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Riparian Buffer Systems in Crop and Rangelands[1]

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Abstract — Riparian ecosystems occupy a narrow belt of land along streams and around lakes and wetlands and are characterized by plant and animal communities that are dependent on close proximity to water. These ecotones function as buffer zones for materials moving from the uplands toward the surface water. They control stream morphology and ecology and also maintain landscape biodiversity by providing diverse habitats and corridors for animals and plants. Most of the riparian zones in the Midwestern agroecosystems and arid and semi-arid western rangelands have been extensively impacted by agricultural cropping and grazing activities. These impacts have generally decreased water quality, impaired riparian and instream biodiversity, increased water quantity, and modified the timing of streamflow. Riparian zones are generally resilient because of their moist, moderate and fertile environments. With proper management, this resiliency can be sustained. Proper management should include construction or restoration of multi-species buffer strips and deferred or rotational grazing or exclusion of livestock. Several riparian zone restoration and management strategies are discussed.

Introduction

Riparian zones lie between aquatic and upland ecosystems in landscapes and play a critical role in the hydrology of watersheds (Smith 1992; Kira 1988; Lowrance et al. 1985a; Lowrance et al. 1984a). Because of their landscape position and their more frequent natural disturbance, riparian zones contain sharp biological and physical gradients. This results in a plant community that often contains a mosaic of age classes of upland species and species adapted to abundant water (Anderson and Masters 1992; Gregory et al. 1991). The typically long and narrow nature, along with the unique physical and biological processes, allow riparian zones to act as "strategic" buffers between upland and aquatic ecosystems (Osborne and Kovacic 1993; Nutter and Gaskin 1989; Lowrance et al. 1985b). Although a riparian zone may occupy as little as one percent of the land area in the arid watersheds of the west, these ecosystems are among the most productive in the landscape (Chaney et al. 1990). This paper will describe the important riparian ecosystem functions, present conditions of riparian zones in Midwestern agroecosystems and semi-arid and arid rangelands, and strategies for their restoration and management. Strategies discussed include the multi-species riparian buffer strip management system and methods of seasonal, deferred and rotational grazing.

Riparian Zone Functions

Riparian zones provide important links between the terrestrial upland ecosystems and aquatic stream or lake ecosystems (Osborne and Kovacic 1993; Franklin 1992; Elmore 1992; Gregory et al. 1991; Welsch 1991; Lant and

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Roberts 1990). Some of the most important functions in agricultural and grazing landscapes include filtering and retaining sediment, immobilizing, storing, and transforming chemical inputs from uplands, maintaining streambank stability, modifying stream environments, and providing water storage and recharge of subsurface aquifers.

Sediment Filtering and Retention

About 1.4 mt of sediment are delivered to surface waters in the US every year (Welsch 1991). Croplands account for 38 percent of this sediment while pastures and rangelands account for 26 percent (Welsch 1991). Excess sediment impairs aquatic life, clogs stream channels, reduces reservoir flood storage and contaminates water supplies. Riparian forest and grass communities can filter up to 90 percent of the sediment entering them from the uplands. The vertical structure of the standing plants and the organic litter provide frictional surfaces which slows water flow causing the sediment to be deposited (Magette et al. 1989; Dillaha et al. 1989; Cooper et al. 1987; Lowrance et al. 1986, 1988; Peterjohn and Correll, 1984; Brinson et al. 1981; Mahoney and Erman 1984). High infiltration rates of undisturbed riparian zone soils allow finer sediments and associated nutrients to enter into the soil before reaching the stream. As a result, as much as 80 percent of the phosphorus adsorbed to sediment particles can be filtered from surface runoff by forested riparian buffer zones (Welsch 1991). However, riparian zones are effective for sediment retention only if surface flow through them is maintained as sheet flow. Concentrated channel flow can destroy the continuity of the filter strip.

Longevity of sediment trapping ability varies between forest and grass communities. Cooper et al. (1987) and Lowrance et al. (1988) suggest that forest riparian buffers can filter sediments over long periods whereas Magette et al. (1989) and Dillaha et al. (1989) indicate that grass buffer strips may have short sediment filtering lives. If cool season, short grasses are replaced by native, tall prairie grasses, grass buffer strips have a longer sediment trapping life span (Schultz et al. unpublished data). In either case, sediment accumulation along the edges of any riparian buffer strip will have to be periodically renovated and areas of concentrated flow will have to be modified. Filtration of sediment from flood flows will also build streambanks and can create wet meadows and floodplain ecosystems (Chaney et al. 1990).

Nutrient and Chemical Processing

A growing body of evidence indicates that vegetated riparian zones can be effective at immobilizing, storing, and transforming chemical inputs from uplands. One of the major problems associated with agricultural production in the US is movement of fertilizers and pesticides from the uplands into the surface waters of the landscape (Knox and Moody, 1991; Lant and Roberts 1990; Felsot, 1988). Nitrogen is one of the most pervasive of the chemical non-point source (NPS) pollutants. Croplands contribute 43 percent of the annual nitrogen input to surface waters while pasture and rangelands contribute 25 percent (Welsch 1991).

