and low reserve energy storage. Botanical composition will likely shift to species most tolerant of short, frequent defoliation, such as bermudagrass (*Cynodon dactylon* (L.) Pers.), crabgrass (*Digitaria sanguinalis* (L.) Scop.), Kentucky bluegrass (*Poa pratensis* L.), endophyte-infected tall fescue, or white clover (*Trifolium repens* L.).

#### 4.4.1.2 Horses

Horses can bite plants at the ground surface, which is extremely damaging to plants that store reserve energy in the stem base. Horses tend to spot-graze herbaceous vegetation regardless of frequency of movement. Because they do bite plants near the soil surface, almost regardless of the amount of forage offered, it is very important that rotations allow sufficient rest between grazing periods to allow the plants to fully recover with several inches of regrowth.

#### 4.4.1.3 Sheep

Sheep choose very specific plant parts because of their lip and teeth arrangement. Sheep will bite the leaves from the stems or bite the entire tiller off near the soil surface, even in situations where the grass may be at an ideal height for cattle to graze easily. If they remain on an area until forage supply becomes limited, sheep may bite all plants off to ¼-inch stubble. Such grazing will make a significant impact on a plant’s reserve energy storage and regrowth rates. Plants that store reserve energy underground or that have lots of leaves near the soil surface will have the best survival in sheep pastures.

Sheep are easier to control than cattle and can be less damaging to riparian ecosystems. The habitat preferences of sheep result in less damage to riparian areas because they tend to prefer hills more than cattle do (Heady and Child, 1994). Heady and Child suggested that grazing management of riparian zones depends upon a combination of strategies: fencing to improve grazing distribution on upland and riparian zones and rotational grazing to adjust for seasonal changes in use. Riparian sites can be restored without eliminating grazing, yet reducing the stocking rate alone is seldom effective. A grazing system for a riparian site usually requires several practices: the creation of one or more additional pastures by fencing, development of off-stream livestock water, removal of upland brush, and seeding of areas alongside the stream. Together these practices led to improved overall management. Like all grazing management systems, they must be designed for the site, flexible to meet climatic and operating variables, and monitored for evaluation of success. Repair of small riparian areas usually requires increasing vegetation cover on the watershed, channel structures, or both.

#### 4.4.1.4 Goats

Goats prefer to graze with their heads above their knees. If supplies of both browse and pasture are available, they may select a diet that is more than 50% browse. They will graze close to the ground when the feed supply is severely limited. Goats can be the most selective in what plant parts they eat. They will eat seed stalks, heads, and other plant parts that cattle, sheep, or horses do not readily eat. Likewise, they will eat plant species that cattle, sheep, or horses do not readily eat. Goats tend to graze a canopy from the top down in a fairly uniform manner. They do not spot graze as much as other animals.

Small ruminants naturally select diets of higher quality than large ruminants. In addition, the efficiency with which small versus large ruminants ingest different plant parts and life forms may not be the same. Therefore, if given limited access to a riparian area, small ruminants such as goats are not as likely to overgraze because they will select the most nutritious plant parts. Goats can also act as a biological control for such species as kudzu (*Pueria lobata*), greenbrier (*Smilax bona-nox*), multiflora rose (*Rosa multiflora* Thunb.), brambles (*Rubus* spp.), honeysuckle (*Lonicera japonica*), and hardwood seedlings (Luginbuhl et al., 1996).

#### 4.4.2 Riparian usage habits

Ample evidence from documented reports and frequent observations indicates that animals with unrestricted access to streams make impacts on watercourses that lead to pollution (Doran et al. 1981; Kauffman et al., 1983). Grazing in a pasture located near a stream can lead to cover destruction and trampling of banks. This provides sediment, associated nutrients, and bacteria with a direct route to the stream. Depending on stream morphology, livestock with direct access to a stream channel can disturb the channel bottom sediment, increasing downstream sedimentation and turbidity, smothering stream bottom life, and increasing the frequency of cleanout. Uncontrolled access is often associated with defecation and urination into streams, which can reduce dissolved oxygen levels and impair fish habitat (Doran et al., 1981).

Belsky et al. (1999) found that nearly all scientific studies record that livestock have no benefit to stream and riparian communities, water quality, or hydrology functions. However, the authors report that findings of many of these studies actually suggested that riparian damage can be reduced by improving grazing methods, herding or fencing livestock away from streams, reducing livestock numbers, or increasing the period of rest from grazing. Attention to past and potential adverse effects of herbivores on native plant communities has tended to overshadow the positive influences of pre-

scribed grazing on forage and environmental resources. Walker (1995) described dual objectives of public land grazing: (1) environmental enhancement and (2) continuation of livestock grazing. They are not mutually exclusive.

In Montana, Davis and Marlow (1990) studied two groups of cattle managed with different grazing methods to determine the effect on grazing behavior and its influence on the time livestock spent in the riparian area. One group—the set stocked group—consisted of 4 cow-calf pairs on a 3-acre pasture for 18 days. A second group—the rotated group—consisted of 11 cow-calf pairs and 1 bull on a “time-controlled system” that involved rotation every 2 to 3 days among eight 1.5-acre pastures. The rotated group was removed from a pasture when 40% of its riparian zone forage was grazed. Both groups spent about the same amount of time (45%) grazing in the riparian area or adjacent to it. However, the set stocked group spent 30% of its time ruminating in the riparian area, whereas the rotationally stocked group spent only 12% of its time ruminating in the riparian area. Ruminating time in the riparian area could have a significant impact on the amount of excreta deposited there. The rotated group also spent more time grazing in the upland and middle uplands areas than the set stocked group.

Livestock ranging and confinement patterns are important in determining defecation placement. There are at least three main factors determining grazing, lounging, and resting patterns: (1) vegetation quality and quantity, (2) location of watering area, and (3) type of grazing system (Heady and Child, 1994).

Some studies have shown the great impact that cattle can have on surface water quality and riparian vegetation. Johnson (1952) conducted a 10-year forest grazing study in western North Carolina at the Coweeta Hydrologic Laboratories. Under grazed conditions, Johnson noted a decline in native trees, an increase in certain plants (such as azaleas), an increase in bare areas, an increase in maximum peak discharge, and a decrease in stream water quality over the 10-year project.

