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Riparian forest buffers in agroecosystems – lessons learned from the Bear Creek Watershed, central Iowa, USA

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Abstract

Intensive agriculture can result in increased runoff of sediment and agricultural chemicals that pollute streams. Consensus is emerging that, despite our best efforts, it is unlikely that significant reductions in nutrient loading to surface waters will be achieved through traditional, in-field management alone. Riparian forest buffers can play an important role in the movement of water and NPS (non-point source) pollutants to surface water bodies and ground water. Riparian buffers are linear in nature and because of their position in the landscape provide effective connections between the upland and aquatic ecosystems. Present designs tend to use one model with a zone of unmanaged trees nearest the stream followed by a zone of managed trees with a zone of grasses adjacent to the crop field. Numerous variations of that design using trees, shrubs, native grasses and forbs or nonnative cool-season grasses may provide better function for riparian forest buffers in specific settings. Properly designed riparian buffers have been shown to effectively reduce surface NPS pollutant movement to streams and under the right geological riparian setting can also remove them from the groundwater. Flexibility in design can also be used to produce various market and nonmarket goods. Design flexibility should become more widely practiced in the application of this agroforestry practice.

Introduction

Intensive agriculture, as practiced in much of the temperate zone, is not environmentally friendly as evidenced by the major non-point source (NPS) pollution problems that have befallen many surface water bodies. The size of cultivated fields continues to increase to accommodate large equipment, and livestock production continues to be concentrated into larger facilities producing major amounts of waste that must be disposed of safely. In many landscapes of the Midwestern United States, more than 85% of the landscape is devoted to row crop agriculture or intensive grazing (Burkart et al. 1994). It is unlikely that these trends will slow in the near future as more food needs to be produced efficiently to feed a growing world population. Increased surface runoff laden with sediment and agrochemicals continue to provide higher and more frequent peak flows that result in more flooding, incision and widening of stream channels, reduction of base flow, and reduction in the quality of aquatic ecosystems (Menzel 1983).

Consensus is emerging that, despite our best efforts, it is unlikely that significant reductions in nutrient loading to surface waters will be achieved through traditional, in-field management alone (Dinnes et al. 2002). Recognizing the gravity of the problem, public agencies are looking to augment these traditional pollution-control efforts by utilizing landscape buffers as off-site sinks for contaminants (Mississippi River/Gulf of Mexico Watershed Nutrient Task Force 2001; Mitsch et al. 2001). One such effort in the United States is the Conservation Buffer Initiative, a public-private program with the goal to assist in the establishment of 3.2 million km of conservation buffers, mainly through the use of the continuous United States

Department of Agriculture (USDA) Conservation Reserve Program. A host of different buffers that reduce surface movement of soil and agricultural chemicals by wind and/or water have been developed. These include such practices as: alleycropping, constructed wetlands, cross-wind trap strips, field borders, filter strips, riparian forest buffers, vegetative barriers, and windbreaks and shelterbelts, to name a few. The effectiveness of most of these practices can be improved if they are used in combination throughout the landscape. However, while conservation buffers have great potential to assist in meeting our stewardship goals, Lowrance et al. (2002) concluded that key knowledge gaps still exist and that future research results need to be translated into up-to-date technical standards and guidelines for conservation buffer design, installation, and maintenance.

Infield conservation practices are designed to trap and slow the movement of materials near their source. Filter strips and riparian forest buffers are designed as ecotones between upland and aquatic ecosystems and provide the last conservation practice that slows movement and traps materials before they enter surface water bodies. These buffers may be the only major perennial plant conservation practice that is used along intermittent streams (channels that carry water only during the wet part of the year) and some first order streams (with no tributaries). Because of the small size of the stream, cultivation can be easily and relatively safely carried on right down to the channel bank putting the stream in direct contact with the cultivated field source of NPS pollutants. In higher order streams (streams with one or more tributaries; example: 4th order stream occurs when two 3rd order streams join) they should be supplemented with other perennial plant conservation practices to insure maximum phytoremediation of NPS pollutants before reaching the buffers.

Riparian forest buffers are a recognized agroforestry practice that not only provide phytoremediation for NPS pollutants but also increase biodiversity of both the terrestrial and aquatic ecosystems. They can also provide stream bank stabilization, moderate flooding damage, recharge groundwater, sequester carbon and provide recreational opportunities and fiber and nonfiber products to landowners.

This chapter will describe the structure, function, design and maintenance of riparian forest buffers and grass filters based on work that has been conducted in the Bear Creek Watershed in central Iowa, United States (42° 11′ N, 93° 30′ W). Because of the extensive research and demonstration activities that have been conducted for more than a decade, this watershed has been designated as a National Restoration Demonstration Watershed by the interagency team implementing the Clean Water Action Plan (1999) and as the Bear Creek Riparian Buffer National Research and Demonstration Area by the USDA (1998). Most of the discussion will address the establishment of new buffers along first to fourth order streams, where present cultivation extends to near the stream edge or riparian grazing is practiced by fencing in the narrow riparian corridor that may be difficult to cultivate with large machinery because of the tight meandering of the stream. Establishing buffers under these conditions usually requires complete restoration of a perennial plant community as none has existed for decades or has been very heavily impacted by grazing pressure.

What is a riparian forest buffer?

A riparian forest buffer is specifically defined as a three zone system consisting of an unmanaged woody zone adjacent to the water body followed upslope by a managed woody zone and bordered by a zone of grasses with or without forbs (Welsch 1991; Isenhart et al. 1997). The major objectives of a riparian buffer are:

1. To remove nutrients, sediment, organic matter, pesticides, and other pollutants from surface runoff and groundwater by deposition, absorption, plant uptake, denitrification, and other processes, and thereby reduce pollution and protect surface water and subsurface water quality while enhancing the ecosystem of the water body,
2. To create shade to lower water temperature to improve habitat for aquatic organisms, and
3. To provide a source of detritus and large woody debris for aquatic organisms and habitat for wildlife (USDA-NRCS 2003).

