Water quality and the grazing animal[1]

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ABSTRACT: Grazing animals and pasture production can affect water quality both positively and negatively. Good management practices for forage production protect the soil surface from erosion compared with conventionally produced crops. Grazing animals and pasture production can negatively affect water quality through erosion and sediment transport into surface waters, through nutrients from urine and feces dropped by the animals and fertility practices associated with production of high-quality pasture, and through pathogens from the wastes. Erosion and sediment transport is primarily associated with high-density stocking and/or poor forage stands. The two nutrients of primary concern relating to animal production are N and P. Nitrogen is of concern because high concentrations in drinking water in the NO_3 form cause methemoglobinemia (blue baby disease), whereas other forms of N (primarily nitrite, NO_2) are considered to be potentially carcinogenic. Phosphorus in the PO_4 form is of concern because it causes eutrophication of surface water bodies. The effect of grazing animals on soil and water quality must be evaluated at both the field and watershed scales. Such evaluation must account for both direct input of animal wastes from the grazing animal and also applications of inorganic fertilizers to produce quality pastures. Watershed-scale studies have primarily used the approach of nutrient loadings per land area and nutrient removals as livestock harvests. A number of studies have measured nutrient loads in surface runoff from grazed land and compared loads with other land uses, including row crop agriculture and forestry. Concentrations in discharge have been regressed against standard grazing animal units per land area. Watersheds with concentrated livestock populations have been shown to discharge as much as 5 to 10 times more nutrients than watersheds in cropland or forestry. The other major water quality concern with grazing animals is pathogens, which may move from the wastes into surface water bodies or ground water. Major surface water quality problems associated with pathogens have been associated with grazing animals, particularly when they are not fenced out from streams and farm ponds. This paper presents an overview of water quality issues relating to grazing animals.

Key Words: Forages, Manure, Nitrogen, Pathogens, Phosphorus, Sediment

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Introduction

Pollution of surface and ground waters from animal wastes is of growing environmental concern. High loading rates of sediment, N, P, and pathogens to soils and waters can occur from animal operations, such as grazing (Besser et al., 1993; Isaacson et al., 1993; Millard et al. 1994, Guan and Holley, 2003). Concentrations of N in excess of 10 mg/L in the nitrate (NO_3) form render groundwater unsuitable for drinking water for humans (Abbott, 1949; Lenain, 1967; Federal Register, 1975). High N concentrations entering streams or lakes may also contribute to eutrophication. Phosphate is adsorbed onto sediments and can be transported with the sediments to lakes and streams where its most significant effect is eutrophication (Clark et al., 1985). Animal waste has been shown to be a source of microorganisms pathogenic to humans (Howell et al., 1995; 1996; Mawdsley et al., 1995; Fraser et al., 1998). When surface runoff or leaching occurs due to excessive irrigation or rainfall, contamination of water resources by enteric bacteria may result (Entry et al., 1999). These same bodies of water are often used for sources of drinking water or for recreational activities; therefore, elevated concentrations of enteric bacteria pose a potential health hazard.

The amount of wet feces produced per 1,000 kg of animal live weight per day for grazing animals ranges from 40 to 86 kg for sheep and dairy cattle respectively

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Table 1. Fresh manure production and characteristics

