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LIVESTOCK GRAZING MANAGEMENT IMPACTS ON STREAM WATER QUALITY: A REVIEW[1]

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ABSTRACT: Controlling agricultural nonpoint source pollution from livestock grazing is a necessary step to improving the water quality of the nation's streams. The goal of enhanced stream water quality will most likely result from the implementation of an integrated system of best management practices (BMPs) linked with stream hydraulic and geomorphic characteristics. However, a grazing BMP system is often developed with the concept that BMPs will function independently from interactions among controls, climatic regions, and the multifaceted functions exhibited by streams. This paper examines the peer reviewed literature pertaining to grazing BMPs commonly implemented in the southern humid region of the United States to ascertain effects of BMPs on stream water quality. Results indicate that the most extensive BMP research efforts occurred in the western and midwestern U.S. While numerous studies documented the negative impacts of grazing on stream health, few actually examined the success of BMPs for mitigating these effects. Even fewer studies provided the necessary information to enable the reader to determine the efficacy of a comprehensive systems approach integrating multiple BMPs with pre-BMP and post-BMP geomorphic conditions. Perhaps grazing BMP research should begin incorporating geomorphic information about the streams with the goal of achieving sustainable stream water quality.
(KEY TERMS: sustainability; agriculture; environmental impacts; water quality; nonpoint source pollution; best management practices.)

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INTRODUCTION

Animal agriculture is a significant component of U.S. agricultural sales, accounting for over 50 percent of the nearly $200 billion in agricultural products sold (USDA-NASS, 1997). Beef cow/calf production alone generated $40.5 billion in sales. Dairy cattle and their associated products (i.e., milk, cream, and butter) along with horses accounted for over 11 percent of sales. In the southern humid region of the U.S., these 14.6 million large grazing animals are a dominant source of income with a total market value of $2.9 billion. Considering the large amount of pastureland and grazed forested lands (15.8 million hectares) in the southern humid region along with the nearly one million kilometers of streams, the potential for damage to riparian ecosystems from uncontrolled livestock access is quite high (Vesterby and Krupa, 1997; USEPA, 2000). For purposes of this paper, the southern humid region is defined as Alabama, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, and West Virginia.

Over 36 percent of the assessed rivers and streams in the southern humid region are classified as impaired meaning that they do not fully support one or more designated uses. The U.S. Environmental Protection Agency (USEPA, 2000) noted that the most common pollutants to the southern humid region's rivers and streams included pathogens, siltation, habitat alterations, organic enrichment, and nutrients. Sources of these pollutants, while often difficult to identify, were attributed primarily to agriculture, hydromodifications including flow regulation and modification, channelization, dredging, dam construction, grazing, and habitat modifications including bank destabilization and removal of riparian vegetation (other than flow). Underscored by the significant

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portion of river and stream impairments that are attributable directly or indirectly to livestock grazing is the fact that grazing lands are one of the largest land uses in the southern humid region.

Research into the effects of cattle grazing on stream water quality has been well documented in the western portion of the U.S. Researchers estimate that 80 percent of the damage incurred by streams and riparian systems in these arid environments was from grazing livestock (USDI, 1994). Stream and riparian damage resulting from livestock grazing includes alterations in watershed hydrology, changes to stream channel morphology, soil compaction and erosion, riparian vegetation destruction, and water quality impairments (Belsky *et al.,* 1999). Clark (1998) theorized that in the arid, western portion of the U.S., water exerts a magnetic force over livestock, largely driving grazing patterns. Additionally, the arid environments of the western U.S. are viewed as more fragile than those of the humid, temperate regions of the eastern U.S. (Clark, 1998). The water quality impacts of grazing cattle in a humid environment, such as that of the fore mentioned eleven states, may differ significantly from those witnessed in the arid West. While the knowledge gained from western grazing studies is valuable to researchers in the southern humid region, the differences between the two regions prohibit the universal transfer of research results.

Adding to the difficulty of assessing the effects of grazing BMPs on the health of streams in the southern humid region is the fact that many cattle grazing studies have examined BMPs for the purpose of improving cattle distribution and thus pasture utilization (Senft *et al.,* 1980, 1985; Bryant, 1982; Roath and Krueger, 1982; Marlow and Pogacnik, 1986; Owens *et al.,* 1991; Smith *et al.,* 1992; Bailey *et al.,* 1996). When water quality issues were examined, researchers often relied upon visual observations for a period of a few days to determine general cattle behavior patterns (Gary *et al.,* 1983; Miner *et al.,* 1992; Sheffield *et al.,* 1997) with a few studies then inferring stream water quality without collecting samples (Miner *et al.,* 1992; Buckhouse and Gifford, 1976). The grazing studies commonly implemented a single best management practice such as rotational grazing, alternate water source, alternate shade source, or exclusion fencing. While this is essential to determining the effectiveness of individual BMPs, a holistic approach encompassing a system of controls integrated with dynamic stream functions may allow for more informed decisions. For reducing the impacts of cattle grazing on the health of a stream, both structural control BMPs and cultural control BMPs are ideal. Structural control BMPs (i.e., riparian buffers and vegetative filter strips) modify the transport of the pollutants to waterways while cultural control BMPs (i.e., managed grazing) are designed to minimize pollutant inputs to waterways through land management practices (Logan, 1990).

Grazing best management practices are often implemented without considering the integrated functions of the control system. Recommendations regarding BMP implementation are based largely on general considerations such as the proximity of grazing pastures to streams, grazing intensity in relation to vegetative cover (i.e., grasses), and livestock access to streams. Often, the effects of BMPs are focused on water quality, perhaps without adequately considering geomorphic stream processes. According to Lane (1955), alluvial streams are in equilibrium when the sediment discharge (Q_s), median streambed particle size (D_{50}), stream discharge (Q_w), and longitudinal slope (S) are in balance such that the product of Q_s and D_{50} is proportional to the product of Q_w and S. A change to one variable, due to implementation of single or multiple BMPs, will result in a proportional change to one or more of the remaining variables until stream equilibrium is achieved (FISRWG, 1998). Theoretically, if a grazing BMP system greatly reduced sediment input to an alluvial stream, channel and/or bank erosion could occur canceling the perceived benefits of the BMPs and possibly degrading water quality or stream stability. To a large extent, the effect of grazing BMPs on these basic variables is not well understood, especially with regards to equilibrium recovery. Following the introduction of grazing BMPs, streams will respond in one of three ways as outlined by Sarr (2002) (Figure 1). Some streams will follow a "rubber band model" characterized by quick recovery times with minimal hysteresis while others will follow a "broken leg model" with a much longer and more distinct period of recovery. Lastly, natural recovery of stream systems may not be possible as represented by the "Humpty Dumpty model," thus necessitating the need for restoration.