Riparian forest buffers can vary in design in response to management objectives. The vertical and horizontal structure of the woody and grass zones may differ from one location to the next, depending on:

1. Landowner objectives, concerns, experiences and biases,
2. Present condition of the site,
3. Major functions of the proposed buffer system, and
4. Short and long term management practices to be employed.

Table 1. Typical landowner concerns about riparian forest buffers.

1. How much can buffers reduce the movement of sediment and other pollutants to the stream?
2. Can buffers heal gullies?
3. What happens to water moving rapidly over grass waterways when it intersects a buffer?
4. Can buffers slow stream meandering?
5. What buffer vegetation produces the best wildlife habitat and fishery?
6. Can buffers reduce stream bank erosion?
7. If a riparian forest buffer is planted will trees fall into the stream and back up water into the fields or drain tiles?
8. Is the buffer a source of weed seeds?
9. Are cool-season grass filters just as effective as riparian forest buffers?
10. Will riparian forest buffers bring beavers that build dams that also back up water?
11. Will deer become a problem for crops?
12. How much maintenance is required and who will do it?
13. If fencing is used to keep livestock out of a buffer will it be damaged by floods?
14. How much land will be taken out of crop production or pasture?
15. Can specific products be harvested from the buffers to offset income losses?
16. Are there consultants who can design, plant and maintain the buffers?
17. Are there government programs to help pay for the practice?

They can consist of existing riparian forests or be established on previously cultivated or grazed land. While this chapter focuses primarily on riparian forest buffers in the agricultural landscape, they may also be found in forested, suburban and urban landscapes.

In a forest landscape riparian buffers are often referred to as streamside management zones and usually consist of only a forested zone. Management activities such as thinning, fertilizing and harvesting are usually dramatically restricted, if allowed at all. In suburban landscapes, riparian forest buffers usually consist of existing forests that border on residential or commercial developments. If these forests are protected and managed they can provide the natural functions of filtering and processing of suburban pollutants associated with runoff from roads, lawns and construction sites. They can also provide noise control and screening along with their wildlife habitat and aesthetic benefits. In the more urbanized environment, riparian forest buffers are often very narrow and fragmented to the point that they may not be completely functional forest ecosystems. However, with proper planning and zoning, these forests can play an important role in storm water management. These forests are often the largest and most continuous forests in the urban environment and therefore provide significant wildlife habitat and recreational opportunities. However, as use of these areas increase, their pollutant control ability is often reduced. Because these buffers often are located on highly prized land, the goal of suburban and urban planning is to protect them from development and overuse by the public (Palone and Todd 1997).

Riparian forest buffers in the agricultural landscape can take numerous forms. In the eastern United States, they may exist as narrow corridors of remnant forests along the stream or as irregular islands along portions of meandering streams. In many cases these forests have been grazed in the past. In much of the intensive agricultural belt of the Midwestern United States, riparian forest buffers have to be reestablished from scratch on land that was cropped or grazed for many decades. In the arid and semiarid west, riparian forest buffers consist of narrow tree and shrub zones in a vast expanse of grazed dry upland shrubs and grasses (Elmore 1992). Because riparian forest communities evolved in the most fertile and moist position of the landscape, they can often be easily reestablished. However, in many agricultural landscapes land uses have so dramatically changed the hydrology that these communities cannot be restored to their original condition. Stream channels have been incised and widened by higher discharge resulting from greater surface runoff from crop fields and heavily grazed pastures. Channelization of meandering streams, tiling of some landscapes and urbanization also have contributed to higher storm flow and lower baseflow (Menzel 1983). In many cases, water table depths have been lowered to the point that restored buffers require a different community structure to function properly. However, with proper planning and design the functions of a healthy riparian forest community can be reestablished.

As an agroforestry practice, riparian forest buffers play an important role in the movement of water through the agricultural landscape and in the movement of NPS pollutants to surface water bodies and ground water. They are linear in nature, and because of their position in the landscape, they provide effective connections between the upland and aquatic ecosystems in a watershed.

Assessing the need for riparian buffers

The design of a buffer system will strongly influence the expression of each of the buffer functions on a specific site. It is therefore imperative that before designing a riparian buffer an assessment of the site be conducted as well as the landowner's objectives and concerns identified. Concerns that landowners typically have about designing and adopting a riparian buffer are summarized in Table 1.

After landowner objectives have been identified and concerns have been satisfied it is time to assess the present condition of the stream and riparian zone. While a lot of information can be gained from aerial photos it is imperative that the entire site is walked and a detailed site map identifying problem areas is developed. Walking the site with the landowner is an excellent option. Items to look for and questions to answer while making the field assessment are indicated in Table 2.

Once the landowner's questions have been addressed and the site assessment has been completed the design process may begin. If the adjacent land-use, including that of the riparian zone is row crop agriculture a riparian forest buffer or filter is probably needed (Figure 1). The choice between a riparian forest buffer and a filter strip will depend on landowner preferences and site conditions. Where steep vertical stream banks of ≥ 2 m exist, some kind of woody vegetation is recommended to provide strong perennial woody roots that strengthen stream bank soils. If the stream bank is gently sloping with a ≥ 3:1 slope (for every 1 unit vertical rise there is a 3 unit horizontal setback), only a native grass/forb filter may be needed depending on the desires of the landowner and the long-term management of the buffer. These options will be discussed in detail in the following sections.

Table 2. Field assessment guidelines for designing a riparian forest buffer.

Questions to address in a site inventory.
1. What is the order of the stream?
2. Is the stream listed as an impaired waterway?
3. Is it a naturally meandering or channelized reach?
4. Is the channel in contact with the flood plain or deeply incised?
5. What is the stage of channel evolution – is it deepening, widening or beginning to stabilize (Schumm et al. 1984)?
6. How high are the banks above the streambed and are they vertical or sloping?
7. Is bank erosion naturally slow or accelerated?
8. Are there major slumps or eroded sections and are these associated with gullies or areas of concentrated flow or on the outside of bends?
9. What is the dominant land use of the riparian zone?
10. What is the land-use immediately adjacent to the channel – does vegetation cover consist of annual row crops, a narrow strip of weedy vegetation, permanent forest or forage production, or grazed pasture?
11. Does the weedy vegetation consist of dense introduced grasses or annual weeds?
12. What is the condition of any forest vegetation?
13. Is livestock grazed rotationally, providing significant rest periods for re-growth or intensively grazed with complete access to the banks and channel?
14. Are there drainage tiles emptying into the stream?
15. Are there upslope areas of concentrated flow that should be in grassed waterways?
16. Is it a cold- or warm-water fishery?
17. Is there evidence of a healthy aquatic invertebrate community?