Item	Units[b]	Animal type[a] Dairy	Beef	Sheep	Horse
		kg (1,000 kg/d)			
Total manure[c]	Mean[d]	86	58	40	51
	SD	17	17	11	7.2
Urine	Mean	26	18	39	10
	SD	4.3	4.2	4.8	0.74
Total solids	Mean	12	8.5	11	15
	SD	2.7	2.6	3.5	4.4
Biochemical oxygen demand, 5-d	Mean	1.6	1.6	3.1	1.7
	SD	0.48	0.75	0.72	0.23
Chemical oxygen demand	Mean	11	7.8	11	NA[d]
	SD	2.4	2.7	2.5	NA
Total Kjeldahl nitrogen[e]	Mean	0.45	0.34	0.42	0.30
	SD	0.096	0.073	0.11	0.063
Ammonia nitrogen	Mean	0.079	0.086	NA	NA
	SD	0.083	0.052	NA	NA
Total phosphorus	Mean	0.094	0.092	0.087	0.071
	SD	0.024	0.027	0.030	0.026
Orthophosphorus	Mean	0.061	0.030	0.032	0.019
	SD	0.0058	NA	0.014	0.0071
Potassium	Mean	0.29	0.21	0.32	0.25
	SD	0.094	0.061	0.11	0.091
Total coliforms[f]	Mean	1,100	63	20	490
	SD	2800	59	26	490
Fecal coliforms[f]	Mean	16	28	45	0.092
	SD	28	27	27	0.029
Fecal streptococci[f]	Mean	92	31	62	58
	SD	140	45	73	59

[a]Differences within species according to usage exist, but sufficient fresh manure data to list these differences were not found. Typical live animal masses for which manure values represent are dairy, 640 kg; beef, 360 kg; sheep, 27 kg; horse, 450 kg (ASAE, 2003).
[b]All values are expressed on wet basis.
[c]Feces and urine as voided.
[d]Mean estimates within each animal species are comprised of varying populations of data. Maximum numbers of data points for each species are: dairy, 85; beef, 50; sheep, 39; horse, 31. NA = data not found.
[e]All nutrients values are given in elemental form.
[f]Mean bacteria colonies per 1,000 kg of animal mass multiplied by 10^{10} colonies per 1,000-kg animal/mass divided by kg of total manure per 1,000 kg of animal mass multiplied by density (kg/m^3) equals colonies per m^3 of manure.

(Table 1). Average amounts of N (kg, wet basis) in manures range from 0.30 kg for horses to 0.45 kg for dairy cattle (Table 1). For P, the range is from 0.071 kg for horses to 0.094 kg for dairy cattle. At both field and watershed scales, grazing animals hence serve as a significant source for nutrients and organic matter.

Environmental Benefits of Forage Production and Grazing Animals

The soil improvement characteristics of grasslands have long been recognized (Ball et al., 2002). After land has been devoted to perennial forages for several years, the trend is for subsequent arable crops to produce better than would otherwise have been the case. The deep root penetration of many forage crops into compacted soil layers can leave channels that improve water and air movement and enhance root penetration of subsequent crops. Perennial grasslands also tend to make the soil more suitable for subsequent arable crops in other ways, including improving soil tilth due to the activity of earthworms, soil insects, and microorganisms. Over time, the nutrient-holding capacity of the soil increases and various mineral cycles operate to increase nutrient availability in the surface layer.

Compared with other agricultural land uses, growing forage crops greatly decreases erosion. Perennial grass sods are particularly effective in reducing soil erosion losses. Ball et al. (2002) concluded that if the percentage of cropland devoted to forage crops were substantially increased, there would be a considerable improvement in overall water quality. When livestock are produced on pasture and the land is not overgrazed, the likelihood of nutrient contamination of water may be much lower than that of heavily fertilized conventionally produced crops. When land has a thick cover of perennial forages, there is little runoff and therefore less chance for fertilizers to be washed away. Most forage crops, especially perennial grasses, form dense root systems that effectively serve as filters to remove contaminants before they can seep into the groundwater.

Organic components of feces and urine from grazing animals can build soil organic matter reserves, resulting in soils having increased water-holding capacity, increased water-infiltration rates, and improved structural stability. These changes can decrease soil loss by wind and water erosion. Soil applied manures decrease energy needed for tillage and reduce impedance to seedling emergence and root penetration (Wright, 1998). Manures stimulate the growth of beneficial soil microbial populations, increase microbial activity within the soil, and increase the population of beneficial mesofauna, such as earthworms.