Working in Colorado, Senft et al. (1985) found that favored lounging sites in summer were low-lying areas, fence lines, and areas near water. In colder months, south-facing slopes and lowland areas were favored. In Ontario, Duncan et al. (1998) reported results from 52 site-days of cattle herd observations at eight different cow-calf operations. The researchers found that beef cattle spent very little of their time during the day in the water: an average of 6 minutes (min) for cows 4 min for calves). The risk of in-stream voiding during this time was typically less than 5% of the time. The study offered reliable data about the direct impact cattle could have when given unrestricted access to waterways.

The use of riparian areas during the summer months by cattle will also vary significantly depending on tall fescue infection by the fungus endophyte *Neotyphodium coenophialum*. One of the symptoms of endophyte toxicity is an elevated body temperature and high respiration rates in affected animals (Bacon et al., 1986). These symptoms routinely result in cattle seeking shade and open water to stand in as a means of cooling. It has been noted that cattle grazing endophyte-infected tall fescue and suffering from the effects of fescue toxicosis have been observed to wallow in mud or stand in ponds or creeks, especially during hot portions of the day (Boman et al., 1973). In this scenario, exclusion of cattle from surface waters could have a possible negative effect on animal performance (Crawford and Cole, 1999), although no research has been published that demonstrates such a benefit from surface water access.

Even though all animals grazing infected fescue will seek shade, only cattle seek to stand in open water. Goats will lounge and cavort on streambanks or stream edges, but they do not like to get their feet wet. Goats also avoid areas where the soil is saturated. Therefore, they are not likely to overuse a riparian area during winter or wet seasons unless their forage supply is limited in the adjacent grazing areas.

Stream crossings are another important aspect of riparian usage. Clark (1996) reported observations made on a farm containing several hundred meters of unfenced stream in a pasture used by 30 cow-calf pairs and a bull. Visual inspection of the entire length of the accessible creek revealed that animals entered and crossed at only three sites along the stream, making the area of actual impact along the stream well under 1% of the total length of potential impact. The chosen points appeared to be relatively narrow and shallow, with footing that appeared somewhat more solid than elsewhere in the creek. This gives some indication that entry points into streams and crossings with solid footings will be used more frequently by animals than soft or muddy entries, which can reduce impact on streambank and water quality in two ways: (1) Entry at only selected areas would decrease the area of potential impact. (2) Entry via areas with solid footing would be less likely to make an impact on the streambank and water quality than entry via soft or muddy areas.

#### 4.4.3 Feces and urine production and distribution patterns

Distribution of feces and urine is an important component of the impact of grazing on surface waters. Peterson and Gerrish (1996) examined excretal distribution by livestock in pasture settings. They reported that excreta were not uniformly distributed throughout the pasture, rather it was deposited in the greatest concentrations near water, shade, and along fences. Similarly, Petersen et al. (1956) reported that over time, the proportion of pasture not covered by manure was still rather high because of uneven distribution. Gburek (2005) found that 13% of manure from pastured cows was deposited in the stream and 46% within 40 m of the stream.

In an observation of hundreds of free-ranging cattle in central Oregon, Larsen et al. (1989) estimated the number of defecations in a stream during different seasons. On average, each animal on a daily basis spent time in the stream as follows: 11.2 min in summer, 2.7 min in fall, 6.0 min in winter, and 4.3 min in spring. The daily average number of defecations for individual cattle in the stream was 0.17 for winter and spring, 0.19 for fall, and 0.41 for summer. The researchers also observed cattle in a feedlot during March with a stream nearby as the only water source and reported the average time for each individual animal in the stream was 3.9 min per day. They proposed that the number of defecations in the stream were higher for the feedlot cattle than the free-ranging cattle in March because the feedlot cattle were fed much closer to the water source. The feedlot cattle lounged in the stream for longer periods than the free-ranging cattle. This scenario resembles most small operations because the animals are on limited pasture and receive supplementary feed in the winter.

In a laboratory runoff study using Kentucky bluegrass sod, Larsen et al. (1994) found that the number of bacteria was reduced by 95% if the distance between sample collection points and applied feces was at least 1.35 m. This has important implications for the distance at which manure deposited near streams could have a significant impact on surface water quality. They also reported a significant reduction in amounts of fecal coliform bacteria found 2.13 m away from manure that was deposited on sand versus plastic-covered soil, which simulated the lower infiltration of frozen soils. This suggests that when infiltration rates are high, the hazard of elevated fecal coliform concentrations decreases. The researchers further suggest that when natural occur-

rences of rains and runoff continue, runoff channels develop and more water runs around the manure pile than through it. Therefore, the number of bacteria entering runoff may decrease as rain events continue.

#### 4.4.4 Learned behavior and training

Most domestic animals learn to come or follow when a vehicle with feed approaches. Animals can also learn to avoid or return to certain places. Provenza and Balph (1987a) reported that cattle learn and remember where they have foraged and whether the forage resources warrant a return visit. The researchers examined the applicability of five diet-selection models to various foraging challenges that ruminants encounter. Early life experiences enable herbivores to develop preferences and aversions to certain plants and to develop the motor skills, within evolutionary constraints, necessary to use preferred forages efficiently. As such, the foraging experiences of young grazing animals likely influence their foraging and dietary habits as adults. The ability of livestock to learn dietary habits early in life presents both problems and opportunities for managers. Diet training may enable managers to create a foraging group more suited to management goals. In a separate publication, Provenza and Balph (1987b) suggested that insight into ruminants' learning through gastronomic consequences could have great potential for grazing management. They postulated that young livestock could be trained to use upland vegetation rather than vegetation from riparian and other sensitive areas.