If a narrow strip of trees, 3 m to 10 m wide is already present along the stream bank only a filter may be needed to effectively intercept upslope runoff. If stream banks are vertical, and if roads, structures or other valuable property is being threatened by stream bank erosion, then stream bank bioengineering techniques may have to be used in addition to any riparian buffers (Figure 2). In-stream structures such as boulder weirs or riffle structures may also be used to help stabilize both the stream banks and the channel bed. If field drainage tiles pass below any buffer on their way to dumping into the stream, consider developing a wetland to intercept the flow before it enters the stream. Biological activity in the wetland can effectively remove a number of the primary chemical pollutants threatening surface waters (Crumpton 2001).

Figure 1. Pasture and crop sites that are in need of riparian buffers. Banks in A are gentle enough that native grasses and forbs could be planted at the edge of the bank. Banks in B are steep enough that their stability would be improved with woody roots.

Designing the buffer

The traditional riparian forest buffer consists of three zones (Figure 3). The first zone is unmanaged forest along the stream bank, left unmanaged to provide shading and large woody debris to the stream. The second zone consists of forest that is managed as a nutrient sink with systematic harvests to remove trees. The third zone consists of a grass and/or grass-forb filter strip that intercepts and slows the usually concentrated surface runoff from adjacent fields and spreads it over a wider front to move more slowly through the riparian buffer.

Experience with landowners in some regions suggests that zone 1 in the three-zone system is of concern to landowners who do not want trees falling into streams slowing water that they feel needs to be carried rapidly from the landscape. This concern resulted in the development of the two-zone multi-species riparian buffer consisting primarily of a woody zone and a grass or grass-forb filter zone (Figure 4). In this model, the whole woody zone is managed but may be planted to combinations of trees and shrubs.

Further experience with this model and landowner acceptance led to the development of a model with multiple combinations of woody and non-woody zones as discussed below (Figure 5). In this model the buffer is divided into three zones that may be occupied by trees, shrubs and grasses or grasses and forbs. Within each of these plant communities, a wide variety of species and zone widths can be used depending on design requirements.

Functions of grasses and forbs

Grasses and/or grasses and forbs provide excellent ground cover (Table 3). They can be designed to provide the frictional surface needed to slow surface runoff from the adjacent field allowing the sediment in the runoff to be dropped in the crop field and converting much of the concentrated flow into a wider front of slower moving water approaching sheet flow. Much of this slower moving water can infiltrate into the buffered soil where it will have extended contact time with the ‘living filter’ of the soil-plant system. Surface runoff that moves through the buffer continues to move slowly dropping further sediment and infiltrating more water and soluble nutrients.

Most non-native forage grasses such as *Bromus inermis*, *Phleum pratense* and *Poa pratensis* do not present stiff leaves to the on-coming surface runoff. Rather they are easily laid down, allowing water to move rapidly over them. This feature is very effective in the grass waterway conservation practice where the objective is to carry water rapidly down sloping depressions within row-crop fields while protecting the mineral soil surface. When these grasses are used in zone 3 of a riparian buffer they may be inundated with sediment in large runoff events because slopes are usually between 0% to 2%, slowing water enough to drop most of the sediment (Dillaha et al. 1989). When this occurs, the filter becomes ineffective in slowing further surface runoff. Even among the native warm-season grasses, differences exist in the presentation of a highly frictional surface to incoming runoff. While most native warm-season grasses are strong clump-forming types providing corridors for movement between the clumps, switchgrass (*Panicum*

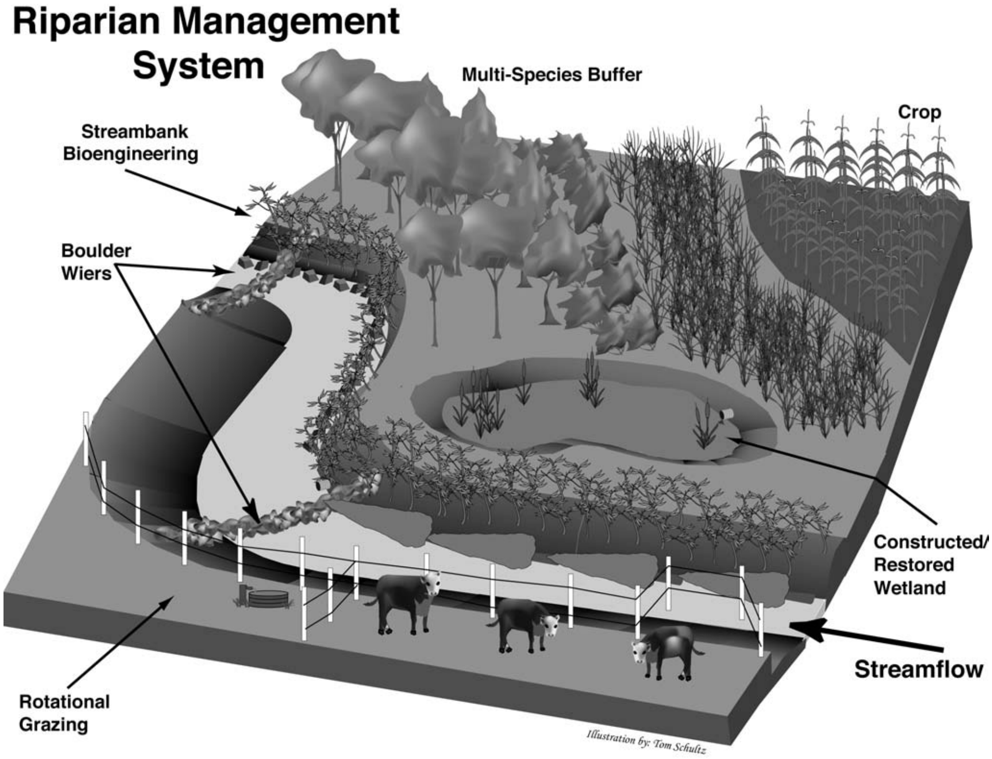

Figure 2. Riparian management system practices including from top right: streambank bioengineering, in-stream boulder weir structures, intensive rotational grazing, constructed wetlands and riparian buffer.
Source: Reprinted, with permission, from Schultz et al. (2000). © 2000 by American Society of Agronomy.