Riparian forests and grass communities reduce nitrogen by 40-100 and 10-60 percent, respectively (Petersen et al. 1992; Osborne and Kovacic 1993). The methods of chemical removal in riparian systems include plant and microbial uptake and immobilization, microbial transformation in surface and groundwater and adsorption to soil and organic matter particles. The effectiveness of these processes will depend on the age and condition of the vegetation, soil characteristics such as porosity, aeration, and organic matter content, the depth to shallow groundwater and the rate with which surface and subsurface waters move through the buffer strip (Groffman et al. 1992; Lowrance 1992).

Plants can assimilate and immobilize nutrients such as nitrogen (N) and phosphorus (P) as well as heavy metals and pesticides. However, to be effective at removing these chemicals, plants must have access to high water tables or there must be sufficient unsaturated flow (Ehrenfield 1987).

Plants will also not remove chemicals from water which is moving too rapidly over the surface or as preferential flow through macropores. Correll et al. (1994) and Schultz et al. (unpublished data) have observed that nitrate is not effectively reduced in coarse textured soils under high flow events when much of the annual N loading of the buffer zone might be taking place. In addition, riparian vegetation will be an effective sink only as long as the plants are actively accumulating biomass. Once annual biomass production is equal to or less than litterfall, there will be no new addition to the standing biomass sink. Plants must be harvested before that time if they are to remain viable agrichemical sinks. However, release of pollutants by litter decomposition may be beneficial if the vegetation removed the nutrients from the groundwater, where the potential for transformation to harmless by-products is often quite low (Groffman et al. 1992; Lowrance 1992).

Microbial processes are also important in reducing NPS pollution in the landscape. Microbe will assimilate and immobilize NPS pollutants but their rapid turnover and relatively small biomass may make this a minor sink. Microbes may also degrade many organic compounds such as pesticides. However, the metabolic breakdown of these organic compounds is dependent on readily available organic matter in the soil (National Research Council 1993).

Under anaerobic conditions microbes can denitrify nitrate into harmless nitrogen gas. This process has been found to occur in surface soils of riparian forests (Haycock and Pinay 1993; Jordan et al. 1993; Groffmann et al. 1992; Ambus and Lowrance 1991; Corell and Weber 1989; Jacobs and Gilliam 1985; Lowrance et al. 1984B; Peterjohn and Correll 1984) and seems to be dependent on the availability of carbon (Starr and Gillham 1993; Obenhuber and Lowrance 1991; Parkin and Meisinger 1989; Slater and Capone 1987: Smith and Duff 1988; Trudell et al. 1986). Wider vegetated buffer strips are usually more efficient at removing nutrients (Petersen et al. 1992). However, the long-term nutrient removal effectiveness of buffer strips is not known (Hanson et al. 1994; Osborne and Kovacic 1993). Wetlands that may be an integral part of integrated riparian management systems are highly efficient at denitrification because of their large quantities of organic sediments and decaying plant material (Crumpton et al. 1993).

Streambank Stability

When riparian vegetation is drastically modified or removed, streambanks become unstable and collapse, resulting in changes in channel width and structure (Fleischner 1994; Elmore 1992; Armour et al. 1991; Platts 1989). The woody and fibrous roots of plants growing on the streambank provide strength to hold the streambank in place. Plant roots increase soil stability by mechanically reinforcing soil and by reducing the weight of soil through evapotranspiration (Waldron and Dakessian 1982). Deeper rooted plants extract more water from greater soil depths than shallow rooted plants. Woody plant roots provide superior soil stabilization when compared to herbaceous plants because of their deeper rooting habit and their larger roots (Waldron et al. 1983). Woody roots provide protection against the hydraulic pressures of high flows while fibrous roots bind the finer soil particles (Elmore 1992). Tall grass prairie species are more effective than short cool season grasses at providing streambank stability because of their deeper fibrous root systems. There can be up to nine times more roots in the top 45 cm of soil and up t five times more at 100 cm depth for prairie grass species than for cool season species (Schultz et al. 1995).

Instream Environment

Loss or modification of riparian vegetation is one of the major reasons for the reduced quality of the aquatic environment throughout the Unite States (Fleischner 1994; Sweeney 1992; Menzel 1983). Riparian vegetation controls the quantity and quality of solar radiation reaching the water surface in lower order streams and thus influences autochthonous production and water temperature (Gregory et al. 1991; Sweeney 1992; Sinokrot and Stefan 1993). Organic matter input into the stream from riparian vegetation is an important energy source for aquatic organisms. Differences in quality and quantity of organic matter inputs between conifer and deciduous forests and between forests and grasslands often determine the structure of the invertebrate populations in the stream (Bilby and Bisson 1992; Gregory et al. 1991; Gurtz et al. 1988; Oliver and Hinckley 1987; Behmer and Hawkins 1986). Finally, large woody debris in the stream channel influences the physical structure of the channel by controlling the distribution of pools which store and detain sediments and riffles which oxygenate the water (Sweeney 1992; Gregory et al. 1991; Bisson et al. (1987). The more riparian zones can perform these "natural" functions the more diverse, productive, and resilient the instream ecosystem will be (Franklin 1992).