According to Roath and Krueger (1982) and Hunter and Milner (1963), ruminants often form specific attachments to environments in which they know the kinds and locations of food, water, shelter, and predators, and their preferences are often transferred culturally from one generation to the next. Often ruminants introduced into a new environment are less productive than those reared in the specific environment. This may be related to food selectivity; previous grazing experience influences the selectivity of foods. Arnold (1964) compared sheep reared on range versus pasture for forage preferences after a 3-week pen-feeding period for stabilization of rumen organisms. The sheep reared on irrigated pasture ranked alfalfa first in preference, but those raised on rangeland selected their previous diets.

Several researchers concur that this information could be useful at controlling riparian area damage. Skovlin (1957) reported that cattle can be trained to use certain areas and will repeat the use in subsequent years. For those cattle not responding to training, Howery et al. (1996) reported that selective culling changed cattle distribution and decreased the use of riparian areas in Idaho.

#### 4.4.5 Response to weather factors, soil characteristics, and landscape

Vegetation type, soils, topography, and climate influence the distribution of grazing animals. Different livestock species often have different innate reactions to these factors. Grazing animals often distribute unevenly on the pasture or range resource, and an irregular pattern of use results (Heady and Child, 1994).

Much research has shown that cattle prefer grazing areas with lower slopes, and this has important implications for riparian grazing. Cook (1966) reported that cattle normally graze heavily on valley bottoms and more level land near water before moving on to rougher terrain. According to Ganskopp and Vavra (1987), cattle and horses both generally avoid grazing on slopes greater than 20%, whereas deer and bighorn sheep differentiate much less on slopes up to 50%. In Utah, slopes between 30 to 40% had greater use by mule deer, elk readily used slopes to 30%, but cattle use was greatest on slopes of less than 10% (Julander and Jeffery, 1964). Gillen et al. (1984) reported preference indices for slope gradient classes during three grazing periods as

determined by direct cattle observations on mountain rangeland in northeastern Oregon and found that cattle made very little use of slopes over 10%.

Percent slope and distance of slope from water were reported by Mueggler (1965) as accounting for 81% of the variation in use of a given slope for foraging. Working in the Blue Mountains in Oregon, Bryant (1982) reported that alternative water sources were not used if separated from riparian zones by steep slopes, but those sources were some significant distance (greater than 1 km as estimated from the site map) and at a higher elevation than the riparian zone being monitored. Bryant also noted that humidity influenced cattle distribution more so than temperature. Cattle tended to prefer a relative mean humidity in the range of 60 to 70% and used the riparian zone more during conditions of high temperature and low humidity in the uplands, but moved upslope of the riparian area when humidity increased from an ideal range. Cattle also preferred areas of the pasture with slopes less than 35%. Also working in Oregon, Dickard et al. (1998) reported more time spent (55 to 85% of observations) in riparian areas in the afternoon than in the morning during periods when daily high temperatures reached the 85 to 100°F range.

## 4.5 Practices that impact riparian zone use by livestock

### 4.5.1 Grazing intensity

Reviews by Heitschmidt (1990) and Matches (1992) have pointed out that in mesic grazing lands, plant communities may produce more herbage as a result of some degree of defoliation, whereas plant communities in arid situations may produce less herbage as a result of almost any amount of defoliation. In his study of livestock in a mountain meadow with annual precipitation ranging from 18 to 39 cm, Clary (1995) reported that defoliation of redbud (*Agrostis stolonifera* L.) at a vegetative and mature stage of growth to 5 cm once or twice per year and associated trampling damage and nutrient return had little effect on biomass production. But such defoliation did reduce the biomass production of communities dominated by sedge (*Carex* spp.). A single defoliation of the sedge communities to 10 cm did not reduce biomass. The “recommended residual stubble height of herbaceous forage” for riparian areas, suggested by the majority of land management agencies, indicates defoliation to 10 to 15 cm. If streams are important to endangered fish species, then stubble height can be managed at 10 to 20 cm (Clary 1990).

Buckhouse et al. (1981) reported no significant increase in streambank erosion when areas with various managed grazing patterns were compared to ungrazed areas. There were wide-ranging variances among treatment areas, but those differences may be attributed to other factors: (1) Streambanks respond differently to perturbations; (2) some lengths of a stream are more susceptible to disturbance than others; and (3) the duration, intensity, and time of year of the perturbation could also be variance indicators.

Packer (1963) maintained that winter grazing by elk reduced plant cover and increased soil bulk density on winter range areas north of Yellowstone National Park. He suggested a minimum groundcover of 70% and maximum bulk density of 1.04 grams cm<sup>-1</sup>, with soil erosion increasing rapidly outside these guidelines. In a compaction study on mixed prairie and fescue grasslands in Alberta, Naeth et al. (1990) reported that heavy-intensity grazing had a greater impact on compaction than light-intensity grazing. Early season grazing was also implicated as having a greater impact on compaction than late season grazing.

**4.5.2 Seasonal use** Riparian zones generally represent a small percentage of the land area within a pasture; however, they may be the most productive zones and can be the location where animals spend a disproportionate amount of time, especially during hot, dry times of the year. In a southwestern Montana study, Marlow and Pogacnik (1986) reported that cattle spent up to 80% of their time in upland sites during the early grazing season. As plants matured, however, and temperatures increased, they spent up to 60% of their time in the riparian areas. Animals obtained nearly 80% of their forage from riparian areas in the late grazing season. To correct or limit this situation, the length of the grazing period can be based on the areas cattle are actually using and not the entire pasture.

Clary and Booth (1993) concluded that spring grazings could be favored in many areas because cattle are less likely to concentrate along streams and wet bottoms during that season. They studied cattle grazing during June in the mountains of central Idaho. The researchers reported that as stocking rates increased from light (1.19 AUM ha<sup>-1</sup>) to medium (2.08 AUM ha<sup>-1</sup>), cattle tended to concentrate most additional use on drier uplands while only slightly increasing use of riparian sites. In an early summer grazing study in Oregon, Roath and Krueger (1982) observed that 81% of the forage removed by livestock on a mountain allotment came from the riparian zone. The area of the riparian zone comprised just 1.9% of the total area and produced ~21% of available forage. The combination of green forage, shade, and drinking water often associated with riparian habitat increases the attraction to grazing animals, especially on hot rangelands during drier periods of the grazing season.