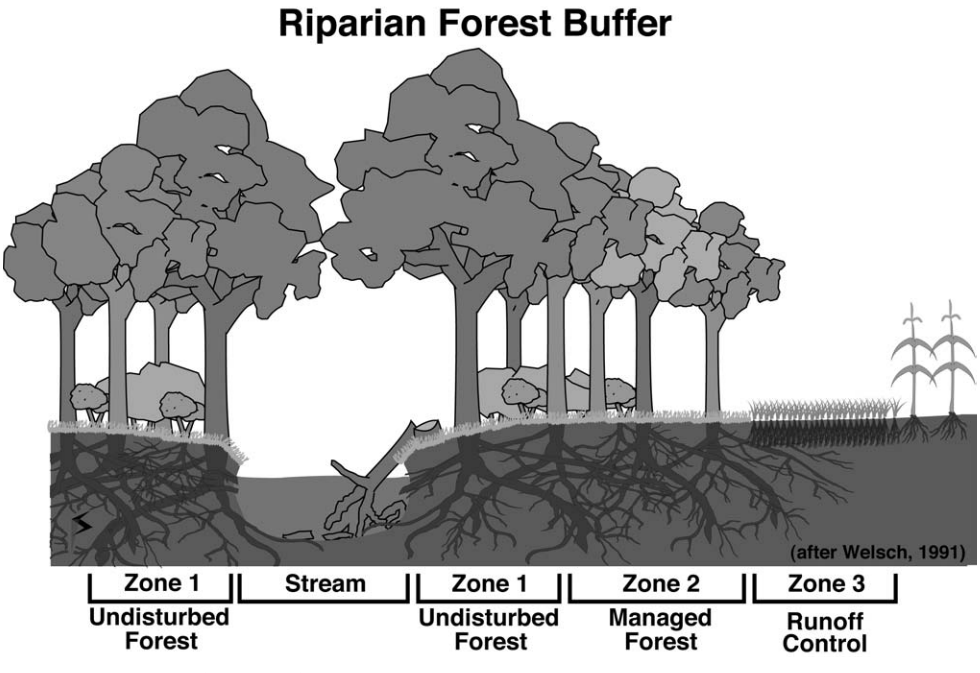

Figure 3. The traditional three zone riparian buffer.
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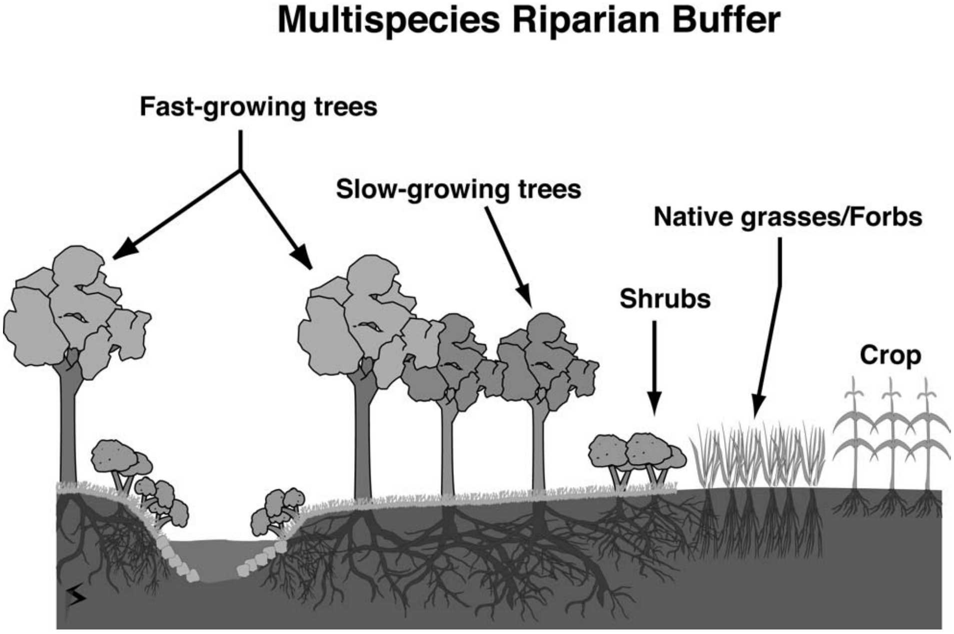

Figure 4. A two-zone multispecies riparian buffer with a woody and grass/forb zone. The whole woody zone is managed to keep large woody debris from falling in the stream. Shrubs are added to the system for a multitude of functions. With the added shrubs, a three-zone system provides numerous planting options as shown in Figure 5.
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virgatum) does not do that and presents such an effective frictional surface to on-coming runoff that water slows, ponds and drops its sediment prior to entering the buffer (Dabney et al. 1994).

Grasses and forbs help to restore biological and physical soil quality by adding large amounts of carbon to the profile from rapid turnover of roots that contain more than 70% of the total biomass of the prairie plants. Litter additions from the aboveground biomass also add carbon to the surface soil. This carbon plays a key role in redeveloping soil macro-aggregate structure that helps facilitate the high infiltration rates needed to get surface runoff into the soil profile. The carbon also serves as a substrate for increased soil microbial activity that is important both in building soil structure and processing some agricultural chemicals that move in the surface and ground water.