Water Storage and Groundwater Recharge

Vegetated riparian zones function to slow flood flow which allows water to spread and soak into the soil thereby recharging local groundwater and extending the baseflow through the summer season (Elmore 1992; Wissmar and Swanson 1990). In the West many streamside aquifers go dry later in the season because of poor livestock management on riparian zones (Elmore 1992). In the Cornbelt states of the U.S., channelization and tile drainage lower watertables to reduce the chance of out-of-channel flood flows in the riparian zone (Menzel 1983).

Riparian ecosystems are also important travel corridors for both animals and plants. They provide lush and diverse habitat for wildlife and because of their rich, moist microenvironments they are often the source of both upland and bottomland plants species in the landscape especially after upland perturbations (Naiman et al. 1993; Gregory et al. 1991).

The functions and processes of long, narrow riparian zones are extremely important to sustaining quality agricultural landscapes. These narrow ecosystems intercept and process nutrients, sediment and organic matter, which originates from the adjacent land. If these materials reach the stream they reduce water quality and their loss from the uplands reduces productivity. Because of the importance of these riparian ecosystems in cropland and rangeland ecosystems, effective methods for saving, restoring and managing riparian zones must be developed (National Research Council 1993).

Present Condition of Cropland and Rangeland Riparian Zones

Midwestern Cropland

The highly productive crop production regions of the midwest are a mosaic of crop and pasture lands, human habitations and small remnants of native prairie, wetland, and forest ecosystems. Most of the natural ecosystems have been converted to intensively managed agroecosystems in the twelve states ranging from Ohio to the eastern portions of the Dakotas, Nebraska, and Kansas, and from the southern portions of the Lake States to the northern half of Missouri. In Iowa, for example, 99% of the prairie and wetland area and more than 80% of the forest area have been converted to other uses (Bishop and van der Valk, 1982; Thomson and Hertel, 1981). Ohio, Indiana, Illinois and Missouri drained more than 85 percent of their wetlands by the mid 1980's (Dahl et al. 1991). In most of the midwest region less than 20 percent of the natural prairie, forest, wetland and riparian ecosytems still exist (Burkart et al. 1994). In a typical watershed in central Iowa about 50% of the total length of stream channel may be cultivated with corn and/or soybeans to the bank edge. Another 30% of the length may be in pasture, most of which is overgrazed (Bercovici, 1994). Annual soil erosion is greater than 6.7 Mg/ha in much of the central part of this region and in some areas is greater than 11.2 Mg/ha despite that fact that many of these same areas have over 50 percent of the land in upland conservation practices (Burkhart et al. 1994). Because they have little other perceived value, many kilometers of Midwestern riparian zones have livestock fenced into them as a management practice. Livestock under these conditions do extensive damage to the stream channel, the streambanks and the riparian zone.

Modern product-oriented agriculture has put this midwestern agroecosystem at risk. The production-oriented function of this landscape has produced unintended and undesirable environmental consequences. These include loss of biodiversity, detrimental alteration of waterways and groundwater aquifers and loss of significant portions of the productive topsoil resulting in greater need for fertilizer and energy inputs. Non-point source pollution has become so pervasive because of rapid surface and subsurface water movement and reduced soil residence time of agrichemicals. It is now apparent that upland conservation practices alone are not effective in reducing NPS pollution (Burkhart et al. 1994; National Research Council 1993). Field and landscape buffers, including riparian buffer zones, are also needed to develop a sustainable agroecosystem with improved soil and water quality (Castelle et al. 1994; National Research Council 1993). However, major issues about buffer strip efficiency and design must be clarified before they can be effectively implemented. These issues include: plant species selection and efficiency; optimal widths for various buffer strips; longevity of the buffer zones as nutrient and sediment sinks; criteria for identifying riparian zones in need of buffers; and criteria for long-term management of buffer strips (Castelle et al. 1994; National Research Council 1993; Osborne and Kovacic 1993).