Streams do not exhibit a universal response to imposed changes, and as such, they will not respond universally to changing conditions (i.e., grazing pressures and BMPs) (Juracek and Fitzpatrick, 2003). While the development of a program of grazing BMPs for streams in the southern humid region should consider the results of western and midwestern U.S. grazing studies, in addition to the few conducted in the eastern U.S., designers would be wise to incorporate stream geomorphic processes into the planning stages of a holistic BMP program that targeted enhanced stream water quality. To develop an effective BMP program, one that will maintain or achieve the appropriate dynamic hydraulic and biologic functions of the stream, geomorphic processes and the factors affecting them probably should receive

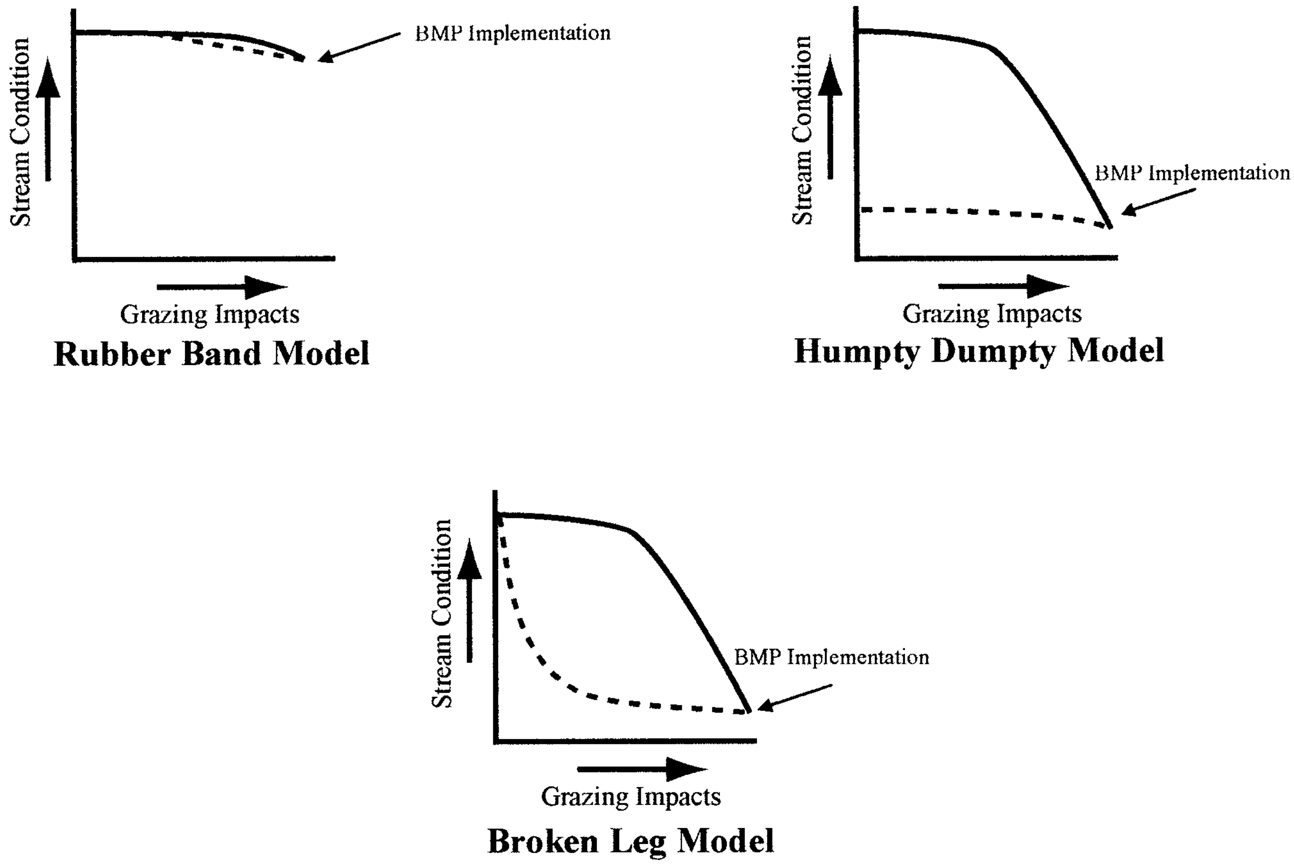

Figure 1. Relationships Between Livestock Grazing and Stream Health (adapted from Sarr, 2002).

consideration. An effort should be taken to focus resources on streams that are most sensitive to grazing impacts and exhibit the least potential for natural recovery. In this paper, research dealing with grazing BMPs and stream water quality is reviewed.

METHODS

A literature search was conducted to identify peer reviewed empirical papers and government documents pertaining to targeted grazing best management practices and water quality specifically in the southern humid region. Grazing studies conducted outside the southern humid region were examined to provide insight into BMP program development when a void in the literature was present. Nonrefereed reports and articles were not cited. Special emphasis was placed on commonly employed BMPs of the southern humid region, and if possible, BMP-induced geomorphic responses were noted. Attempts were made to note morphological features that affect ameliorating and transporting water quality constituents, such as the dimension, pattern, profile, and bed material of the streams along with any influencing factors such as watershed area, land use or land cover, soil and geologic characteristics, topography, climate, and human impacts within the watershed.