Environmental Problems Associated with Grazing Animals

Sediment

Water quality of streams, lakes, or other water bodies may be degraded by excessive amounts of dissolved or suspended sediment in surface runoff or base flows. Numerous studies have reported sediment concentrations and loads for a variety of drainage systems (Long and Bowie, 1963; McGuinness et al., 1971; Griffiths, 1982; Neff, 1982; Carling, 1983), along with information relating loads to rainfall intensity and duration, runoff amount, drainage area, or land use (Dragoun and Miller, 1966; Dendy and Bolton, 1976; Costa, 1977; Ostry, 1982). Heavy loads of suspended sediment in streamflow can reflect erosion from grazed pastures with poor forage stands and heavy traffic from grazing animals.

It has been recognized that for over 90 yr, heavy, continuous grazing accelerates erosion and runoff (Rich, 1911; Duce, 1918; Sampson and Weyl, 1918). The literature is filled with examples of the adverse impacts of overgrazing on watersheds (Dunford and Weitzman, 1955; Ellison, 1960; Smeins, 1975; Dregne, 1978; Crouch, 1979). Love (1958) wrote, "There is a large body of information leading to the conclusion that heavy grazing has had bad hydrologic consequences." It is doubtful that more investigations are needed to emphasize this conclusion.

Nitrogen

The compound form of N of primary concern is NO_3 nitrogen. Nitrate movement into surface and ground waters is of concern both for health and environmental quality reasons (Galloway et al., 2003). Nitrate concentrations in excess of 10 mg/L cause methemoglobinemia, which is toxic to infants (Federal Register, 1975). Most cases of methemoglobinemia occur after consuming water with high concentrations of NO_3 nitrogen. Infants are particularly susceptible, as are people who receive kidney dialysis treatment (Follett and Follett, 2001). In the United States, NO_3 nitrogen concentrations exceed this level in more than 15% of groundwater samples from four of the 33 major regional aquifers most commonly used as sources of drinking water (Nolan and Stoner, 2000). Other effects associated with elevated concentrations of NO_3 nitrogen in drinking water include respiratory infection, alteration of thyroid metabolism, and cancers induced by conversion of NO_3 nitrogen to N-nitroso compounds in the body (Follett and Follett, 2001). Eutrophication of lakes or other water bodies occurs when excess plant or algal growth takes place. Nitrogen may be a limiting nutrient to growth of these species, and hence excess NO_3 nitrogen levels entering streams or lakes with surface runoff or by shallow subsurface flow may cause environmental quality problems.

Nitrogen exists in soil as NO_2, NO_3, or NH_4 nitrogen, or in organic forms within the soil organic matter fraction. Nitrate ions are repelled by the clay particles in the soil and generally are not absorbed within the soil matrix. Hence, as water moves through the soil, NO_3 nitrogen generally moves freely with the water. The actual movement of NO_3 nitrogen through soil lags behind the wetting front due to mixing processes such as diffusion and hydrodynamic dispersion, which occur between the resident soil solution and the infiltrating water from irrigation or rainfall. Numerous studies have documented NO_3 nitrogen concentrations greater than 10 mg/L in groundwater associated with agricultural activities including cropping enterprises, livestock, and grazing (Spalding and Exner, 1980; Hubbard et al., 1986, 1987; Naney et al., 1987; Sharpley et al., 1987; Hubbard and Sheridan, 1989, 1994). Nitrate contamination of groundwater can also occur in urban areas from septic tanks or over fertilization of lawns (Hubbard and Sheridan, 1994).

Nitrogen from the urine and feces of grazing animals can negatively affect water quality when the number of grazing animals per land area exceeds the N fertility needs of the forages. Campbell et al. (1977) compared standard beef cattle pasture stocking rate, double pasture stocking rate (cattle were supplemented with silage when necessary), confinement, and a natural area and found that NO_3 nitrogen concentrations in shallow groundwater wells at 1.2 m increased at the double stocking rate compared with the other treatments. A water quality problem can also occur when the sum of N from the inorganic fertilizers applied to produce quality forages plus N from the grazing animals exceeds N uptake by the forages. An example of such a problem is shown in Table 2 from Hubbard et al. (1987). This table shows NO_3 nitrogen concentrations in shallow groundwater from a study where dairy lagoon wastewater was applied by center pivot at two different wastewater application rates (496 or 1,018 kg of $N \cdot ha^{-1} \cdot yr^{-1}$). A control area received N fertilizer at recommended rates (491 of $N \cdot ha^{-1} \cdot yr^{-1}$) for production of coastal bermudagrass (*Cynondon dactylon* L.). All of the areas were grazed by cattle during the winter months. Table 2 shows that the highest NO_3 nitrogen concentrations in the shallow groundwater at a depth of 3.6 m were found under the control area. Although the control