The season of use is also important when considering bank and channel damage. Marlow and Pogacnik (1985) reported the highest level of channel damage in a sequential grazing experiment during late June and early July when cattle use of the riparian zone was relatively low (~20 to 30% of time) compared to later in the season when the soil moisture content of the banks was 18 to 25%. By early August, soil moisture had declined to 8 to 10% and bank damage did not exceed natural changes though riparian usage by the cattle was much higher.

### 4.5.3 Alternative water sources

Offering off-stream water sources to animals can reduce the amount of time spent drinking from streams, without fencing off the stream (Godwin and Miner 1996). In their study in Oregon, four cows with access to water solely at a stream spent an average of 60 min day<sup>-1</sup> at the stream. However, when provided with a watering at a tank 75 ft. away from the stream in a 3-acre pasture, they spent only 15 min day<sup>-1</sup> at the stream, a 75% reduction in the amount of time spent at the stream.

Goodwin and Miner (1996) also monitored two horses grazing a fenced 3-acre pasture (s 1.5-acre wet site and s 1.5-acre dry site) with access to a creek. Providing a pasture pump located 175 ft from the stream and with no stream access, the amount of stream water used was reduced by 17 to 53%, depending on whether the pasture site was dry or wet. This indicates that on dry pasture, a pasture pump can greatly reduce the amount of water horses take from a stream. On wet pasture, horses may not be taking any more water from the stream but obtaining more of their water from the pasture.

In an alternative water source study, Miner et al. (1992) monitored drinking and lounging habits of cattle on a winter-feeding site with a stream traversing the area. The stock density of the paddock containing the water tank about 300 ft upslope of the stream was about 20 heifers a<sup>-1</sup> (50 head on a 2-acre paddock). Animals with stream-

only access to drinking water spent 25 min day<sup>-1</sup> in the stream, whereas those animals with access to a tank spent 1.5 min in the stream and 12 min at the tank. The tank was more than 99% effective at attracting the animals during periods when thirst was the driving factor of behavior. At other times, the tank effectively competed with the stream as a lounging area more than 80% of the time. The authors suggested that the tank's 2° to 14°F warmer water temperature and ease of access as compared to the steep and muddy streamside explained at least part of the cattle's preference for drinking from the tank.

In southwestern Virginia, Sheffield et al. (1997) studied the potential for off-stream water sources to improve water quality and prevent streambank damage. After BMP installation of water tanks near an off-stream water source, an 89% reduction in time (6.7 to 0.7 min.) spent by each animal drinking from the stream was reported. In addition, researchers reported that the amount of time spent within 4.6 m of the stream was reduced by ~75% if forage available in the pasture was adequate for herd demands. However, when cattle were put into a paddock that had been harvested for hay on the day before, there was no reduction in time spent in the stream area. On a farm site with a stock density of 200 cows and 170 calves on 136 ha, a 77% reduction in streambank loss due to sloughing by cattle was reported. This was likely part of the reason for an 89% reduction in the "flow-weighted" concentration of total suspended solids at the watershed outlet.

In Georgia, Byers et al. (2005) used GPS collars to track cattle movement in unfenced pastures with and without off-stream water troughs. Availability of a water trough decreased the time cattle spent in the stream area in a pasture with little nonriparian shade, but had no influence on the time cattle spent in the stream in a pasture with a significant amount of shade outside of the riparian area. This study demonstrates that off-stream water and off-stream shade work together to alter cattle activity in the stream area and that both should be considered when BMPs are installed in attempts to redistribute cattle activity on the landscape.

In another Oregon study, Clawson et al. (1993) reported that cattle preferred to use water tanks rather than streams or springs as sources of water. Daily stream or spring use per cow was reduced from ~5 min before installation of a trough to ~1 min after installation. Each cow used a stream or spring in a "bottom area" about 8 min day<sup>-1</sup> before trough installation, and only ~4 min day<sup>-1</sup> afterwards. Cattle preferred to drink from the watering trough, watering 73% of the time at the trough, compared to 24% at the "bottom area" and 3% at the stream. However, the tank size limited the number of animals that could drink at once. Therefore, some animals moved to the bottom or stream because of competition for water during the peak gathering periods.

Data from a second experiment (Clawson et al. 1993) showed that cattle tended to trail to the watering site around noon and spend the afternoon loafing in shaded areas close to water. Loafing accounted for 91% of the time each cow spent in the riparian area, an average of 47 min day<sup>-1</sup> of loafing. With many implications for water quality, 60% of loafing time was spent at the stream. However, cattle mainly used the area for watering rather than loafing during the morning and evening. To reduce time spent loitering near the stream, the researchers experimented with providing restrictions to the animals' access to the stream by providing narrow access areas across the stream. The researchers reported that no defecations from the 124 cows landed directly in the water during a 6-day observation period in May when stream access was restricted.

The distance livestock must travel to reach water can significantly impact animal performance. Sneva et al. (1973) researched the effect of water restriction and trailing distance to water on cattle performance. When cattle did not have to walk to water, weight gains were improved by 6 to 25% for calves and 22 to 41% for yearling cattle (Table 7). This can have important implications for encouraging farmers to adopt certain BMPs.

**Table 7. Change in average daily gain (lb/day) with elimination of trailing to water**

<b>May 20 - August 17, 1970</b>	<b>Trailing (1 mile)</b>	<b>No trailing (water nearby)</b>	<b>Difference (lb)</b>	<b>Difference (%)</b>
Cows	1.11	1.32	0.21	18.9
Calves	1.68	2.05	0.37	22.0
Yearlings	1.10	1.37	0.27	24.5
<b>April - August 1971</b>				
Cows	0.48	0.41	-0.07	-14.6
Calves	1.70	1.80	0.10	5.9
Yearlings	1.32	1.86	0.54	40.9

Source: Adapted from Sneva et al. (1973)

Although off-stream water has been shown to reduce the time that livestock spend in the riparian zone, Bryant (1982) reported that salt placement did not attract cattle away from the riparian zone. However, the salt placement was approximately 1 km from the riparian zone (as estimated from the study area map) and up a slope greater than 35%. The author suggested that the cattle were unwilling to expend the energy necessary to obtain the salt.