RESULTS AND DISCUSSION

A large volume of research, predominately in the western and midwestern U.S., has documented the negative impacts grazing animals can have on riparian ecosystems (Kauffman and Krueger, 1984; Clark, 1998; Nader *et al.,* 1998; Belsky *et al.,* 1999; CAST, 2002). Examples of grazing damage include alterations in watershed hydrology, changes to stream morphology, increases in soil compaction and erosion, vegetation destruction, and water quality impairments. Although many studies reported grazing impacts, others found minimal changes. Gary *et al.* (1983) noted that even when cattle spent more than 65 percent of the day within 100 m of a Colorado stream and 5 percent of the day in or adjacent to the stream, only small changes to water quality parameters (i.e., suspended solids, ammonia nitrogen, nitrate nitrogen) were identified. Buckhouse and Gifford (1976) examined differences in bacterial concentrations on cattle grazed pasture in Utah and noted no significant differences as a result of grazing. The difficulty then becomes one of identifying the cause of these inconsistencies. This is especially true when studies were performed in different climatic regions and on different stream types (i.e., alluvial, colluvial, bedrock), with varying capacities to alleviate or convey water quality constituents, and little or no geomorphologic information provided to enable the reader to assess stream factors and characteristics. For the southern humid region, reaching a consensus regarding the degree of impact grazing has on the water quality of a particular stream, and the subsequent reduction of these impacts by BMPs, becomes a difficult task.

To reduce the influence of grazing on stream water quality, several BMPs are currently recommended by the National Resources Conservation Service. These BMPs include livestock exclusion fencing, animal crossings, offstream water source, and buffer strips (USDA-NRCS, 2003a). Unfortunately, only a small percentage of the literature has actually examined the ability of these BMPs to reduce grazing impacts to streams (Table 1). Of these studies, few have specified geomorphologic trends of the stream on which the study was conducted, thus allowing for a more successful transfer of the technology. As stated by Coffey *et al.* (1998), there is a need for information regarding the effects of BMPs on water quality, so that farmers can be educated on selection of appropriate BMPs for their production practice.

Alternate Water Source

Few studies have addressed the ability of an offstream water source to improve stream water quality. Of these studies, only one monitored water quality constituent concentrations while the others inferred water quality improvements without any actual data to support their arguments. As with the majority of research targeting the effectiveness of grazing BMPs on improving water quality, the results were not consistent. While work by Sheffield *et al.* (1997) in Virginia pointed to significant water quality improvements as a result of an offstream water source, Line *et al.* (2000) stated that the effect of an offstream water source is not in and of itself effective at reducing pollutant loads from grazed pastures in North Carolina.

Alterations in grazing patterns and subsequent water quality impacts resulting from an alternate water source along three southwest Virginia spring-fed, first-order streams were examined by Sheffield *et al.* (1997). These streams were located in predominately fescue pastures that were traditionally grazed by beef cattle. After the implementation of the BMP, researchers noted changes in cattle behavior and improvements in water quality. Following the installation of the water trough, researchers noted an 89 percent reduction in the average length of time each cow spent drinking in the stream and a 51 percent reduction in the amount of time each cow spent in the near stream area. Water quality improvements included a 77 percent reduction in stream bank erosion, a 90 percent reduction in total suspended solids (TSS), a 54 percent reduction in total nitrogen (TN), an 81 percent reduction in total phosphorus (TP), and a 75 percent reduction in sediment bound phosphorus. Reductions in fecal bacteria (fecal coliforms and fecal streptococci) were also noted. Levels of dissolved nutrients such as nitrate nitrogen (NO_3-N) and orthophosphates (PO_4-P) increased, but the trends were not significant.

As part of the Long Creek 319(h) National Monitoring Program Project in North Carolina, Line *et al.* (2000) examined the effectiveness of an offstream water source to reduce pollutant loads from dairy pastures located in a hilly, 57 ha watershed that had been grazed for the past 100 years. Implementation of the BMP occurred along a flashy headwater stream in the western Piedmont region. The authors provided significant geomorphologic detail to which the reader is referred. While small decreases in nitrate-nitrogen, nitrite-nitrogen, total suspended solids, and total solids were noted, these differences were not significant. The researchers concluded that the installation of an offstream water source by itself was not an effective grazing BMP for reducing pollutant loads. As an observation, Line *et al.* (2000) noted that the offstream water source was less effective with older dairy cows that more readily sought relief from the heat in the stream.

Godwin and Miner (1996) evaluated the effectiveness of an offstream watering system in small commercial and noncommercial productions for reducing water quality impacts to Oregon streams during the late summer period. These operations typically consisted of a few animals on a limited area. Fluvial geomorphologic characteristics were not provided. In one study, the researchers discovered that the four monitored cows spent 75 percent less time within 4.5 m of the stream when a water trough was provided. Based on estimated defecation rates of beef cows, they concluded that the provision of an offstream water source would reduce the amount of instream defecations from once a day to once every four days. Using two horses, Godwin and Miner (1996) conducted a second study to identify the ability of an offstream water source to reduce streamside drinking under wet and dry pasture conditions. When pasture conditions were wet, the horses consumed 53 percent less water from the alternate water source located in a pasture with stream access in comparison to a pasture without stream access, instead acquiring water from forage and the stream. When the pasture conditions were dry, use of the offstream water source located in the pasture with stream access declined by 17 percent in comparison to the pasture without stream access, indicating that location of the offstream water source is critical to its success in luring animals away from riparian areas.

Similar results were noted during the winter months for hay fed cattle. Miner *et al.* (1992) compared the time the cattle spent near an Oregon stream when an alternate water source was provided. The researchers discovered that an alternate water source reduced the amount of time cattle spent near the stream during times of thirst, which was defined as the time within four hours of feeding, and an 80 percent reduction in loitering, which was defined as the time cattle spent in the stream not drinking. As with Godwin and Miner (1996), collection of water quality data was beyond the project scope, so Miner *et al.* (1992) only made assumptions concerning the impacts of this BMP on water quality. Fluvial geomorphic information was not provided.

While these studies evaluated the ability of an offstream water source to modify cattle behavior as a first step to improving water quality, they did not address the effectiveness of an offstream water source as it relates to seasonality (i.e., temperature and humidity). Kelly *et al.* (1955) indicated that results from five years of data collected in southern California demonstrated that beef cattle used water as a cooling agent. Under hot weather conditions, the cattle consistently drank from the cool water (18.3ºC) as opposed to warmer water (31.1ºC). This research highlights an important point as to the effectiveness of an offstream water source to alter cattle behavior and thus potentially improve stream water quality. None of the studies regarding offstream water sources examined the relationship between the temperatures of the drinking water sources and a temperature humidity index (THI) to determine cattle preference.