Table 2. Mean NO_3 N concentrations in shallow groundwater by depth and treatment at dairy lagoon wastewater application site

Treatment	Depth, m		
	1.2	2.4	3.6
Wastewater			
Low N rate, 496 kg of $N \cdot ha^{-1} \cdot yr^{-1}$	45^{ax}	36^{ay}	16^{bz}
High N rate, 1018 kg of $N \cdot ha^{-1} \cdot yr^{-1}$	42^{ax}	28^{by}	16^{bz}
Control			
Inorganic N at recommended rates, 491 kg of $N \cdot ha^{-1} \cdot yr^{-1}$	34^{bx}	28^{bx}	31^{ax}

[a,b]Means within depths with different superscripts differ ($P < 0.05$) according to a LSD test.
[x,y,z]Means within treatments with different superscripts differ ($P < 0.05$) according to a LSD test Hubbard et al. (1987).

area was selected with the initial hypothesis that it would have low NO_3 nitrogen concentrations in shallow groundwater compared with areas receiving dairy lagoon wastewater (because it received less applied N and did not have wastewater applied daily), in reality, the inorganic N applications at recommended rates for quality forage production plus waste from the grazing animals resulted in higher NO_3 nitrogen concentrations in the shallow groundwater at 3.6 m under the control area, than those found under the areas receiving lagoon wastewater. This finding of worse groundwater quality for NO_3 nitrogen under forage production with grazing compared with high loadings of liquid animal wastes shows that it cannot be assumed that grazing and forage systems will enhance water quality. Without careful consideration of total N applications from the grazing and forage production system, NO_3 nitrogen contamination of shallow ground water can occur.

Phosphorus

Phosphorus is of environmental concern because excess amounts in surface water bodies may cause eutrophication. Phosphate is a soluble agricultural chemical that may be moved from point of application by surface runoff or move out of the soil surface layer with percolation. In general, PO_4 is considered to be of concern primarily for surface runoff since it binds to Fe, Al, or Ca in the soil depending on pH and is not readily leachable. Soluble PO_4 and PO_4 associated with sediment in surface runoff have been found to vary linearly with P application rate (Romkens and Nelson, 1974). Low concentrations of dissolved PO_4 have been found in runoff from deep incorporation of fertilizers (Holt et al., 1970). Movement of PO_4 through the soil profile varies with soil texture. For nonsandy soils, the leaching of PO_4 with percolating water is extremely low or indetectable. The PO_4 content of percolate from nonsandy soils can be within an order of magnitude of 0.1 mg/L (Russell, 1961). Numerous investigators (Spencer, 1957; Hingston, 1959; Russell, 1960; Bolton and Coulter, 1996), however, have shown that in very sandy soils, PO_4 will move down the profile to a considerable depth (>1.0 m). On the basis of diffusion studies, Olsen and Watanabe (1970) concluded that there was an eight-times-greater risk of PO_4 pollution of ground water from sands than from clays.

The contribution of P from animal wastes can under some circumstances represent a significant fraction of the P circulating in agricultural systems. Where fecal matter is deposited into farm ponds or streams the direct effect may be noticeable. Most severe P problems related to animal wastes may arise where there are local, high density animal populations in feedlots, barnyards, or pastures close to streams (Schepers and Francis, 1982; Schepers et al., 1982; Fisher et al., 2000). Actual losses will depend upon management practices. Chichester et al. (1979) showed that concentrations of P in runoff were not increased by summer grazing of pasture in Ohio, but where animals were pastured throughout the year, winter damage to the soil surface (trampling from hooves damaging vegetation and causing soil compaction) caused both increased runoff and nutrient discharge.