Western Rangeland

Recent reviews by Fleischner (1994), Kauffman and Krueger (1984), Elmore (1992) and Chaney et al. (1990, 1993) identify livestock grazing as having dramatically changed riparian zones in the rangelands of the west. The changes by livestock have been so great and cover so much of the western landscape that it is even difficult to determine what the natural vegetation was or what the effects of livestock grazing has been (Fleischner 1994). Riparian zones in the semi-arid and arid West are probably even more important to the overall landscape than they are in the cropland of the Midwest. While they occupy less than one percent of the landscape they are the most productive and biodiverse ecosystem in that landscape. More than 75 percent of the wildlife in many of these watersheds depends on the riparian zone for existance (Chaney et al. 1990). Riparian ecosystems in the arid and semi-arid west also function to filter sediment, stabilize streambanks, store water and recharge subsurface aquifers (Fleischner 1994; Elmore 1992; Chaney et al. 1990). Excluding isolated examples, the condition of the riparian zones throughout the semi-arid and arid west are the worst they have been in history (Chaney et al. 1990).

Livestock tend to congregate in the riparian zones where there is succulent vegetation, shade, and water. In the process they compact the soil and destroy the bank by climbing into and out of the stream. Livestock will also rub, trample, and browse the vegetation, and relieve themselves directly in the stream. This results in the widening of the stream channel, decreasing average stream depth and increasing average stream temperature, and sediment and nutrient loads. Alterations in the timing and volume of streamflow and lowering of the local water table also occur (Kauffman and Krueger 1984; Platts 1981). These activities along with the lack of management strategies unique to riparian zones are responsible for the poor condition of these riparian ecosystems (Armour et al. 1991). Many kilometers of Midwestern riparian zones have also suffered the same fate.

In summary, riparian zones in crop and rangeland landscapes are presently in poor condition. However, these ecosystems are among the most resilient in the landscape because of their moist, fertile and microclimatically less extreme conditions and therefore should respond well to mangement and restoration activities. Research should be accelerated to develop design and management standards for landscape buffer zones in the crop and range landscapes (National Research Council 1993; Armour et al. 1991). It is especially important to understand the dynamics of riparian zone processes, to describe the impact of good management of riparian habitats on all natural resources and to develop predictive methods to determine optimal widths and management intensities needed to accomplish specific soil and water quality objectives.

Restoration of Riparian Zone Conditions

Cropland Remediation

The United States Department of Agriculture (USDA) Forest Service (FS) and the USDA Natural Resource Conservation Service (NRCS) have developed guidelines for riparian forest buffers (Welsch 1991). These buffers have three distinct zones. Zone 1 is a 5 m wide strip of undisturbed mature trees that begins at the edge of the streambank and provides the final buffer for materials moving through the buffer strip and directly influences the in-stream ecosystem by providing shade and large and small organic matter inputs. Zone 2 is a 20 m wide zone of trees managed to provide maximum infiltration of surface runoff, and nutrient uptake and storage while also providing organic matter for microbial processing of agrichemicals. Zone 3 is a 6 m wide zone of grazed or ungrazed grass which filters sediment from sheet flow generated in the uplands and causes large quantities of water and agrichemicals to infiltrate into the biologically active rooting zone where nutrient uptake and microbial processing occur. The FS and NRCS guidelines were developed after extensive reviews of forested riparian zones in the eastern United States. However, the guidelines and model may not be well suited to the agroecosystems of the Midwest and Great Plains where many smaller order streams drain highly modified (prairie) agricultural and grazed landscapes with few trees.

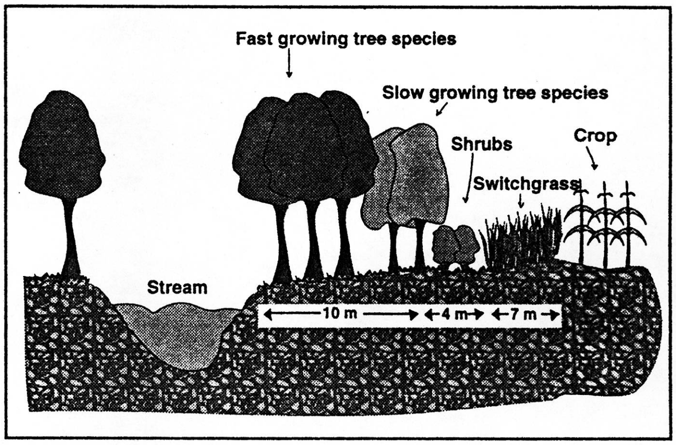

Figure 1 — The Leopold Center for Sustainable Agriculture, Agroecology Issue Team, Multi-Species Riparian Buffer Strip (MSRBS) Model. This model can be varied depending on site conditions, land-use practices, and owner objectives.