Alternate Shade Source

Research into the effects of shade on cattle has mainly dealt with attempts to increase weight gains rather than modify behavior (Bond *et al.,* 1954; McIvan and Shoop, 1971; Squires, 1981; Buffington *et al.,* 1983; Daly, 1984; Blackshaw and Blackshaw, 1994). While observing the effects of an alternate shade source on the grazing patterns of steers, McIvan and Shoop (1971) noticed that steers without shade loafed around the water trough the majority of the day. Grazing patterns were largely driven by the location of water followed by salt and then shade. Blackshaw and Blackshaw (1994) noted that increased levels of feed intake resulted in higher metabolic rates and water intake rates resulting in greater levels of heat in cattle.

A significant problem in the southern humid states is the presence of tall fescue infected by endophytic fungi of the genus Neotyphodium. Tall fescue is the most widely grown pasture grass in the southern humid region (Hoveland, 1993). Estimates are that 95 percent of tall fescue pastures in the United States are infected with endophytic fungi. Cattle grazing on endophyte infected fescue experience increases in body temperature largely from an inability to transfer heat cutaneously as a result of decreased peripheral circulation (Al-Haidary *et al.,* 2001). Because of their ability to sweat more easily, horses tend not to experience similar increases in body temperature (Cross, 1997). Controlling the amount of incoming radiation that an animal receives is one of the best methods for keeping an animal cool (Bond *et al.,* 1954; Mitlöhner *et al.,* 2001). By providing an alternate method for cooling, the amount of time cattle loaf in streamside areas may be reduced. The potential effect of using both natural and constructed shade, as a BMP to improve stream quality, has not been thoroughly researched.

Forage Availability

Cattle behavior is dictated in large part by the surrounding environment. Factors such as water and shade location, seasonality, topography, and forage availability are keys to grazing area selection. Areas that attract cattle will lead to increased depositions of waste (USDA-NRCS, 1997). Nitrogen, phosphorus and potassium levels have been shown to accumulate in close proximity to shade, water sources and supplemental feeding areas (Mathews *et al.,* 1994). While some factors such as seasonality are uncontrollable, others such as stocking density and timing of riparian grazing can be managed to better protect streams and stream water quality.

Increasing forage availability within a pasture should be done strategically with consideration given to location and species. Research by Senft *et al.* (1985) in Colorado indicated that cattle selected areas for grazing based on plant species. During the growing season (summer), cattle preferred to graze in the riparian areas while they shifted to the uplands

TABLE 1. BMP Effectiveness at Significantly Reducing Grazing Impacts to Streams.

BMP	Location	Water Quality Parameters	Geomorphic Parameters	Habitat Parameters	Source
Alternate Water Source	Virginia*	Decreased: Total suspended solids, total nitrogen, total phosphorus, fecal coliforms, fecal coliforms, fecal streptococci, sediment bound phosphorus Increased: Nitrate-nitrogen, orthophosphate	Decreased: Streambank erosion	–**	Sheffield *et al.,* 1997
Alternate Water Source and Exclusion Fencing/ Riparian Buffers	North Carolina*	Decreased: Total suspended solids, total solids, total Kjeldahl nitrogen, total phosphorus, nitrate-nitrogen, nitrite-nitrogen	–	–	Line *et al.,* 2000
Alternate Shade Source	–	–	–	–	–
Forage Availability (fertilizers/herbicides)	–	–	–	–	–
Exclusion Fencing/ Riparian Buffers	Tennessee*	–	Decreased: Streambank erosion	–	Trimble, 1994
Exclusion Fencing/ Riparian Buffers	Oregon	–	Decreased: Streambank erosion	–	Kauffman *et al.,* 198
Exclusion Fencing/ Riparian Buffers	Utah	–	Decreased: Streambank angle Increased: riparian vegetation, streambank stability, channel bed material particle size	–	Platts and Nelson, 1985
Exclusion Fencing/ Riparian Buffers	California California	–	No significant streambank erosion	–	Kondolf, 1993
Exclusion Fencing/ Riparian Buffers	Ohio	Decreased: Annual flow weighted sediment concentration, average annual soil loss	–	–	Owens *et al.,* 1996
Exclusion Fencing/ Riparian Buffers	Oregon	–	Decreased: Bankfull width, glide area Increased: Bankfull depth, pool area	–	Magilligan and McDowell, 1997
Exclusion Fencing/ Riparian Buffers	California	–	No significant streambank erosion	–	Allen-Diaz *et al.,* 1998
Exclusion Fencing/ Riparian Buffers	Oregon	–	Increased: Water table, lateral expansion of hyporheic zone	Increased: Bird density and diversity	Dobkin *et al.,* 1998

TABLE 1. BMP Effectiveness at Significantly Reducing Grazing Impacts to Streams (cont'd.).

BMP	Location	Water Quality Parameters	Geomorphic Parameters	Habitat Parameters	Source
Exclusion Fencing/ Riparian Buffers	Wisconsin	–	–	Increased: Small mammal density and diversity	Chapman and Ribic, 2000
Exclusion Fencing/ Riparian Buffers	Minnesota	–	–	No significant species changes	Sovell *et al.,* 2000
Exclusion Fencing/ Riparian Buffers	Wisconsin	–	–	Increased: Macro-invertebrate diversity	Weigel *et al.,* 2000
Exclusion Fencing/ Riparian Buffers	California	–	No significant streambank erosion	–	George *et al.,* 2002
Exclusion Fencing/ Riparian Buffers	Arizona	–	–	Increased: Bird density	Krueper *et al.,* 2003
Exclusion Fencing/ Riparian Buffers	Alberta, Canada	Increased: Coarse particulate organic matter	Increased: Streambank stability, riparian vegetation	Increased: Macro-invertebrates (shredders)	Scrimgeour and Kendall 2003
Controlled Grazing	Colorado	Decreased: Fecal coliform, fecal streptococci, ammonia nitrogen	–	–	Gary *et al.,* 1983
Controlled Grazing	Idaho	–	Decreased: Stream embeddedness, width:depth	–	Clary, 1999
Controlled Grazing	Wisconsin	–	Decreased: Streambank erosion, fine substrate levels, width:depth	–	Lyons *et al.,* 2000
Controlled Grazing	Minnesota	Decreased: Fecal coliforms, turbidity	Decreased: Fine substrate levels	–	Sovell *et al.,* 2000
Supplemental Feeding	Oregon	–	Decreased: Streambank instability, streambank erosion potential Increased: riparian vegetation	–	McInnis and McIver, 2001

*Southern Humid Region.
**Not examined.

during the dormant season (winter). Marlow and Pogacnik (1986) noted that cattle spent the majority of their time during the late summer and early fall in the riparian zone of a Montana stream. Similar grazing distribution patterns were identified by Parsons *et al.* (2003) along a northeastern Oregon mountain stream. Increased grazing pressure in the riparian zone was linked to more palatable forages with a higher nutrient quality. During the summer months, Bryant (1982) observed that even though the cattle were excluded from the riparian zone of an Oregon stream, they continued to graze near the riparian zone. In the latter part of the grazing season towards the cooler months, the cattle preferred to graze on the upland vegetation. Smith *et al.* (1992) noted a higher rate of usage in the floodplain or riparian zone during the fall months.