Pathogens

Water quality in many lakes and rivers has been impaired by the presence of high levels of fecal coliform bacteria, which is indicative of contamination by feces (Jones and Roworth, 1996; Ackman et al., 1997). Such contamination brings the threat of infection for people who use the water for drinking, bathing, or watering fruits and vegetables. Underlying this concern are numerous reports of waterborne outbreaks of disease involving fecal organisms such as *Escherichia coli* O157:H7, *Campylobacter jejuni*, *Salmonella* species, *Vibrio cholerae*, and shigellae (Jones and Roworth, 1996; Gugnani, 1999; Licence et al., 2001). Other bacterial infections that can be transmitted in water from animal to animal and from animal to human include *Listeria*, *Leptospira*, *Brucella*, *Coxiella*, and *Mycoplasma* (Hensler et al. 1970; Young 1974; Hatfield et al., 1998). Nonbacterial infectious agents that can be transmitted in water include fungi and protozoa (*Cryptosporidium*). Managers of modern manure management systems, including grazing, must take into account the possibility of disease transmission through the environment and must therefore try to prevent manure-laden runoff from reaching water bodies. It is also important to determine whether the source of fecal contamination is of human, livestock, or wildlife origin, as microorganisms of human origin are regarded as having greater potential to cause disease in humans (Puech et al., 2001).

Recent interest in this area has focused on *Cryptosporidium parvum*, a widespread protozoan parasite afflicting animals and humans (Wright, 1998). The dominant mode of transmission of *C. parvum* to humans is believed to be via contaminated drinking water and recreational waters. Zoonosis is the term used to describe infections crossing hosts, such as the case with *C. parvum*. Although no clear-cut epidemiological cause and effect has been established, it is widely believed that farm animals are the predominant source of *C. parvum*. Dairy farms are particularly suspect as potential sources of *C. parvum* because newborn calves are readily infected and excrete large numbers of the infectious stage (oocyst) of this organism (Wright, 1998).

Oxygen-Demanding Materials

Manure from grazing animals contains organic matter, which can serve as oxygen-demanding materials (Hatfield et al., 1998). Organic matter serves as an energy source for aerobic bacteria in a receiving stream or lake. Increased bacterial metabolism resulting from a discharge of organic waste into a water body increases the oxygen depletion rate of the water. If the rate of oxygen depletion exceeds the aeration rate of the stream, oxygen depletion occurs. Decreased or depleted oxygen levels can result in fish kills and anaerobic conditions in the stream or other water body.

Organic matter in contaminated waters has historically been measured as biochemical oxygen demand (**BOD**). This is a measure of the amount of oxygen required to metabolize waste during a specified time, usually 5 d (Hatfield et al., 1998). Another measure of organic strength of a waste is chemical oxygen demand (**COD**), which is based on chemical rather than biological oxidation. Chemical oxygen demand will exceed the BOD demand value for animal wastes, since animal manure and other waste products contain organic materials resistant to aerobic bacterial degradation. Chemical oxygen demand/BOD demand ratios vary from 3.5 to 6.5 depending on species and feed rations (Hatfield et al., 1998). The ASAE standards (2003) show COD ranging from 7.8 to 11 kg and biochemical oxygen demand ranging from 1.6 to 3.1 kg (Table 1).

Importance of Landscape Scale in Evaluating Potential Water Quality Effects of Grazing Animals

Concerns with grazing animals relate primarily to animal density and quality of forage stand. Assuming a good forage stand with protection of the soil surface against erosion, there are few environmental concerns at low grazing animal density. Concerns at low animal density primarily relate to the animals having free access to water bodies in which they can deposit urine and manure, and the accompanying problems with N, P, pathogens, and organic matter, which affect biochemical oxygen demand and chemical oxygen demand. Common good grazing management practices at both low and medium animal densities that alleviate nutrient and pathogen management issues include rotational grazing, portable water supply, portable shade source, and fencing animals from water bodies.