Major differences in impacts on the soil ecosystem can occur depending on the dominance of C3 or C4 grasses in a buffer. C3 grasses tend to have lower lignin and C:N ratios than C4 grasses (Pearcy and Ehleringer 1984). This leads to more rapid litter decomposition, higher soil respiration, more active soil organic matter (OM), less soil C accumulation, less nitrogen immobilization and more net nitrogen mineralization. The result is faster restoration of soil's quality-related functions in filter systems planted to C3 grasses. However, these soil improvements usually are not noticed as deeply in the profile as under C4 grasses. The major Mollisol (prairie) soils of the world have developed under prairie plant communities dominated by C4 grasses. Given enough time, soils planted to C4 grass strips also demonstrate improved soil quality to greater depths.

While pure stands of switchgrass may be the most effective plant community at slowing surface runoff and trapping sediment, it is not the most effective in providing wildlife habitat. The dense nature of its stand of stems may provide good winter cover for upland game birds but it provides poor nesting cover. In landscapes where the slope of the adjacent fields providing the surface runoff is $> 5\%$, a pure stand of switchgrass may be planted in a 5-m to 6-m wide strip at the leading edge of the filter with a mixture of other grasses and forbs planted on the down slope stream side of the switchgrass. The mixture of grasses and forbs provide more structural diversity for wildlife habitat. The result is that they can provide good nesting cover, because of the more open nature of the stand, and good winter cover, because they can resist being bent over by high winds and snow loads, for game bird species. Grasses and forbs do not shade the

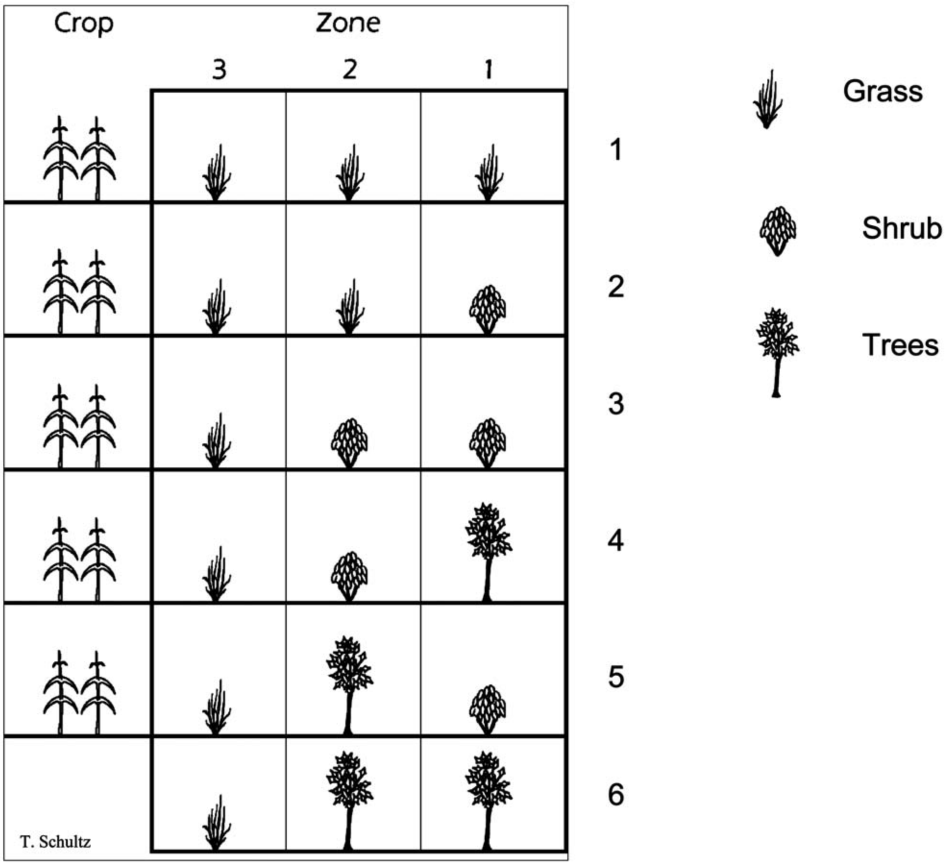

Figure 5. Vegetation combinations in a three-zone buffer system. The crop field is on the left and the stream is on the right. Vegetation zones can vary in width in addition to species and species of trees, shrubs and grasses can vary within a zone.

stream, which is important in warm water ecosystems, nor do they provide significant detrital inputs for the aquatic ecosystem.

Functions of shrubs

Shrubs add the longevity of a woody root system and a more permanent nutrient sink to the buffer (Table 3). While most shrubs are multi-stemmed they are able to sequester nutrients in their woody biomass. The woody root system provides strength to soil profiles. Annual leaf fall and fine-root turnover provide significant organic matter (OM) to the O and A horizons of the soil profile. OM additions are not usually found as deep in the profile as under C4 grass and forb ecosystems (Tufekcioglu et al. 1999) but C:N ratios of many native shrub leaves are conducive to rapid decomposition that helps to rapidly rebuild surface soil quality.

The multiple stem nature of shrub species provides an effective barrier that traps floodwater debris in the buffer rather than letting it move out into the adjacent fields. The multiple stem system also provides cover for wildlife and wind reductions near the ground providing thermal cover. Their size and shape provides another layer of vertical structure that fits between the grasses and trees. In most regions, a wide variety of shrub species can be planted in riparian buffer settings providing a diverse food source and cover for a wide variety of bird and wildlife species as well as providing the potential for ornamental woody cut production.

Because shrubs are usually limited to < 5 m in height, they do not provide much shade to the channel but provide perennial woody roots that can add strength to stream bank soils. While the larger woody roots of shrubs are not as massive as those on trees they can still add more effective strength to the stream bank profile than grasses and forbs. Because of their shorter

Table 3. Functions of the grass, shrub and tree components of riparian buffers.