Both stocking density and forage type must be considered when developing a grazing management system. In a simulation study, Stout *et al.* (2000) concluded that nitrogen-fertilized orchard grass would allow for higher stocking rates than an orchard grass-white clover mix that utilized biological nitrogen fixation. Stout *et al.* (1999) noted that when legumes such as alfalfa or white clover supplied nitrogen, nitrate-nitrogen leachate increased dramatically during times of drought as the legumes underwent decomposition.

Exclusion Fencing/Riparian Buffers

As agricultural settlements arose along streams and rivers, farmers often removed riparian vegetation and straightened the streams for livestock and crop production (Aus, 1969; Guthrie, 2000; Baker, 2001). In their efforts, these settlers were removing one of nature's natural filters. By decreasing the velocity of runoff and increasing the tortuosity of flow paths, vegetative buffers provide a setting conducive to the settling of sediments and large organic particles, an increase in infiltration rates, and greater levels of nutrient uptake (Brady and Weil, 1999). Riparian zones provide numerous benefits to adjacent water bodies not only through the reduction of nonpoint sources of pollution but also with other ecological gains. Riparian buffers assist in the stabilization of streambanks, the filtering of runoff, the reduction of peak floods, and the enhancement of habitat by controlling water temperatures and providing shelter to wildlife (Beeson and Doyle, 1995; Lowrance *et al.,* 1997; Dosskey, 1998; Hutchens, 1998; Lowrance *et al.,* 2002).

The effectiveness of a riparian buffer as a BMP can be increased through the use of both deep rooted and shallow rooted vegetation. Riparian buffers consisting mainly of trees and shrubs are highly effective at stabilizing stream banks and are moderately effective at filtering dissolved pollutants such as nitrate-nitrogen and orthophophates. Those buffers consisting mainly of grasses provide a high level of sediment filtration with a moderate level of dissolved nutrient filtration (Dosskey, 1998). Sovell *et al.* (2000) detected a greater percentage of fines and higher turbidity levels in the streambed of wooded buffer sites as compared to grass buffer sites along streams in Minnesota. A riparian BMP that combines both vegetation types, either in series or within one area, should produce significant water quality improvements in waterways located along grazing areas (Lowrance *et al.,* 2002). As for flood control, Line *et al.* (2000) witnessed decreases in discharge following the development of a 16 m wide riparian buffer along a North Carolina stream traversing through grazed pastures. Several soft and hardwood species of trees were planted in a 3 m zone adjacent to the stream within the riparian buffer. Since differences in precipitation levels prior to and following the riparian buffer development were not significant, the researchers attributed the decrease in discharge to increased evapotranspiration rates from the established vegetation.

One means of protecting riparian buffers is through the installation of fencing to exclude cattle. However, economic constraints have been cited as one reason producers are hesitant to install exclusion fencing along streams (Soto-Grajales, 2002). Barao (1992) noted that the technological practices most readily adopted amongst Maryland farmers were those with the lowest cash investment. Removing a stream from use as a drinking water source is an added expense to the producer. While producers can receive assistance to construct exclusion fencing, they must finance a significant portion of the projects themselves. The Environmental Quality Incentives Program (EQIP) conducted by the Natural Resources Conservation Service (NRCS) is the main source of funding for fencing. From 1997 to 2001, the national average cost share rate was 36 percent meaning that farmers themselves financed a significant portion of the environmental improvement projects. Of the over $900 million funded for this period, nearly $53 million was used for fencing and use exclusion (USDA-NRCS, 2003b). However, hesitation to adopt exclusion fencing comes not only from having to install an alternate water source and additional fencing, but also from permanently removing a portion of the pastures from production. One alternative that merits further exploration is timed grazing of the stream area otherwise known as riparian pasture. With this management method, stream-side areas could be grazed for short periods when the stream is least sensitive to the effects of grazing.

Since streams do not universally respond in the same manner to grazing, considerations for when to install exclusion fencing should include information on the propensity of a stream to incur damage from grazing and to naturally recover once grazing has ceased. Sarr (2002) cites several grazing studies from the western U.S. that relay mixed geomorphological results with regards to exclusion fencing. While some studies demonstrated positive geomorphic changes such as channel narrowing, others documented no recovery. Careful consideration of the geomorphological characteristics of a stream along with the ability of a given BMP, such as exclusion fencing, to aid in the attainment of stability may enable funding agencies to more effectively utilize resources to achieve maximum water quality benefits.

MORPHOLOGIC RESPONSES TO EXCLUSION FENCING/RIPARIAN BUFFERS

Owens *et al.* (1989) stated that increases in sediment transport from a continuously grazed site in Ohio might justify the use of exclusion fencing along fragile riparian areas. Although not directly attributable to stream fencing, Brannan *et al.* (2000) postulated that total suspended solid loads and flow weighted concentration reductions in a Virginia watershed were the result of exclusion fencing. In a later study, Owens *et al.* (1996) examined the effects of stream fencing on sediment losses in an Ohio stream located in a heavily grazed watershed. The researchers noted a 57 percent decrease in the annual flow weighted averages for sediment concentration and more than a 40 percent decrease in average annual soil losses when cattle were fenced out of the stream. Line *et al.* (2000) evaluated the effectiveness of exclusion fencing combined with planting trees to reduce pollutant loads to a small North Carolina stream, and noted significant reductions in total suspended solid (82.3 percent) and total solid (81.7 percent) loads. Reductions in total Kjeldahl nitrogen (55.2 percent) and total phosphorus (78.5 percent) loads were seen along with reductions in nitrate-nitrogen and nitrite nitrogen. The researchers theorized that as the trees in the riparian area mature, both uptake and denitrification rates will increase. Prior to installation of exclusion fencing, Line *et al.* (2000) found that the streambanks and channel bed were undergoing rapid degradation in several places. A section of the eroding stream was restored, so this action may have contributed to the significant reductions in sediment concentrations noted by the authors.