Most environmental concerns with grazing animals occur at high animal densities. With high animal densities, forages may be overgrazed, trodden, and significant soil erosion may occur. Pluhar et al. (1987) compared selected grazing treatments in the Texas Rolling Plains and showed that grazing caused a significant decline in infiltration rates and a significant increase in sediment production as compared to an ungrazed enclosure. High animal densities result in large amounts of urine and feces deposited in relatively small areas and increased probabilities for nutrients and pathogens to move with surface runoff or enter groundwater. Urine and feces from grazing animals are deposited at separate times and in different areas of the pasture. Grazing animals avoid feces piles and surrounding vegetation due to odor at first, and then to maturity of the vegetation afterwards. Grazing animals also tend to congregate in shady areas or around water supplies, which means that there are localized areas within pastures with much greater trampling damage and loads of urine and feces.

Landscape scale is an important consideration when evaluating the potential environmental impacts on water quality associated with grazing animals. At the individual pasture or field scale, consideration is primarily related to maintaining a good forage stand, having the proper numbers of animals per land area, and fencing animals out of streams and other water bodies. At the large landscape or watershed scale, grazing animal densities and proximity of operations to streams, rivers, and lakes are important. An example of a gauged watershed where hydrologic flow is measured and water samples are collected for sediment, N, P, and pathogen analyses is shown in Figure 1. This is the Little River Watershed, as gauged by the Southeast Watershed Research Laboratory, Tifton, GA. The watershed is 334 km^2 in area and is gauged in a nested design from the smallest subwatersheds (K, J) in the upper part of the Little River Watershed to Station B, which gauges the entire 334 km^2. This watershed has relatively few grazing animals. However, the size and nested design of this gauged watershed illustrate the scale at which the impact of grazing animals on water quality should be evaluated.

Although individual pastures with grazing animals may not appear to be causing water quality problems if there is no obvious erosion and the animals are fenced