Kind of Plant	Functions
Prairie grasses/forbs	1. Slow water entering the buffer
	2. Trap sediment and associated chemicals
	3. Add organic carbon to a range of soil depth
	4. Added carbon improves soil structure
	5. Improve infiltration capacity of the surface soil
	6. Above ground nutrient sink needs annual harvest
	7. Provide diverse wildlife habitat
	8. Do not significantly shade the stream channel
	9. Provide only fine organic matter input to stream
	10. Can provide forage and other products
Shrubs	1. Multiple stems act as a trap for flood debris
	2. Provide woody roots for bank stabilization
	3. Litter fall helps improve surface soil quality
	4. Above ground nutrient sink needs occasional harvest
	5. Adds vertical structure for wildlife habitat
	6. Do not significantly shade the stream channel
	7. Provide only fine organic matter input to stream
	8. Can provide ornamental products and berries
Trees	1. Strong, deep woody roots stabilize banks
	2. Litter fall helps improve surface soil quality
	3. Long-lived, large nutrient sink needs infrequent harvest
	4. Adds vertical structure for wildlife habitat
	5. Vertical structure may inhibit buffer use by grassland birds
	6. Shade stream, lowering temperature and stabilizing dissolved oxygen
	7. Provide both fine organic matter and large woody debris to the channel
	8. Can provide a wide variety of fiber products

stature, shrubs often are not major sources of in-stream detritus that can support aquatic invertebrates.

Functions of trees

The aboveground woody biomass of trees provides a large C and N sink that can be systematically removed to maintain the storage capacity of a buffer (Table 3). The large woody roots that often can be found extending 2 m to 3 m or more into the soil provide additional strength to stream banks. High transpiration rates and deep roots help to dewater moist stream banks improving their stability.

Native riparian species are always a good choice on most sites but many landowners have concerns with some of them because they tend to be short-lived and break up easily under natural storm events. Most of the native riparian species are prolific spring seeders and either root- or stump sprout; so, even though they may be short-lived and may succumb to storm events they rapidly re-establish themselves. Root sprouting species are ideal for planting directly adjacent or on stream banks because they can spread rapidly presenting a highly frictional surface to base and storm flows. Planting these species near the field edge of the buffer is not recommended, however, because these same root sprouting species often migrate out into portions of the crop field becoming a nuisance to farmers.

Depending on the depth of the aerated root zone, a wide variety of tree species can be planted. If channels are incised at least 2 m to 3 m in depth, many common upland species can be included in the design especially if care is taken to plant them on the microtopographic rises of the riparian zone. These species are often requested by landowners who see them as providing potential quality fiber products at some future date and hard mast for a variety of wildlife species. While conifers are usually not recommended for planting near the channel because of the damage that they can incur from flooding, they can provide effective winter cover if planted in double or triple rows on rises in the riparian zone. Species diversity in the tree component of any buffer is critical to the longevity of that component. Mixing species within and between rows is strongly recommended to reduce the potential of large holes in the buffer corridor resulting from insect or pathogen problems. Native species are also recommended over non-native species and hybrids as they are usually better adapted to the site over the long run.

The size and shape of trees provides yet another dimension to the vertical and horizontal structure of a buffer site. This addition to structure can provide habitat that will attract the largest diversity of wildlife and bird species to the buffer. However, if specific species of birds, such as grassland birds, are desired the added vertical structure can be detrimental because of the abrupt edges that are introduced in the narrow corridor. In addition, trees provide perches for major avian predators who can wreak havoc on other birds and mammals that are ‘trapped’ in the corridors created by the buffers.

Trees are effective in shading streams and providing both fine and large detritus to the channel. The fine detritus provides a readily available carbon source for many invertebrates while the large woody debris provides structure to the channel that can create pools and riffles that provide stability to channel discharge and additional habitat within the channel. Shading of many streams in agricultural landscapes can help control stream water temperature and reduce the wide fluctuations in dissolved oxygen that often degrades the quality of the fishery. (Wesche et al. 1987)

Questions may be raised about the appropriateness of planting trees in previously prairie landscapes if restoration is an issue. While native prairie grasses and forbs may be desirable trees may provide functions, such as stream bank stabilization, that are needed in the present riparian corridor. This is especially true in dominantly agricultural landscapes where the hydrology of the landscape has been drastically modified and many channels are no longer in contact with their riparian zone.

Examples of different combinations of plant communities in the three zone system

Filter strip

The combination depicted in Figure 5.1 is effective in narrow buffers along intermittent and first order streams in row-crop landscapes where shading of adjacent crops is a concern or where warm-water prairie fisheries are being managed. Species options include non-native cool-season forage grasses that could provide forage harvests, or, if fenced, could be flash-grazed several times per year. Native warm-season grasses and forbs provide another option if prairie restoration and grassland bird-habitat are desired or if serious surface runoff problems exist. Pure switchgrass could be planted if there is a biomass market or if crop field slopes are $\geq 5\%$. If the stream bank is gently sloped (slopes of 6:1) and the channel not deeply incised, then either of the grass species options would be effective. As the banks become steeper (slopes 4:1) and the channel more incised, the native prairie species would provide more bank-stability control because of deeper roots.

Filter strip with bank-side shrubs

The system depicted in Figures 5.2 and 5.3 can also be used in a headwaters reach (first order stream) along a warm-water fishery in a prairie or crop-field landscape. The advantage of shrubs over trees is that they do not shade the stream and do not provide large woody debris that some landowners may not want. The shrubs would be introduced primarily to provide more stream bank stability on channels that are incised with steep banks (slopes 4:1 to 3:1). While bioengineering of stream banks is an option, it is a costly one – and, realistically, not cost-effective in most settings. Depending on the severity of the incision, the shape of the banks and the dynamics of the channel both the stream-edge zone (zone 1) and the second zone could be planted to shrubs recognizing that, over time, some of the first rows of shrubs might not hold the eroding banks and may drop into the channel. Shrubs could also be planted along streams with flashy flood flow responses where large quantities of debris could be trapped between the shrubs and the channel instead of extending out over and beyond the whole buffer. This might be an important consideration in suburban buffers where trails are a part of the buffer.

Classic multi-species riparian forest buffer

Introduction of trees into the buffer is warranted when streams are deeply incised and in the widening morphological phase of the channel-evolution model (Schumm et al. 1984), when maximum aboveground nutrient storage is desired, cooler more stable stream temperatures are desired, and/or when the land owner wants maximal structural habitat diversity, a woody fiber crop, or wind protection. Figures 5.4 and 5.5 depict this option. Trees also provide large woody debris and finer detrital inputs to the channel. Addition of the shrubs in zone 2 not only provides more structure to the system but can effectively keep woody and other flood debris within the woody zone of the buffer (Schultz et al. 1995).