Dobkin *et al.* (1998) examined riparian meadow recovery following long and short term grazing impacts in southeastern Oregon. The researchers noted that in the four-year period following livestock removal from the area, the water table rose expanding the hyporheic zone laterally from the channel. Furthermore, water continued to flow in the stream for weeks longer even during the dry years. The more rapid recovery time exhibited by this Oregon stream was due in part to the relatively active floodplain (as indicated by a high entrenchment ratio) present in the channel at the time of livestock removal. The entrenchment ratio describes the relationship between the width of the flood-prone area and width of the channel at bankfull stage (Rosgen, 1994; Figure 2). A high entrenchment ratio indicates a wider active floodplain that helps to dissipate energy during flood flows. At the opposite spectrum, a low entrenchment ratio indicates a narrow floodplain typically observed in gulleys and other incised stream channels. These channels are subjected to higher shear forces during flood flows and are typically unstable. For incised streams with lower entrenchment ratios, the period of recovery would likely take much longer.

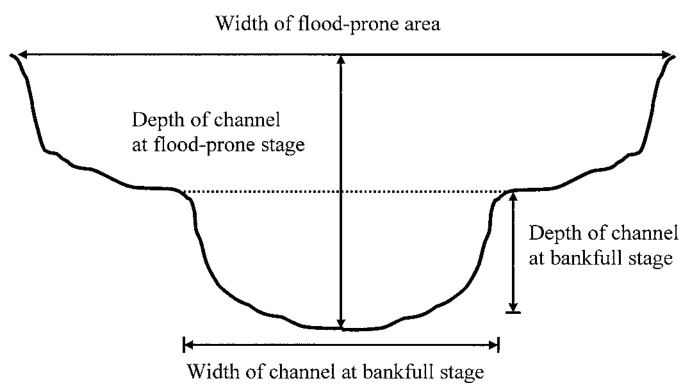

Figure 2. Entrenchment Ratio and Width to Depth Ratio. Entrenchment ratio is defined as the width of the flood prone area divided by with width of the channel at bankfull stage while the width to depth ratio is defined as the width of the channel at bankfull stage divided by the average depth of the channel at bankfull stage.

Kauffman *et al.* (1983) evaluated soil losses from grazed and excluded areas along a fourth-order Oregon stream. The researchers compared differences in streambank erosion and morphology changes between pastures with late season grazing and pastures excluded from grazing. Results indicated that the grazed areas had significantly greater streambank loses as compared to the areas with no grazing. The total annual streambank loss for the enclosed areas was 9 cm while that for the grazed areas was 27 cm.

The authors suggested measuring animal intensity in riparian pastures by animals per length of streambank rather than animals per unit area. Scrimgeour and Kendall (2003) examined streambank stability along three grasslands streams in Alberta, Canada, thought to have undergone grazing by bison or cattle over the past 7,000 years. The researchers found significant increases in streambank stability two years following cattle removal. The percentage of riparian vegetation along the exclosed streambanks was approximately three times greater than that of the unexclosed streambanks. Trimble (1994) noted a sixfold increase in streambank erosion as a result of uncontrolled cattle grazing along a Central Basin Tennessee stream when compared to a pasture with exclusion fencing. Bank breakdown was more attributable to trampling rather than the removal of riparian vegetation. Trimble (1994) noted that uncontrolled grazing was a primary cause of stream widening in the eastern U.S., especially since typical producers of this region practice year-long grazing, graze as many cattle as possible, and allow cattle unlimited access to streams.

Magilligan and McDowell (1997) examined stream morphological changes following 14 years of cattle exclusion from four steep, alluvial, gravel bed streams in eastern Oregon. Slopes were between 1 and 2.9 percent, and sinuosities (channel lengths divided by valley lengths) were between 1.06 and 1.68. The researchers noted decreases in bankfull width on the order of 10 to 20 percent that they strongly attributed to riparian vegetation. They concluded that the riparian vegetation trapped sediment resulting in a narrower channel. Bankfull depth was less responsive with increases reported in only a few of the examined reaches. Pool area was the second most responsive morphological parameter with this variable increasing by 7 to 14 percent in all exclosures. Increases in pool area were accompanied by a decrease in glide area. On the other hand, Kondolf (1993) did not find any significant morphological changes in a 24-year old exclosure along a Californian stream. Although lush vegetation within the exclosure suggested narrowing of the channel, channel width was not significantly different from grazed reaches outside the exclosure. Similarly, Allen-Diaz *et al.* (1998) and George *et al.* (2002) did not detect any morphological changes to headwater streams located in seasonally grazed pastures in the Sierra Foothills of California.

Platts and Nelson (1985) evaluated stream response to the removal of livestock pressures along Big Creek in northeastern Utah. The rangeland removed from grazing was in between two grazed areas along the same stream. Following 11 years of exclosure, the researchers noted improvements in the conditions of the riparian vegetation, streambanks, and stream channel. A greater abundance of overhanging riparian vegetation, a feature attractive to fish, was noted in the ungrazed field. The average streambank angle, a measure of steepness, in the ungrazed area was less than that of the grazed fields indicating less of a potential for bank slump. Differences between the treatments with regards to the channel material were also evident. While the bed material of the exclosed area contained a greater percentage of larger sized particles than either of the grazed areas, an indication that the exclosed reach is more hydraulically efficient, it received a significant sediment supply from the upstream grazed field. This downstream migration of sediment indicates the potential impact that unmanaged upstream grazed riparian zones can exert on downstream reaches.

BIOTIC RESPONSES TO EXCLUSION FENCING/RIPARIAN BUFFERS

Chapman and Ribic (2000) investigated the effect of managed intensive grazing and buffer strips on small mammal abundance along southwestern Wisconsin streams. No difference was detected between the continuously grazed pastures and those under the managed intensive grazing strategy. However, pastures with buffer strips had a significantly richer and more abundant small mammal community. Furthermore, the density of the small mammals was greatest near the stream (within 5 m) for all pastures regardless of buffer presence.