#### **4.6 Site characteristics affecting the impact of hoof action**

The effects of treading or hoof action on pastures depend on the interactions of soil texture, type of vegetation, and amount of vegetation source. Soil texture (the proportion of sand, silt, and clay in a soil) determines the soil’s drainage and water-holding capacity and thus its “firmness” in wet conditions. In general, the well-drained soils are also the ones that provide the most flexibility under wet and dry conditions. This is partially due to the fact that more desirable plants can be grown and maintained in well-drained soils. Clays tend to become compacted on the surface, whereas sandy soils tend to form a compacted layer beneath the surface, both of which can reduce infiltration of water.

Different vegetation types often show variation in responses to hoof action, which could affect the impacts of livestock on riparian areas. Kauffman et al. (1983) studied impacts of cattle on streambanks in Oregon related to vegetation type and channel morphology. Three types of vegetation were examined:

- herbaceous: Kentucky bluegrass (*Poa pratensis*), sedges (*Carex spp.*), rushes (*Juncus spp.*), and forbs;
- woody shrub: hawthorne (*Crataegus douglasii*), snowberry (*Symphoricarpos albus*), and/or Wood's rose (*Rosa woodsii*); or
- tree: black cottonwood (*Populus trichocarpa*), thin leaf alder (*Alnus incana*), or both.

The vegetation types were examined with four channel morphologies (straight, top-outside, middle-outside, and bottom-outside) under grazed and ungrazed conditions. The study was conducted over two grazing seasons with the stocking rate of ~1.5 ha AUM<sup>-1</sup> for grazing treatments. The cattle had access to about 1,800 m of streambank, or about 30 m of accessible streambank per AUM. Grazed areas lost significantly more streambank than ungrazed enclosures for the two combined grazing seasons, 27 cm compared to 6 cm. No significant differences were reported in the amount of loss for the three vegetation types.

Some grasses withstand treading better than others because of the location of growing points, extent of rhizome and stolon development, and height of grass during grazing (Table 8).

**Table 8. Pasture species resistance to treading**

Treading Resistance Rating	Pasture Species
May benefit from treading	perennial ryegrass ( <i>Lolium perenne L.</i> ), white clover
Very resistant to treading	tall fescue, Kentucky bluegrass, bermudagrass ( <i>Cynodon dactylon L.</i> )
Fair resistance to treading	orchardgrass, red clover ( <i>Trifolium pratense L.</i> ), small grains
Sensitive to treading	annual ryegrass ( <i>Lolium multiflorum Lam.</i> ), smooth bromegrass ( <i>Bromus inermis Leyss.</i> ), alfalfa

Tall vegetation typically tolerates treading better than short because of protection to growing points and surface roots. Also, less soil is directly exposed to hoof action. Tall vegetation helps to protect the soil from treading by providing a dense layer of top growth and surface root mass.

## 4.7 Conclusion

Although differences in animal behavior may directly influence livestock impact on riparian areas, management of individual species also has an influence on the impact. The seasons of the year in which the livestock are present in the watershed, their numbers, and their proximity to the stream are major considerations. A further consideration might be how vegetation responds to livestock, as each class of animal has a different vegetation preference. The cow that grazes grasses and likes to stand in surface water will evoke a different watershed response than will a goat that prefers shrubs and avoids wet areas.

## 5. Ecosystem parameters

### 5.1 Streambank stability

Streambank stability refers to the bank's resistance to change and its resilience after change. This term is determined by the soil of the bank and the type, amount, and vigor of the vegetative cover (Bohn 1986). Streambank stability has several important implications for water quality. Several studies have documented increased streambank erosion and sediment loss in grazing situations. In a Pennsylvania watershed study, Wohl and Carline (1996) compared grazed and ungrazed riparian areas with a similar channel morphology. They reported streambank erosion at 81% for the grazed riparian areas compared to 6% for the ungrazed. In a 10-year study in Idaho, Yankey (1991) reported that sediment from grazed areas was 2 to 5 times greater than sediment from cropland and primarily due to streambank instability. In another Pennsylvania study, sediment embeddedness increased in reaches of a stream where cropping and grazing were the dominant land uses and resulted in lowered quality of aquatic habitat (Brooks 1991).

An analysis of stream stability rating (SSR) for 724 stream reaches (each 200 ft) in Nevada determined the probability factor for each of 15 specific indicator variables based on the (Rosgen, 1985) method of stream classification (Myers and Swanson, 1992). The researchers reported that of the stream types studied A3 (steep, coarse-grained channels), A4 (steep, fine-grained channels), B3 (moderate-gradient, cobble-bed channels), C3 (low-gradient, gravel-bed channels), and C4 (low-gradient, sand-bed channels) streams were the most susceptible to streambank damage by livestock.

Grazing management has been shown to reduce livestock impact to streambanks without total exclusion (Sheffield et al., 1997; Myers and Swanson, 1995). In a summary of Wisconsin research on riparian areas, Ramisch et al. (1999) indicated that a single farm may represent a length of 150 to 500 m on a given stream and that appropriate management can have a significant impact on bank erosion, fine substrate, and channel shape characteristics. Yet, the conditions likely do not alter the fish community, which may be controlled by a set of conditions dependent on the larger watershed, such as water temperature. Rotational grazing was noted to be a viable alternative to establishment of woody buffer strips, where the grassy buffer effect in rotational grazing maintains a lower width to depth ratio of the stream and less fine substrate than the woody buffer strips. Perhaps one important factor is the presence of roots to resist erosion. It has been demonstrated that soils containing a volume of roots or rhizomes greater than 3 mm (millimeters) per mm<sup>3</sup> (cubic mm) of soil were unerodible in a flume wall at relatively high erosive force (Myers and Swanson, 1992).