Multi-Species Riparian Buffer Strip (MSRBS) System

The Agroecology Issue Team (AIT) of the Leopold Center for Sustainable Agriculture located in Ames, Iowa and the Iowa State University Agroforestry Research Team (IStART) have developed multi-species riparian buffer strip (MSRBS) system for application in the Midwestern and Great Plains agroecosystem (Schultz et al. 1993, 1995). The MSRBS contains three zones similar to those of the FS and NRCS riparian forest buffer strip model. However, the widths and plant species compositions of the zones in the MSRBS model can be varied depending on landowner objectives, the upland land use patterns and the characteristics of the riparian zone. The MSRBS system is an integrated management system which also includes willow-post soil bioengineering features to stabilize streambanks and small, constructed wetlands, within the buffer strip. The wetlands are placed at the outlet of field drainage tiles to process agrichemicals contained in tile flow before it enters the stream. Figure 1 illustrates the three zone MSRBS model while Figure 2 illustrates the whole MSRBS system.

Beginning at the streambank edge, the first zone of the MSRBS is 10 m wide and contains 4-5 rows of rapidly growing trees, the second zone is 4 m wide and contains 1-2 rows of shrubs, and the third zone is a 7 m wide zone of native, warm-

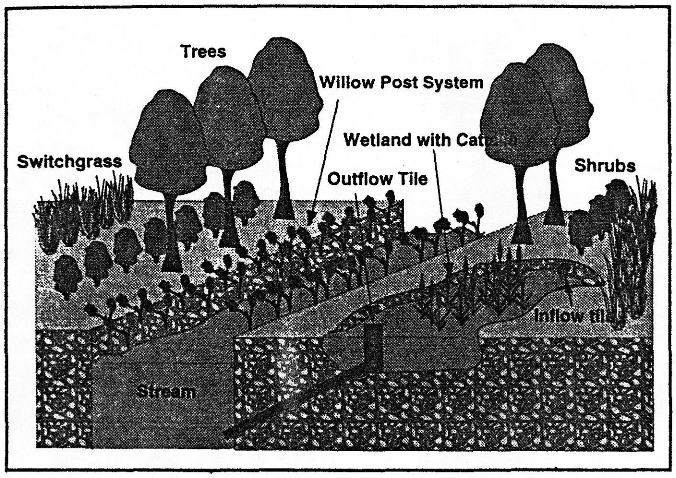

Figure 2 — The Leopold Center for Sustainable Agriculture, Agroecology Issue Team, Multi-Species Riparian Buffer Strip Model System which integrates the willow-post soil bioengineering system for streambank stabilization and constructed wetlands for reducing non-point source pollution in agricultural drainage tile flow.

season grasses. This zonation is important because the trees and shrubs provide perennial root systems and long-term nutrient storage close to the stream, while the shrubs add more woody stems near the ground to slow flood flows and provide a more diversified wildlife habitat. The native grasses provide the high density of stems needed to dissipate the energy of surface runoff and the deep and dense annual root systems needed to increase soil infiltration capacities and provide organic matter for large microbial populations.

Fast-growing trees are needed to develop a functioning MSRBS in the shortest possible time. It is especially important that rows 1-3 (the first row is the closest to the streambank edge) in the tree zone (zone 1) include fast-growing, riparian species such as willow (*Salix* spp) and cottonwood (*Populus* spp) species. If, throughout the year, the rooting zone along the streambank is more than 1.2 m above normal stream flow and soils are well drained, then upland deciduous and coniferous trees and shrub species can be planted in rows 4 and 5. Although these slower growing species will not begin to function as nutrient sinks as quickly as faster growing species, they will provide a higher quality product to the landowner at harvest. Shrubs are included in the design because their permanent roots help maintain soil stability, their multiple stems help slow flood flows and their presence adds biodiversity and wildlife habitat. Many native shrubs can be used and are often selected because of their desirable wildlife and aesthetic values.

As in the FS and NRCS forest buffer strip model, the native grasses function to intercept and dissipate the energy of surface runoff, trap sediment and agricultural chemicals in the surface runoff, and improve soil quality by increasing infiltration capacity and microbial activity as a result of their annually high turnover of roots. Native tall-prairie grasses are better suited to the MSRBS than the introduced cool season grasses that are usually used for grassed waterways because of their taller and stiffer stems and their more deeply distributed roots. The native grasses have 9 times greater root mass extending more than three times as deep as cool season grasses (Schultz et al. 1994, 1995). A minimum grass zone width of 7 m is recommended to dissipate the surface runoff, trap sediment, and promote significant infiltration.

The three zone MSRBS model of trees, shrubs, and prairie grasses is well suited to the agroecosystems of the Midwest and eastern Great Plains. Although these species combinations provide a very effective riparian buffer strip plant community, there are other combinations that can be effective. These might include combinations with more trees or shrubs or without any trees or shrubs, except for those used for streambank stabilization. The grass zone is the most critical of the three zones in the MSRBS. Site conditions, major buffer strip biological and physical functions, owner objectives, and cost-share program requirements should be considered in specifying species combinations.