Weigel *et al.* (2000) did not find any significant ecological differences with regards to macroinvertebrate feeding type when examining reaches with continuous grazing, intensive rotational grazing, or buffer strips in southwestern Wisconsin. However, the researchers did note larger shredder populations in reaches with woody buffers as opposed to those with grass buffers. Continuously grazed reaches were the least taxonomically rich. Sovell *et al.* (2000) did not detect any differences in benthic macroinvertebrate and fish habitat between stream reaches in wooded and grassed buffered zones in southern Minnesota. The researchers found similar percentages of canopy cover for both buffer types with almost complete stream coverage for segment widths up to 4 m. Special consideration should be given to buffer type as the stream width increases to ensure adequate canopy cover and thus temperature regulation.

Dobkin *et al.* (1998) examined the rate of recovery for riparian bird species by monitoring species richness and abundance inside and outside an exclosure established along an Oregon stream for a three-year period. Not only did the researchers note a greater number of birds within the exclosure, they also found changes in species types. A greater number of riparian bird species were identified within the exclosure while a larger concentration of upland birds was seen outside the exclosure. Krueper *et al.* (2003) also detected increases in riparian bird species following the removal of cattle from riparian areas along the San Pedro River in southeastern Arizona.

Scrimgeour and Kendell (2003) examined the effects of grazing on benthic invertebrate numbers and composition along three streams in Alberta, Canada. While increases in total benethic invertebrate abundance was not detected between grazed and exclosed reaches, the researchers noted greater concentrations of coarse particular organic matter and shredders in the exclosed reach. With the large populations of collectors and scrapers present in agricultural systems, the addition of these benthic organisms to the ungrazed reach signaled the onset of recovery.

MICROBIOTIC RESPONSES TO EXCLUSION FENCING/RIPARIAN BUFFERS

Livestock walking or loafing in streams can introduce pollution via fecal deposition. While unable to predict the percentage of fecal coliform contamination in relation to distance of manure deposition from a stream, Larsen *et al.* (1994) were able to conclude that the presence of bovine feces in a stream had a much greater water quality impact than those deposited within a few meters (less than 2.5 m) from the stream. The researchers concluded that a 95 percent reduction in bacterial loads was possible if the minimum distance of 2.5 m between the feces and the collection point (i.e., stream) was maintained. While research points to the potential health hazards of fecal contamination to streams (Pell, 1997), research regarding the effectiveness of commonly recommended grazing BMPs such as an alternate water source, supplemental feeding and exclusion fencing is relatively nonexistent.

One concern is the effect of sediments on bacterial survival rates. Research into the role of stream sedimentation and fecal coliforms indicates that bottom sediments act as reservoirs for the organisms. Stephenson and Rychert (1982) indicated a definite relationship of greater concentrations of *E. coli* in bottom sediments as compared to the overlying waters. Van Donsel and Gelreich (1971) noted similar results with concentrations of sediment fecal coliforms 100 to 1,000 times greater than that of overlying waters. Disturbance of bottom sediments resulted in higher *E. coli* concentrations in the overlying waters from their resuspension (Stephenson and Rychert, 1982). Streams impacted by grazing or greatly reduced sediment load due to BMPs may become unstable resulting in erosion. The creation of a bacterial reservoir may then occur as a result of the inability of unstable streams to transport sediment though the watershed. A significant reduction in peak flow associated with selective structural BMPs may also increase stream bed depositional processes depending on the sediment transport capacity of the stream.

A second area that requires consideration is the size of sediment that is supplied to the stream. In addition to sedimentation, particle size had a crucial effect on the survival rate of fecal coliforms. Howell *et al.* (1996) discovered that the mortality rates of fecal coliforms were much lower in clay-sized sediment as opposed to coarser sediments. Similarly, fecal streptococci mortality rates declined in clay sized sediments. Sherer *et al.* (1992) also noted a relationship between sediment type and fecal survival rates with higher survival rates occurring in fine sediments. Burton *et al.* (1987) observed that *E. coli* survived longer in sediments containing at least 25 percent clay. Implementation of BMPs designed to reduce fecal contamination may be more critical in those streams dominated by silt and clay channel materials.

Controlled Grazing

The literature indicates that careful management can reduce the damage cattle cause to streambanks. Practices such as continuous grazing and confined feeding degrade stream ecosystems. Owens *et al.* (1997) noted a 60 percent increase in sediment loss in an Ohio watershed that experienced summer rotational grazing and winter-feeding as compared to only summer rotational grazing. In Pennsylvania, Stout *et al.* (2000) examined the effects of stocking rates on nitrate leachate in an intensively grazed system consisting of a series of paddocks. While this management system can improve profitability for dairy farmers, it can also increase the amounts of nitrate to levels negatively impacting water quality. Owens *et al.* (1989) linked increased grazing pressure from a continuous grazing practice to increases in organic nitrogen, total organic carbon, and sediment concentration and transport.

Alternatives to continuous grazing include grazing management strategies such as intensive rotational grazing (IRG) and seasonal grazing. Installation of an intensive rotational grazing system in Wisconsin resulted in reductions in streambank erosion and fine substrate in the channels (Lyons *et al.,* 2000). For IRG systems and grassy buffer strips, the researchers noted similar stream enhancements in reduced streambank erosion, lower fine substrate levels, and reductions in width to depth ratios when compared to continuous grazing. Sedgwick and Knopf (1991) examined prescribed grazing as a management strategy to minimize grazing impacts along a Colorado stream. The researchers discovered that riparian vegetation proved resistant to grazing impacts when the pastures were stocked at 90 percent capacity. Clary (1999) stated that light to medium grazing for short duration did not negatively impact an Idaho stream. When grazing utilization was maintained at or below 50 percent for a two-week period during the latter part of June, the stream responded positively with reductions in width to depth ratios and stream embeddedness (percentage of larger particles such as gravel and boulders covered by fines). For this mountainous region of the U.S., the latter part of June corresponds to the period when dry meadow vegetation along central Idaho streams is at its optimum state. The short-duration, light to moderate grazing examined in the study allowed for the re-establishment of riparian vegetation in a once heavily grazed area.