This buffer combination can be modified by reversing the shrub- and tree zones with the shrubs in zone 1 adjacent to the channel. This modification would be considered along warm-water prairie streams where the landowner wants woody products and other tree benefits but does not want the tree influence on the channel, including input of large woody debris. Similarly, this combination would be effective along deeply incised channels of prairie streams where woody vegetation is desired to help stabilize the stream banks. Multiple rows of shrubs and trees would be advised especially on outside bends that move continuously and where woody plants would provide effective control until they have reached critical sizes. This combination could also be effective in urban settings with widely spaced rows between which trails could be placed. The more open wider spacing would provide a more expansive visual experience and a safety factor for trail users.

Classic three-zone riparian forest buffer

The riparian forest buffer depicted in Figure 5.6 would be used in naturally forested landscapes and in cold-water fisheries especially where small streams have significant channel slope and can benefit from large woody debris inputs. In prairie landscapes, this model is also effective in deeply incised settings with actively meandering channels. In these settings making both the grass buffer and the woody zones as wide as possible can provide long-term bank control in lieu of stream bank bioengineering.

This model also provides the largest aboveground nutrient sink and can be managed as either a two or three zone system depending on the need to remove nutrients from the site and the desire for in-stream, large woody debris. By being sensitive to microsite conditions, a wide variety of species can be planted to provide a variety of fiber product options to the landowner.

All three zones can be planted to trees in riparian pastures. In this setting surface runoff laden with sediment is not a major concern but limiting access of livestock to the stream channel providing bank stability is. With the proper spacing, such a planting could be managed as a silvopastoral system with rotational grazing to control the time livestock spend on stream banks and in the channel.

Additional general design considerations

When working in agricultural landscapes, buffer edges should be as straight or gently curving as possible to accommodate farming practices (Figure 6). Buffers will be maintained and supported by farmers if they do not see them as hindering their farming operation. This often means spending time on site with the landowner to discuss his or her field layout. Differences in buffer width to accommodate field borders can be absorbed by either the woody or the grass-forb zone, depending on the site. In those landscapes where surface runoff is more problematic than stream bank stability, maintaining a wider grass-forb zone would be favored over a wider tree-shrub zone.

In tightly meandering reaches, the buffer should be placed outside of the channel meander belt. The areas within the meanders as well as other small odd-sized areas provide ideal opportunities for developing prime wildlife habitat. Along channelized streams, buffers should be as wide as possible to accommodate the future re-meandering of the channelized reach. The landowner is more likely to allow the re-meandering if the adjacent riparian area is no longer being used for crop production. If the channelized reach is part of an organized drainage district, only grasses or grasses and forbs should be planted across all three zones to allow access for channel maintenance.

The potential also exists in any buffer planting to include even more agroforestry options. These might include planting horticultural varieties of shrubs for making jams, selling nuts, or providing ornamental woody material for home decorating. Fruit or nut trees could also be planted. These options may provide unique opportunities for small-truck farmers or hobby farmers but may not suit grain and livestock farmers who often do not have the time to invest in such plantings. The potential also exists that these more ex-

Figure 6. Examples of buffers placed outside the meander belt of the stream and smooth buffer borders to accommodate efficient farming of the upland crop fields. Areas within the meander belt are also planted to a variety of species to provide diverse wildlife habitat.

pensive plants could be severely damaged during flood events and a substantial investment in time and money could be lost.

Establishing buffers

Establishing buffers is best accomplished by working with local natural resource professionals who understand the unique requirements of each site. The underlying assumption for most of the chapter has been that recommended buffers and filters would be restored on sites that previously were intensively managed for livestock grazing or row-crop agriculture. Some general establishment considerations follow.

One of the major differences between planting buffers and planting forest plantations to maximize timber production is that woody buffer plants must compete with ground vegetation that is designed to provide the frictional surface required to slow surface runoff. As a result, when planting a riparian forest buffer into previous row-crop field soils, it is advisable to plant a cover of grasses and/or forbs that provide minimal competition of young trees and shrubs. Density of the trees and shrub planting should be such that the surface cover community remains viable during the life of the buffer or at least until a major organic (O) horizon has been developed above the mineral soil.

Site preparation before planting is imperative if good establishment is to occur and should begin the fall prior to spring planting. Previously row-cropped sites may be shallow-disked several times, followed by broadcast or drilled seeding of undercover grasses. If planting into an abandoned pasture, using herbicide to create narrow strips or individual circles into which to plant the trees and shrubs is recommended. Herbicides can be used but great care must be taken because of the neighboring stream channel. Herbicide recommendations are best obtained from local natural resource professionals. Other weed-control options such as shade cloth or plastic or organic mulches can be effective in some circumstances but may be more costly to apply to the large plantings.

If planting native prairie grasses and forbs, disking should be followed by packing to allow proper depth control for the drilled small seeds of many prairie species. Broadcasting of prairie seeds followed by rolling can also be successful. Once again, it is important to contact local professionals for the best method of establishment. Planting of woody material can be done in rows or in a random broadcast manner. Rows allow seedlings to be planted more rapidly with machines and allow easier mechanical maintenance for the first few years. If using seedlings, select individuals with large root systems that include five or more large lateral roots to assure rapid establishment and growth. Replanting holes of missing woody plants during the first two to three years should be done to establish a continuous buffer barrier. Broadcast planting of tree seeds can also be done rapidly; but then there is no initial control of density and less control of species diversity. However, broadcast seeded plantings may require less early maintenance because germination produces very dense stands of seedlings that control competing vegetation. The dense sapling stands also thin themselves effectively over time.

Maintenance of planted riparian buffers

Mowing of both the woody and grass zones can be beneficial during the first few years of establishment. Native grasses and forbs often germinate and grow more slowly than local weeds or non-native grasses. Local weeds can pose a problem for the farmer. Mowing at 40 cm to 60 cm heights, twice a season, before major annual weed seeds mature, can minimize those problems. Using a flail chopper mower instead of a brush-hog will scatter the cut debris rather than windrowing it. Windrows of debris can choke some small young prairie plants. The last mowing may be planned for late summer or fall to allow enough regrowth to occur to provide fuel for prescribed spring burns.