Wohl and Carline (1996) used a combination of BMPs in a stream rehabilitation project: streambank fencing 3 m from the stream edge, bank stabilization with 15- to 30-cm diameter limestone, and installation of rock-lined animal crossings. Pre-BMP implementation stream discharge and TSS were monitored for 1 year. Two watersheds were treated, one at a 90% level and the other at 33%. Both watersheds exhibited 50 to 57% reductions in median total suspended solids within 1 year, while a reference

stream did not change significantly over the same period. Streamflow in the two experimental watersheds was similar to the pre-BMP period.

The desire to identify one or several strategies for managing grazing in riparian areas may not provide a workable solution. In Montana, Rhodes et al. (1995) established progressive grazing management strategies for four watersheds and found that stream channel response to land management practices was inconsistent. In some cases, cattle exclosures, cattle and large game exclosures, and the grazed areas were not significantly different with regard to changes in channel morphology. However, Platts (1981) reported on a study that involved heavily and lightly grazed sheep pastures in Idaho and noted that the stream in the heavily grazed pasture was shallower and contained a higher percentage of gravel than the lightly grazed stream. The heavily grazed pasture also had eroded and outslipped streambanks, with little bank overhang.

## 5.2 Wildlife habitat

### 5.2.1 Fish

Some evidence suggests that riparian grazing negatively impacts aquatic fish habitat, though there is little specific data relating to different levels of grazing management. Meehan and Platts (1978) noted the sparsity of quantitative data dealing directly with the interrelationship between grazing livestock and coldwater fish habitat. Similarly, Larsen et al. (1998) found little sound scientific research that reported on the impact of livestock on fish habitat. The researchers also generalized that research has not shown that livestock change aquatic habitat in undesirable ways and that livestock and aquatic habitat can coexist in sustainable riparian ecosystems.

In a study by Gunderson (1968), cited by Meehan and Platts (1978), researchers found 32.5% more brown trout (*Salmo trutta*) in stream sections next to ungrazed pastures compared to areas next to grazed pastures. This could have been due to decreased streamside cover as well as a lower percentage of the stream in pools and runs in the stream adjacent to grazed pastures. In central Pennsylvania, Wohl and Carline (1996) reported similar findings of higher values for substrate permeability of potential spawning sites for brown trout and higher densities of macroinvertebrates in an ungrazed riparian buffer compared to two grazed riparian areas of 2.5 and 4.1 km. The grazed riparian reaches of stream had a complete lack of woody vegetation, in contrast to the mixture of grasses, shrubs, and trees in the ungrazed sections of the riparian area.

In a Wisconsin study that considered grazing management, Lyons et al. (2000) examined intensive rotational grazing (IRG) impacts on fish habitat quality and fish communities in trout streams. The researchers examined 23 stream reaches with four treatments: continuous grazing (stocking density 0.5 to 5.9 AU ha<sup>-1</sup>), IRG (stocking density 0.8 to 1.8 AU ha<sup>-1</sup>), grassy buffer strip, and woody buffer strip. While there was no difference in the “fish variables” studied in the project, there was a significant difference between treatments in bank erosion and percent of fine substrates, both of which negatively impact fish habitat. By modeling their data, the researchers predicted erosion to be significantly higher under continuous grazing than the other three treatments, which were similar. Continuous grazing and woody buffer strips showed the highest predicted mean values for fine substrates, while the IRG treatment values were significantly lower. The grassed buffer strip treatment had the lowest mean predicted values.

**5.2.2 Other wildlife** Not surprisingly, many species of wildlife use productive and protective riparian habitat. Generally, studies have shown that as physical disturbance increases, habitat quality decreases. A Wisconsin study on watershed land use and habitat quality examined a buffer 100 m wide for 134 sites on 103 streams (Wang et al., 1997). While a general relationship existed between increased agricultural land use and declines in habitat quality, there were some sites that maintained good habitat quality due to the high gradients and rocky substrates that resisted channelization. This likely typifies stream conditions that resist degradation. A land use ratio with high urban land use in comparison to all other land uses was also strongly associated with poor biotic integrity and poor habitat quality. When agricultural land use was below 50% in a watershed, no apparent relationship was detected between (1) land use and (2) IBI (index of biotic integrity, a broadly based measure of biological conditions in a stream) and habitat. At land use proportions of greater than 50%, IBI and habitat quality decreased. However, certain management practices on agricultural land allowed habitat and IBI scores to remain high.

Robinson and Minshall (1995) conducted a rapid bioassessment on 60 second- to fourth-order streams in the northern basin and range and Snake River plain ecoregions of the intermountain West. These streams represented degraded sites where lowland areas were perturbed primarily by open-range livestock grazing and agricultural inputs. Habitat assessment scores were approximately 40% lower in the grazed sites, with higher water temperatures and greater ionic concentrations in the grazed sites. Typical effects of grazing degradation included reduced riparian cover, exposed streambanks, higher sediment levels, greater water temperatures, and higher nutrient levels than in nongrazed streams. In addition, heptageniid mayflies (*Heptageniidae*) and rhyacophilan caddisflies (*Rhyacophilidae*) were rare in grazed systems as a result of the higher water temperatures, slower flowing water, and reduced cobble substrata.

In 2000, participants in a Wisconsin workshop on riparian research concluded that from a farm perspective, upstream watershed management outweighed the effect of on-farm riparian management on fish and aquatic invertebrate communities (Ramisch 1999). Grassland birds responded to management in the uplands more than riparian area management, indicating that management of the entire farm is more important for grassland birds than management of just the riparian areas. For the systems observed, rotational grazing stock densities ranged from 0.34 to 0.71 AU a<sup>-1</sup> and continuous grazing ranged from 0.19 to 2.40 AU a<sup>-1</sup>. In general, different management scenarios are required depending on the objectives. Small mammals (such as ground squirrels, meadow voles, and meadow jumping mice) thrived in grassy buffers, but grassland birds were not found in these areas. Continuous grazing was reported to be the least favorable management option for aquatic insects and vegetation structure, but other wildlife species were overshadowed by land management on a broader scale. Perhaps it is best to directly manage for those species that most rely on the riparian habitat, rather than species (such as grassland birds) that incur little measurable benefit from riparian zone management.