Figures 3 and 4 show the dramatic changes that can take place in as little as four growing seasons after establishment of a MSRBS system located on the Risdal farm, along Bear Creek, near Roland, Iowa. This buffer strip has trapped 80-90 percent of the sediment carried in surface runoff and has reduced nitrate and atrazine agrichemical pollutants moving through the soil solution of the rooting zone or in the shallow ground water by over 90 percent, with resulting concentrations

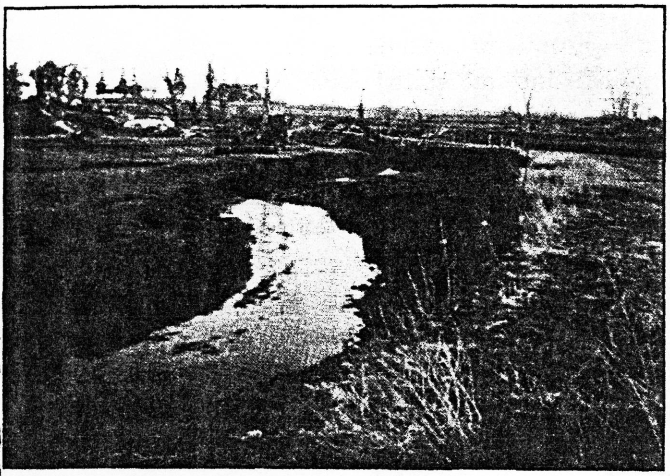

Figure 3 — The Bear Creek MSRBS site near Roland, Iowa in March 1990. The land on the right hand side of the stream had been in cultivation and the land on the left hand side had been grazed. Notice the condition of the streambanks.

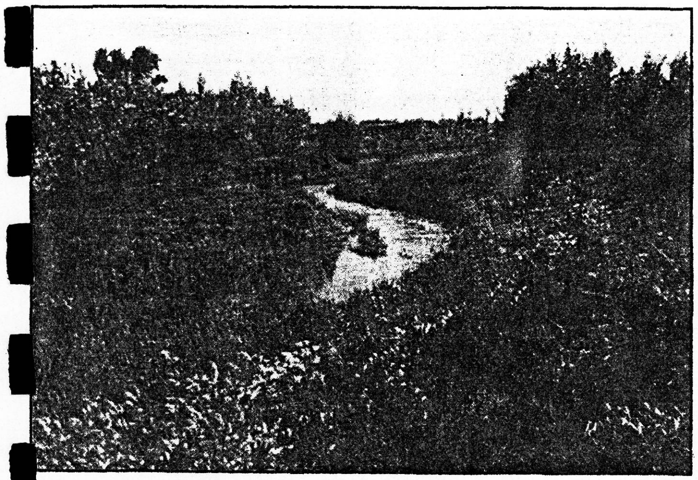

Figure 4 — The Bear Creek MSRBS site near Roland, Iowa in June 1994. Notice the rapid growth of riparian vegetation and the dramatic improvement in the condition of the streambanks after only five seasons since establishment of the MSRBS.

well below the maximum contaminant levels allowed by the US Environmental Protection Agency.

It costs about $875 per ha to install the three zone MSRBS. This includes plant purchases, site preparation, planting, labor, and maintenance costs in the first year. About $50 per ha should be planned for annual maintenance for the first 3-4 years.

Although the MSRBS model was developed to be 21 m wide on each side of a stream, different widths may be needed to fit specific sites and land ownerships. The total width of the buffer strip depends in large part on its major functions and the slope and use of the adjacent land. If the major purpose of the buffer strip is sediment removal from surface runoff, a width of 15 m may be sufficient on slopes of 0-5%. If excess nutrient removal also is an important function, a width of 15-30 m might be necessary depending on the kind and quantity of agricultural chemicals applied and the soil and cultivation system used.

As the slope, intensity of land use, or total area of the land producing NPS pollutants increases, or as soil permeability decreases, a wider MSRBS is required. Castelle et al. (1994) recommend buffer strips 10-60 m wide for sediment removal, 5-90 m wide for nutrient removal, 5-100 m wide for species diversity and 15-30 m wide for stream water temperature moderation. Welsch (1991) summarizes the work of others and suggests that buffer strip widths could be 20% of the total NPS pollutant area, or widths of land capability classes I, II, V = 29 m; III & IV = 36 m; VI & VII = 52 m. The FS riparian forest buffer model has a width of at least 29 m.

MSRBS Streambank Bioengineering and Tile Wetland Options

Streambanks that have been heavily grazed or that have had row crops planted to the edge of the bank are often very unstable and need extra protection beyond that provided by the MSRBS. In these situations soil bioengineering techniques, such as the willow post method, can be employed (Frazee and Roseboom 1993). On vertical or actively cutting streambanks, combinations of dormant willow 'posts' are planted along with anchored dead tree revetments to protect streambanks. These plant materials provide a frictional surface for absorbing stream energy, trapping sediment, and provide shade and organic matter for in-stream biota. Dormant willow posts (> 7.6 cm diameter and 2.1 m long), willow stakes (2.5-7.6 cm diameter and 0.5-1.8 m long) and willow cuttings (0.5-2.5 cm diameter and 30-45 cm long) are collected during the winter or very early spring. Rows of posts are driven into the streambank beginning at the waters' edge with spacing between posts of 90-120 cm. Up to 4-5 more rows of posts, stakes, or cuttings are planted in parallel rows up the bank from the base row using 60-120 cm spacing within and between rows.