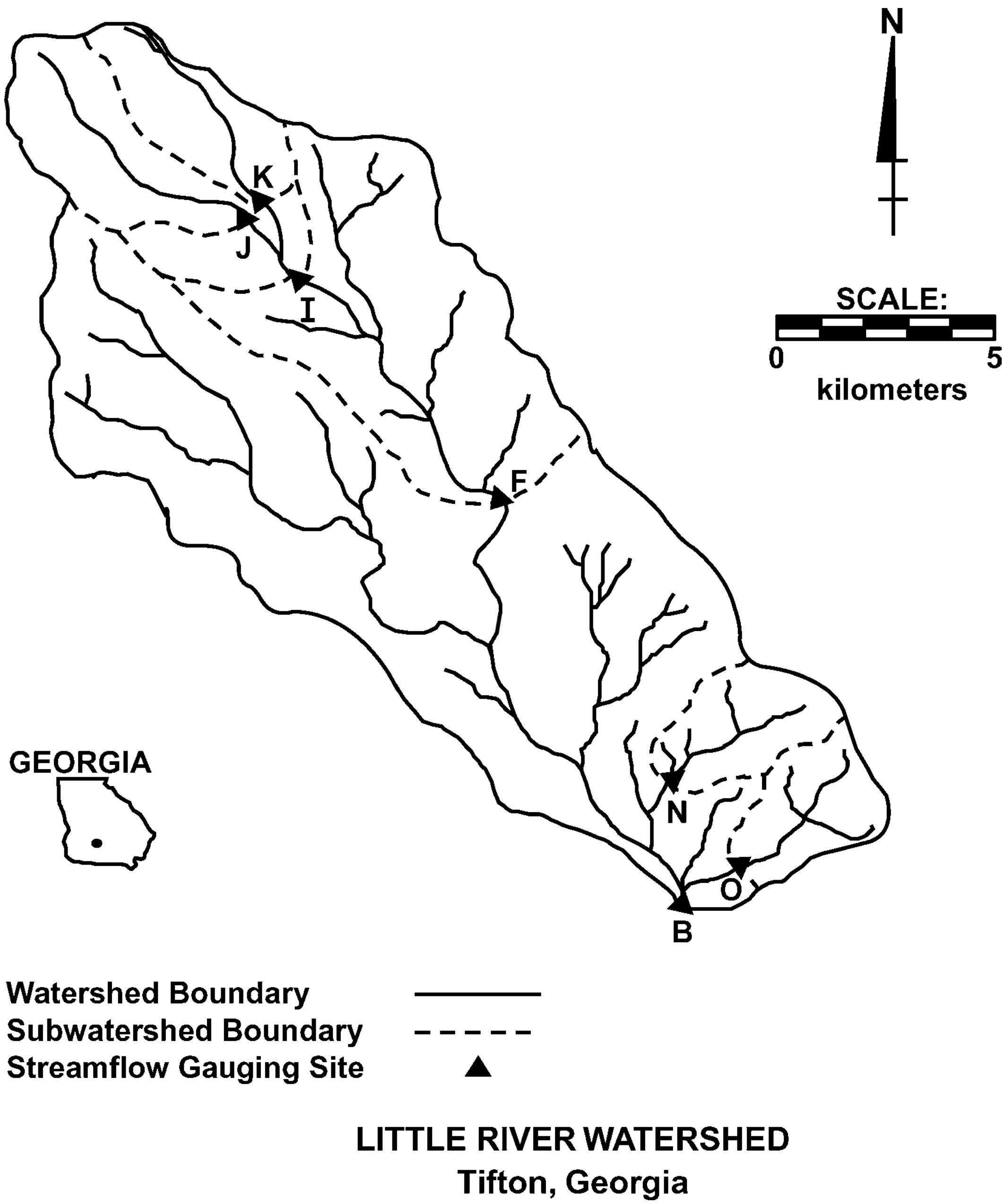

Figure 1. Schematic of Little River Watershed with subwatershed boundaries and streamflow gauging sites (Tifton, GA).

out of the streams and riparian zones, the true impact of animal production systems (including grazing) is determined by measurements at a larger landscape or watershed scale. The overall impact of grazing animals is the sum of the total animals at the large scale, how they are distributed over the watershed, and management practices within each operation. Water quality problems associated with grazing animals tend to be most serious when the total number of animals in a landscape or watershed significantly exceeds the carrying capacity of the land, poor management practices are used, and when animal operations are in the lower part of the landscape. Assessment of overall impact of animal production at the landscape scale must also consider confined animal production operations. These operations in general pose a much greater risk to soil and water quality at both the local and landscape scale than do grazing operations.

Riparian Buffer Systems

One landscape management tool that has been found to be effective in reducing water pollution from both cropland and grazed areas in the humid eastern part of the United States is use of riparian buffer systems. Many studies at different sites in the Gulf Atlantic Coastal Plain region have shown that concentrations and loads of N in surface runoff and subsurface flow