In a study of bird species using mandated 1- to 3-m riparian buffer strips on the Boyer River in southern Quebec, Deschênes et al. (2003) found that wooded and tall shrubby buffers supported a greater number of bird species than other buffer types: short shrubby, grassy herbaceous, nongrassy herbaceous, and bare ground. Many farmers feel that uncontrolled riparian strips attract crop-damaging birds to their fields. The researchers noted that although more bird species that have the potential to damage

crops were found in wooded buffers, this was not the case in adjacent crop fields. The buffer strips did not serve as important nesting habitat for any of the potentially damaging species. The buffers did, however, support a large number of beneficial bird species that feed exclusively on insects.

## 6. Economic considerations of grazing BMPs

The value of riparian land can be broken down into obvious market values and less obvious nonmarket values. Market values include the forage produced on the land, for example. Riparian land derives nonmarket values from less obvious functions, such as removing and trapping sediment and nutrients from runoff, maintaining habitat for fish and other aquatic organisms, providing terrestrial habitat, and offering recreational and tourist opportunities. If these nonmarket values are ignored, farmers will tend to undervalue the ecological, biological, and recreational functions of riparian land compared to its agronomic values (Wenger and Fowler, 2000).

BMPs consider both the agronomic and nonmarket values of riparian land and are defined as practical, affordable approaches to conserving water and soil resources without sacrificing agricultural productivity. Farmers, researchers, Extension staff, and agribusiness professionals together decide what qualifies as a BMP (Wossink 2000).

For the (local or federal) government, most of the actual costs of utilizing BMPs on riparian land relate to market values, while many of the benefits are nonmarket (Wenger and Fowler, 2000). At the farm level, the costs of BMPs are market values and include both installation and maintenance costs. The first category of costs will occur only in the first year when the BMP is installed. The other costs, such as the opportunity costs of the land and cost of labor, may occur yearly through the life of the BMP to maintain it. The farm-level benefits of BMPs mainly are the payments provided by cost-share programs. Farmer adoption of a particular BMP depends on whether its use will maintain farm profitability. Cost-sharing incentives to entice adoption should be sufficiently profitable that enough farmers adopt the BMP to achieve the water-quality goal.

Estimates of the implementation and maintenance costs of BMPs allow improved decision making, both at the farm level and at the regulatory level. BMP cost estimates will help farmers make better decisions about adopting BMPs. For regulators, the assessment of technically and economically feasible and environmentally effective BMPs by area and type of farming will be helpful in efficiently allocating public resources (Wossink, 2000).

Platts and Wagstaff (1984) list 10 options available to range managers for restoring riparian and stream habitats: do nothing; improve animal distribution; change season of use; implement specialized grazing seasons and strategies; rest entire grazing unit for 5 years or longer until recovery occurs; fence the entire riparian zone; fence the streamside corridor; combinations of the above; re-vegetate with woody cover; or eliminate grazing altogether. In this section we discuss the literature on the main design elements included in this list: (1) fencing; (2) buffer width; (3) controlled grazing, haying, or both; and (4) off-stream watering, feeding and shading facilities. To some extent, the sources we reviewed also included costs. In addition, we discuss the literature on the site-specificity of design and costs and on the comparison of costs and expected environmental improvements of various designs.

## 6.1 Fencing

Platts and Wagstaff (1984) conclude that fencing is the best alternative, particularly to provide maximum protection for fish and riparian habitats, and the best chance for rehabilitation in the shortest period of time. However, they also conclude that fencing may not be an economically efficient solution. Their cost estimate is based on the popular four-strand high-tensile fence (two positive and two negative wires) used in the western United States, which sums to about \$3,000 per mile to build and about \$30 to \$90 annually to maintain. The USDA Fencing Technical Guide (USDA, 1994) states that for the Southeast, an all-positive three-wire fence is sufficient for cross fences where the purpose is rotation of cattle in an intensive grazing system. However, if experience shows that the soil on site will dry to the point that the wire will not shock the animal, a combination of positive and negative wires should be used. Moore et al. (2000) state that to fence cattle out of a stream (and for rotational grazing), a single or double strand of high-tensile electric fence is often the best choice. Costs are not given for the three-wire, single, or double electric fence but will be less than \$3,000 per mile—about \$0.57 per foot (ft).

Fence locations should allow livestock access to water. If this results in undesirable fence placement, the installation of alternative water sources should be investigated. In addition, fencing will imply some loss of productive land because the fence cannot be placed exactly at the water's edge. Control of vegetation that grows along electric fence with herbicides or mowing is needed to keep tall weeds from overgrowing and shorting the fence.

The high cost of fencing would be justified only in selected areas where the expected environmental benefits of fencing are very high. Fencing off the stream from all use may also be detrimental to wildlife movement (Platts and Nelson, 1985).

## 6.2 Buffer width

The USDA Fencing Technical Guide states a minimum buffer for streambank protection: fencing 5 ft from the top of the streambank and 10 ft from where banks are crumbling and falling away (USDA, 1994). The benefits of reduced erosion, improved water quality, protection of cattle from injury, and more wildlife habitat increase as the distance from the stream increases. The main cost of a riparian buffer is the cost of lost grazing, and this could equal 1 AU a<sup>-1</sup> in the highly productive riparian zone. For example, a 100-ft wide buffer would contain about 12 acres mi<sup>-1</sup>, or the equivalent of 12 AU mi<sup>-1</sup>. Fencing all riparian habitat rather than just a 5- to 10-ft wide corridor would, therefore, become expensive (Platts and Wagstaff, 1984), especially in areas with high levels of forage productivity.