Where there is a concern for active undercutting of the bank, bundles of eastern red cedar or small hardwoods (3-4.5 m long silver maples, willows, etc.) can be tied together into 2-4 tree bundles. A row of these bundles is laid along the bottom most row of willow posts with the lower trunks pointed upstream and the bundles anchored to the willow posts or streambank.

In areas of artificial drainage, small wetlands can be constructed at the end of field tiles to interrupt and process NPS pollutants before they enter water bodies. A 0.5-1 m deep depression is constructed at the ratio of 1:100 (1 ha of wetland for 100 ha drainage). A berm should be constructed along the stream. It can be stabilized on the stream side with willow cuttings and seeded with a mixture of prairie grasses and forbs. If a coarse textured soil is encountered, the bottom of the wetland can be sealed with clay and topped with original soil. A gated control structure for controlling water level should be installed at the outflow into the stream. In designing the wetland it is important to remember that most of the chemical transformation and retention occurs at or near substrates (sediments or plant litter). Wetlands containing large amounts of vegetation and decaying plant litter will thus have a much greater capacity for pollutant removal. Any management technique which accelerates vegetation establishment (active regeneration) of litter buildup (addition of organic substrate) will improve chemical retention.

The willow-post soil bioengineering technique and the small field tile wetland are integral components of a complete riparian zone management system that effectively intercepts and treats NPS pollution. However, a MSRBS system cannot replace upland conservation practices. An agricultural landscape will be more sustainable if both upland conservation practices and a MSRBS system are in place.

Applying the MSRBS system at the landscape level becomes a real challenge because of ownership patterns and government set aside programs. Critical riparian areas in a watershed must be protected with riparian buffer strips. Farm boundaries typically are not based on watershed topography, and set-aside programs such as the Conservation Reserve Program encourage farmers to set aside whole fields rather than setting aside the same area of land as riparian buffer zones. Both voluntary or mandatory measures are needed to motivate landowners to install riparian buffer strips at the field level. At the landscape or watershed level, new or highly modified agricultural policies may be required to allow consumers and producers in areas without riparian zones to compensate producers who establish buffer strips and protect riparian zones for the loss of land necessary to meet watershed-wide soil conservation and water quality goals (National Research Council 1993).

Grazing Land Remediation

The semi-arid and arid western rangelands cover a wide latitudinal and elevational range with many potential plant communities so that prescription of the ideal grazing program for the riparian zone is difficult. In developing a grazing program for a given riparian zone several principles should be remembered (Chaney et al. 1993). First, grazing access to the riparian zone should be limited during those times when streambank soils are moist and most susceptible to compaction and collapse. This condition frequently exists during the early spring following snow melt and early spring rains. Second, enough plants and stubble or plant heights should be left on the streambank to ensure protection of the banks (Clary and Webster 1990). Stubble heights of 1.5-2.5 cm are often recommended. Third, grazing pressure should be controlled enough to allow desirable plants enough time to regrow and store enough carbohydrates for overwinter dormancy and competition with other undesirable species. Various seasonal strategies are available and will be discussed below.

Within any rangeland ecosystem the riparian zone will be most heavily used because of favorable forage, water, and microclimatic conditions.

Excluding livestock from the riparian zone is the simplest method of management. However, exclusion is often not necessary if intensity, duration, and season of grazing are controlled (Chaney et al. 1993; Elmore 1992). Using riparian pastures that are separate from upland pastures can control the grazing of the riparian vegetation but increase the complexity of management. The most complicated strategy is to attempt control of grazing intensity and timing through herding (Chaney et al. 1993).

Chaney et al. (1993), Elmore (1992) and Clary and Webster (1990) provide the following summary of grazing strategies for western riparian zones. Season-long or continuous grazing is the most detrimental unless it can be strictly controlled according to recommended stubble heights. With this scheme plants receive no rest for regrowth and carbohydrate storage for the dormant season. Woody plants are heavily impacted because constant browsing removes any new growth. This is the grazing practice which is most responsible for the deteriorated conditions of most of the riparian zones in both the cool and warm season grass ranges. Spring and summer grazing can be almost as damaging as season-long grazing because both cool- and warm-season grasses are grazed during their active growing and reproductive times. In addition, new growth on woody plants is severely browsed and livestock are present on streambank soils during wet periods. Spring and fall grazing has problems similar to those of spring and summer grazing.