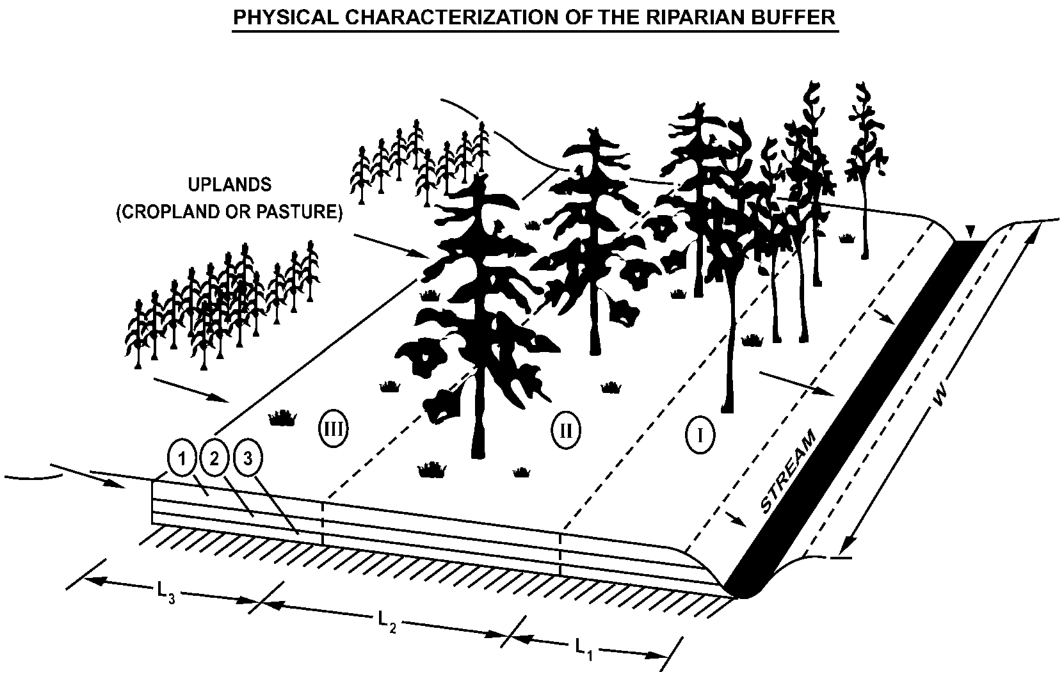

Figure 2. Schematic of three zone riparian buffer system. Zone III is grass; Zone II represents managed trees that are periodically harvested; Zone I shows hardwood trees that protect the stream bank.

are markedly reduced after passage through a riparian forest (Lowrance et al., 1983, 1984; Peterjohn and Correll, 1984; Jacobs and Gilliam 1985; Hubbard et al., 1996). The limited field data on using riparian forests to control agricultural nonpoint source pollution has been integrated into draft national specifications for riparian buffer systems by the USDA-Natural Resources Conservation Service and Forest Service. These draft specifications provide for a riparian buffer system of three zones (Figure 2). Zone 1 is a narrow band of permanent trees (5 to 10 m wide) immediately adjacent to the stream channel, which provides streambank stabilization, organic debris input to streams, and shading of streams. Zone 2 is a forest management zone where maximum biomass production is stressed, within limits placed by economic goals. Zone 2 may be harvested on appropriate rotations (20 to 60 yr). Zone 3 is a grass buffer strip up to 10 m wide used to provide control of coarse sediment and spreading of overland flow. In drier portions of the United States, where tree growth is difficult, buffers of grasses have been advocated. However, recent work by Hubbard et al. (2003) indicates that grasses alone are not as effective in assimilating nutrients as combined grass-riparian forest buffers.

On January 15, 2003, the U.S. Environmental Protection Agency adopted new Federal rules governing animal feeding operations (http://cfpub.epa.gov/npdes/index.cfm). All states must now adopt new rules that are at least as stringent as these new federal rules. The new rules require 30.4 m setbacks from surface water or 10.6 m vegetated buffers on all large animal feeding operations. Although these rules are specific to confined animal feeding operations rather than grazing animals, inclusion of riparian buffers into grazing of pastures is recommended.

Implications

Forage production and grazing animal systems can both positively and negatively affect water quality. Compared with cropland, forage systems protect the soil surface from erosion, and, if fertilizer and animal waste inputs are low to moderate, both surface and ground water quality under grazed areas may be better than that under cropped areas. The water quality contaminants of concern from grazing systems are sediment (erosion), N, P, pathogens, and organic matter. Grazing animals negatively affect water quality when the number of animals exceeds the carrying capacity of the land (at both the pasture and watershed scales). Forage production may have negative effects on water quality when fertilizer plus animal waste inputs exceed crop nutrient needs, or when forage quality is poor and soil erosion can occur. Grazing animal systems should be managed to include adequate land area for animal numbers at the field and landscape scale, fencing animals out of streams and lakes, and use of riparian buffer systems to assimilate sediment, nutrients, and pathogens from grazing animals.

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