## 6.3 Controlled grazing/haying

An alternative to excluding cattle from the riparian zone by fencing is to reduce grazing intensity on riparian land. Particularly on western rangelands, the main share of forage consumed by cattle in mid- and late summer may come from the riparian zone. Consequently, holding cattle in the pasture to get them to use forage in the uplands leads to overuse and trampling of riparian vegetation. To correct or limit *overuse*,

Marlow (1985) suggests this: Base the length of the grazing period and the grazing intensity on the forage in the area the cattle are actually using: the riparian zone plus the immediate adjacent upland. Regrazing the same pasture should not take place at intervals of less than 30 days. Adjusting the length of the grazing period will do little to alter the level of *trampling*, which is a function of soil moisture rather than the number of grazing cattle. If grazing is scheduled on riparian land during periods when soil moisture is low, streambanks remain intact and continue to produce vegetation. The resulting grazing schedule requires at least three riparian pastures that are grazed at different dates in a 3-year rotation, with stocking rates during mid- and late summer based on only 20 to 30% of the riparian forage base. The overall change in the total amount of forage from this measure is expected to be minimal, given the fast regrowth of riparian vegetation and the prevented forage loss from trampling.

Controlled haying is particularly advocated to provide waterfowl nesting habitat. Ducks Unlimited Canada has management agreements with farmers that provide payment to offset the loss in nutritional value of the hay that comes with a later cut. In addition, landowners can receive tax benefits from guaranteeing certain conservation activities (Vaisey and Strankman, 1999).

### 6.4 Watering, feeding, and shading facilities

With a limited access approach to restoration, naturally rocky areas should be used for livestock watering to reduce trampling damage and loitering. If cattle are completely fenced out, an alternative watering system, such as the use of nose pumps, is required. Livestock push a piston with their noses to turn on the pump. Cattle learn to use the pumps within a few hours, so no power source is needed. With a moderate cost of approximately \$450 (add in costs for mounting brackets and concrete pads), nose pumps are a cost-effective option. Two nose pumps easily have enough capacity for 50 cows and calf pairs (Moore et al., 2000). Alternatively, ponds can be constructed by excavation or embankment to provide water for livestock. According to the Natural Resources Conservation Service (NRCS) Practice code 378, side slopes of excavated ponds should not be steeper than one horizontal to one vertical, and a watering ramp with a slope of three horizontals to one vertical should be included. The depth of the water table should be considered in pond design.

Alternative water supplies, mineral stations, feeding stations and shading facilities can also be developed specifically for the purpose of attracting animals away from streams as much as possible. (A livestock shade structure [NRCS Practice code 473] is a portable metal, PVC, or pipe frame with a mesh fabric roof. Shade structures prevent livestock from excessive heat and reduce pollution of surface water.) Stillings (1997) uses a bio-economic nonlinear programming model to assess the economic feasibility of off-stream water and salt supplies to reduce grazing pressure in riparian areas. Data to feed the model were collected in July and August of 1996 and 1997 on an experimental farm with only riparian land at Oregon State University. When an environmental management objective of restricting riparian vegetation use to 35 percent was strictly enforced, permitted AU months (AUM) were reduced and led to a 10% reduction in herd size. However, when the alternative scenario of cattle dispersion by upland water and salt supply was employed, the consumption of more upland forage allowed the herd size to remain at the traditional numbers with an increased weight gain. The initial installment costs for off-stream water supply and mineral stations

were estimated at \$2,400 and the operating cost at \$104 per month for 300 cow-calf pairs. The estimated net return of dispersion (weight gain minus annualized investment and annual operating cost) at median cattle prices was \$3,312 for the 300-cow operation.

### **6.5 Absolute and relative impacts of grazing are site specific**

A great deal of the older but still commonly cited literature on livestock access to watercourses pertains to arid, western areas of the United States where these conditions apply: (1) Water exerts a particularly magnetic influence on livestock; (2) riparian meadows provide up to 20% of the summer range forage (Kauffman, 1982); and (3) grazing livestock is the only economic activity influencing water quality. In the humid, temperate zone, the impact of livestock on watercourse pollution can be expected to be more moderate. Livestock impact varies with climatic region, soil type, drainage and other biophysical factors. Besides, in humid, temperate zones other land uses, such as confinement feeding systems, can be more important sources of pollutant delivery than grazing. Policies seeking to implement cost-effective measures need to acknowledge both site-specific conditions and other sources of pollution (Clark, 1998).

### **6.6 Cost versus environmental improvements**

When farmers and regulators consider competing BMPs, break-even analysis provides a tool for evaluating whether fluctuations in the economic and biophysical environment will affect the costs of alternative production practices and how great any effect will be. Break-even analysis also provides insight into the economic ranking of competing, cost-shared BMPs. This provides a basis for a farmer's decision to find a practice that is "the Best of the Best," assuming that the allowed set of BMPs indeed includes the best practices. This economic ranking can be compared a ranking of the BMPs based on their potential environmental benefits. For cost-share and incentive programs to be efficient, the two rankings have to be identical (Wossink and Osmond, submitted).

### **6.7 General riparian area management principles**

From this review, it is apparent that the nonpoint source pollution from pastured cattle is a function of many factors: climate, seasonality, stocking density, grass type, feeding practices, alternative water and shade availability, and fencing. Most studies documented increases in nutrients, sediments, and bacteria when cattle were allowed access to riparian areas. In some studies, however, good pasture management practices (such as alternative watering and shade) reduced nonpoint source pollution from livestock and other negative impacts on stream stability and aquatic wildlife. Based on this literature review, we recommend the following:

1. Practices should be used that encourage more uniform livestock distribution over the pasture.
2. Riparian areas should not be used as shade paddocks, holding areas, or feeding areas. In addition, because riparian areas are very important in maintaining water quality, rotational stocking systems should be encouraged that limit the duration of

grazing in riparian areas to a maximum of 3 days and that provide an adequate nongrazing recovery period of 3 weeks.

3. Access to the riparian area should not occur (a) when soils are wet or boggy, and (b) when acceptable forage is available on riparian sites within the same grazing unit.
4. Consider using goats or sheep to graze riparian areas in preference to cattle or horses.
5. Fencing is the most reliable way to minimize the impacts of livestock on riparian areas. If, however, this is not possible, at least fence the most vulnerable stream-side corridors for complete habitat preservation, while providing strategic access to drinking water for grazing animals.

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