Fall or winter grazing is a good strategy because plants are grazed when they are dormant and much of their food reserves are stored in tissues at or below ground level. To maintain a frictional surface for streambank protection it is important to adhere to a recommended stubble height of 1.5-2.5 cm. Browsing of woody plants often removes new growth from the past season requiring new growth from lateral or adventitious buds. One advantage is that cold air drainage often keeps livestock from concentrating along the stream. Care must be taken to reduce trampling during wet periods.

Early season grazing allows growth of plants the rest of the year while it puts pressure on upland plants during the summer and fall. In this system livestock should be removed while the plants are still in their vegetative growth stage and before they begin their vegetative growth. Woody plants benefit from this system because livestock graze on the lush herbaceous forage. Streambanks may be susceptible to compaction and trampling during this period but because of more available forage and less demand for water, livestock may be more dispersed over the whole range.

Deferred three pasture rotational grazing provides a rest period for each pasture every year. During the first year grazing occurs in spring, during the second it occurs in summer and during the third there is no grazing. This system is great for herbaceous plants but is detrimental to woody plants because they heavily grazed during two of the three years keeping them in a shrubby condition.

Two pasture rotational grazing provides growing season rest for each pasture every other year. During the first year grazing occurs in spring for cool season grasses or late spring-early summer for warm season grasses. The following year grazing occurs after vegetative growth has been completed, summer for cool season grasses and late summer-early fall for warm season species. This system is hard on any woody plant seedlings.

Chaney et al. (1993) suggest that no one system applies to all riparian locations and that any grazing strategy is only as good as it is managed. They further suggest that riparian exclosures and riparian pastures reduce the complexity of management and insure more rapid restoration of deteriorated riparian zones.

Summary

Because of the critical functions of riparian buffer systems in crop and rangelands across the US, development of riparian zone systems is a very important topic at the present time. To manage agricultural and rangeland landscapes for sustainable crop, forage, animal, and other non-market outputs means that NPS pollution must be controlled, water quality maintained at a high level, and biodiversity enhanced. Sustainable agriculture also means diversifying the economic and environmental opportunities for the farmer or rancher as well as diversifying the landscape. The MSRBS system provides an opportunity to accomplish a combination of social, economic, environmental, and political objectives. To date most riparian zone research has been conducted either in existing naturally vegetated riparian zones or using cool-season grass buffer strips. Also, research has focused on either a buffer strip, a wetland, or streambank stabilization models. The MSRBS system is an integrated model. It takes a systems approach to the complex set of crop and rangeland riparian problems and economic and social issues facing farmers and ranchers. Adaptation is the rule rather than the exception with the MSRBS system.

It seems that a MSRBS system offers numerous additional advantages over the traditional cool season grass buffer strips and could be designed to be more efficient at trapping sediment and reducing agrichemicals than existing natural systems. Moreover, the MSRBS system is designed to diversify the agricultural landscape by introducing wildlife corridors with a variety of habitats along streams and provide for enhance aesthetics. The opportunity exists for farmers or ranchers to "sell" hunting rights associated with riparian zones where the MSRBS system has been developed. Market products such as hay from the warm-season grasses, fuelwood from the fast-growing trees, and sawlogs from slower-growing quality hardwood tree species can be produced by the MSRBS over time. In fact the removal of such "crops" enhances the functioning of the MSRBS. The MSRBS system offers a way to address the field tile problem whereby NPS pollution by-passes the living filter/ agrichemical transformation and sink functions of the vegetative (tree/shrub/grass) buffer strip. A constructed wetland is an important component of the MSRBS system. A relatively small constructed wetland can effectively treat the NPS pollution from agricultural land 100 times its size. Yet another important component of the MSRBS system are the streambank stabilization soil bioengineering techniques using willow or other vegetation to reduce bank slumping and storm scouring, and causing soil deposition among the woody stems and collected debris.

Livestock exclusion is the simplest approach to management of the rangeland riparian zones of the arid and semi-arid west. However, this approach excludes the most productive ecosystem from livestock use and may not be an option in narrow Midwestern riparian zone pastures. An alternative would be to manage the riparian corridors as pastures separate from the uplands. In that way grazing can be regulated by season, intensity and duration. Planting of multiple species of adapted plants can be done to improve forage production as well as to stabilize streambanks and create wildlife habitat.

There are still many unanswered questions about the design, function, and management of the MSRBS, constructed wetlands, streambank stabilization designs, or any other buffer strip designs. Among the most important are quantification of the sediment trapping ability and the nutrient and pesticide reduction ability of the buffer strips. Quantification of changes in soil and water quality and in-stream environment resulting from the presence of the permanent MSRBS system are also needed. Wildlife habitat values must be assessed and a careful accounting of all socio-economic and environmental benefits and costs of these systems must be made. However, riparian buffer strip systems provide a method of developing productive and sustainable crop and range landscapes in the Midwestern and Great Plains agroecosystems and the semi-arid and arid western rangelands.

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