Marlow *et al.* (1987) noted that along a Montana stream, cattle use alone did not account for the changes to the stream channel profile. Rather the greatest amount of streambank damage occurred during periods of high stream flow, high soil moisture levels, and cattle use. Similarly, Owen *et al.* (1997) stated that less than 4 percent of the average annual sediment losses were attributed to the period of August to October. In the southern humid region, this period typically corresponds to the driest time of the year. Furthermore, the authors noted that the impacts of a grazing system, consisting of summer rotational grazing with winter supplemental feeding, did not last longer than one year following a management change to only summer rotational grazing.

Gary *et al.* (1983) examined the impacts of seasonal cattle grazing on the water quality of a Colorado stream. Only minor changes to the physical, chemical, and bacteriological properties of the stream water were noted. Stocking density was critical to managing bacteria densities in the stream. Fecal coliform and fecal streptococci levels significantly increased when stocking densities were 1.75 cow/calf pairs per hectare or greater.

As an alternative to continuous grazing, Sovell *et al.* (2000) examined the physiochemical and biological impacts of rotational grazing on five Minnesota streams. Over a two-year period, the researchers found higher fecal coliform and turbidity levels for the continuously grazed sites. Additionally, continuously grazed sites had higher percentages of fines likely due to greater areas of streambank exposure. No distinction was made between either management strategy and fish density, and concentrations of benthic macroinvertebrates were inconsistent across sites.

Supplemental Feeding

McInnis and McIver (2001) evaluated the influence of offstream water and trace mineralized salt on grazing distribution and subsequent changes in streambank cover and stability under moderate stocking densities. Bed material of the stream transecting the treatment plots varied from a cobble to sand substrate mixture for the upper most third to a predominately sand mixture for the downstream two thirds. The implemented BMPs were effective at reducing the development of both uncovered streambanks (i.e., those without sufficient vegetation or armoring) and unstable streambanks (i.e., those exhibiting breakage, slump, fracture, or steep vertical banks) by 9 percent over two grazing seasons. While McInnis and McIver (2001) noted that grazing increased the potential for erosion, the use of an offstream water and mineral supplement may not be effective once accelerated erosion had begun. Such occurrence will likely require intervention through stream restoration.

Using the same study location and period as McInnis and McIver (2001), Porath *et al.* (2002) examined the distribution patterns of the cattle both with and without access to offstream water and supplement. During the early portions of the grazing period (July), the authors noted that cattle without access to offstream water or supplements approached the stream earlier and spent more time within the riparian area as compared to cattle supplied with offstream water and supplements. However, both groups of cattle spent more time grazing in the riparian areas during the latter portions of the grazing season. Porath *et al.* (2002) noted no significant difference in the amount of manure deposited within the riparian areas between the two groups of cattle. Based on counts of fecal deposits within a 1 m buffer of the stream and estimates of defecation amounts and rates for a 500 kg cow, Porath *et al.* (2002) estimated that 252 kg of manure were deposited within the monitored one-meter riparian zone of the 2.4 km reach during the 42 day study period. This equates to approximately 1.5 percent of a cow total manure production. No estimates were provided for manure deposited directly in the stream, nor were estimates given for urine production.

Multiple BMPs

Information pertaining to the effectiveness of individual BMPs and the functional relationships among a system of controls is useful when designing and implementing BMPs in a watershed. By linking this information to the stream, managers could design a more economically and environmentally effective sustainable BMP program that comprehensively addresses stream water quality. Brannan et al. (2000) identified reductions in both loads and concentrations for several water quality constituents following the installation of multiple BMPs in a Virginia watershed. The animal waste BMP system consisted of waste storage facilities, nutrient management, exclusion fencing along streams, water troughs, and stream crossings. Reductions were detected for total suspended solids concentrations (35 percent), soluble organic nitrogen concentrations (62 percent), nitrate nitrogen concentrations (35 percent), particulate phosphorus concentrations (78 percent), and soluble phosphorus concentrations (39 percent). However, orthophosphate concentrations increased by 7 percent. The researchers noted that when phosphorus is the primary water quality concern, nutrient management plans should be based on bioavailable phosphorus.

Edwards *et al.* (1997) evaluated the effects of nutrient management, dead poultry composting, waste storage and utilization, as well as pasture and hayland management on storm flow stream quality in a northwest Arkansas watershed consisting predominantly of pasture and forest land. For the two streams monitored, storm flow concentration reductions were noted for nitrate-nitrogen (23 percent), ammonia-nitrogen (45 percent), total Kjeldahl nitrogen (48 percent), and chemical oxygen demand (29 percent). Of the various BMPs implemented, the researchers stated that nutrient management was the most probable BMP responsible for the constituent reductions. Edwards *et al.* (1996) noted decreases in ammonia-nitrogen (65 percent), total Kjeldahl nitrogen (59 percent), and chemical oxygen demand (53 percent), but nitrate-nitrogen concentrations were stable from the pre to the post-BMP period.

CONCLUSIONS

There is a lack of scientific information regarding the effectiveness of several commonly implemented grazing BMPs in protecting water quality and stream stability. Of the 21 BMP studies examined in this paper that were effective at significantly reducing grazing impacts to streams, six studies documented water quality effects associated with the implemented BMPs, 14 studies assessed geomorphic changes to the stream, and six studies examined habitat changes. Of these studies, only three simultaneously examined water quality effects and geomorphic changes due to implementation of the BMP(s). The bulk of the literature examined the use of exclusion fencing/riparian buffers as a grazing BMP with a few studies targeting alternate water sources. The ability of certain grazing BMPs, such as alternate shade and forage availability (i.e., fertilizer and/or herbicide use), to impact water quality and stream morphology was not present in the literature.

During a four-year period from 1997 to 2001, approximately $910 million dollars was distributed through the EQIP alone. At a cost share rate of 36 percent for this period, the federal government and farmers spent over $2.5 billion dollars combined (USDA-NRCS, 2003b). Without a clear understanding of the ability of grazing BMPs associated with stream processes to enhance stream water quality developing an effective and cost efficient BMP program for a watershed becomes a difficult task. To develop such a program, stakeholders will need answers to questions regarding which BMP or combination of BMPs is best for their specific situation and stream.

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