Mowing between woody plant rows reduces shading of young seedlings and helps identify rows. However, during very hot dry windy weather shading by taller weeds may benefit young seedlings. Mowing between woody plant rows late in the season may concentrate rodents in the seedling rows where they may girdle plants, unless herbicides have kept the seedling rows clear of weeds. Careful use of pre-emergent herbicides in the woody plant rows may help rapid establishment of seedlings.

Prescribed fire is a useful tool to help establish prairie communities. Annual spring burns during the first three or four years can produce good stands of desired grasses and forbs. Burning regimes of three to five year frequency should be used once the desired species are established. Alternating fall burns may be used to stimulate forb species over grasses that are stimulated by spring burns. Care is required to conduct these prescribed burns in the narrow zones that can lie between woody species and extensive row crops. With good planning and careful attention to weather and site conditions, these burns can be successful. As with other planting and maintenance recommendations, it is always good to check with local professionals about the best burning regime to establish and maintain the filter zone planting.

Trees can be pruned to improve form if trees will be harvested for timber products in the future. This is especially true for the higher quality hardwood species that are planted on the higher microtopographic locations of the buffer. Systematic thinning and harvesting are required to maintain an active woody plant nutrient sink. Once a given number of stems in a buffer have reached the natural production limit of the buffer, no new nutrient storage biomass is added to the trees. Instead, the trees naturally thin themselves allowing the surviving trees to continue to expand. The trees that die naturally will add their nutrients back to the buffer soil making it available for transport to the stream. A management plan should be developed with the help of a local natural resource professional to schedule these removals and to assure regeneration of the next stand.

One of the major fallacies with buffers is that they can be planted and then left on their own. For them to remain effective buffers, extensive management is required. While not intensive during each year, annual site evaluation and long-term maintenance is a must. For example, if sediment berms are found to be building up along the filter edge between the crop field and the buffer, corrective disking and replanting may be required to reduce the chance that concentrated flow pathways do not develop through the buffer.

How well do buffers carry out their prescribed functions?

Extensive studies in the Bear Creek Watershed over the past decade have demonstrated the efficacy of buffers to remove non-point source pollution from surface and ground water as well as improve the biological integrity of both the terrestrial buffer and the adjacent aquatic stream ecosystem. However, these studies have also demonstrated that there is wide variability of functions related to the variability of alluvial landscapes and that buffers may not be effective at controlling pollution in some settings.

Process-oriented studies that have been completed as part of the Bear Creek Watershed Project include: soil carbon and aggregate dynamic studies (Marquez et al. 1999; Marquez 2000), denitrification and soil microbiological studies (D.M. Haake 2003. Land use effects on soil microbial carbon and nitrogen in riparian zones in Northeast Missouri. M.S. Thesis. Iowa State University. 56 pp.; J.L. Nelson. 2003. Denitrification in riparian soils in three NE Missouri watersheds.

M.S. Thesis. Iowa State University. 44 pp.; J.E. Pickle 1999. Microbial biomass and nitrate immobilization in a multi-species riparian buffer. M.S. Thesis. Iowa State University. 86 pp.); surface runoff and infiltration studies (Bharati et al. 2002; Lee et al. 1999, 2000, 2003); above- and below-ground biomass, carbon, nitrogen and soil respiration studies (Tufekcioglu et al. 1999; Tufekcioglu et al. 2000; Tufekcioglu et al. in press); fine root decay rates (M.E. Dornbush. 2001. Fine root decay: a comparison among three species. M.S. Thesis. Iowa State University. 109 pp.); streambank erosion studies (G.N. Zaimes 1999. Streambank erosion adjacent to riparian land-use practices and stream patterns along Bear Creek, in north central Iowa. M.S. Thesis. Iowa State University. 58 pp.; Zaimes et al. 2004); and surface flow path and spatio-temporal modeling studies (Hameed 1999; D. Webber. 2000. Comparing estimated surface flowpaths and sub-basins derived from digital elevation models of Bear Creek Watershed in central Iowa. M.S. Thesis. Iowa State University. 82 pp.). A series of studies have been conducted on stream substrate and fish diversity, small mammal diversity in native grass and forb vs. cool-season grass filter portions of the riparian forest buffer and bird species composition (unpublished data).

Hydrogeological studies have also been conducted to establish the connection between surface and groundwater processes. These studies have included: geology and hydrogeology of the 1990 planting site, groundwater interaction with Bear Creek, hydrogeology and groundwater quality below a cool-season grass buffer and two multi-species buffers, assessing groundwater velocity and denitrification potential beneath a multi-species buffer using natural-gradient tracer tests and application of geophysics and innovative groundwater sampling to optimize placement of future buffers in the watershed (Simpkins et al. 2002). Several socioeconomic analyses have also been conducted in the Bear Creek Watershed and in the Mark Twain Watershed in Missouri where companion studies have been conducted (Brewer 2002; Colletti et al. 1993). Major conclusions from these studies include those listed below.

1. A 7-m wide native-grass filter can reduce sediment loss by more than 95% and total nitrogen and phosphorus and nitrate and phosphate in the surface runoff by more than 60%. Adding a 9-m wide woody-buffer results in removal of 97% of the sediment and 80% of the nutrients. There also is a 20% increase in the removal of soluble nutrients with the added width.
2. Water can infiltrate up to five times faster in restored six-year old buffers than in row cropped fields or heavily grazed pastures.
3. Soils in riparian buffers contain up to 66% more total organic carbon in the top 50 cm than crop field soils. Poplar hybrids (*Populus* spp.) and switchgrass living and dead biomass sequester 3000 and 800 kg C ha^{-1} yr^{-1} and immobilize 37 and 16 kg N ha^{-1} yr^{-1}, respectively. Riparian buffers have more than eight times more below ground biomass than adjacent crop fields.
4. Buffers show a 2.5 fold increase in soil microbial biomass and a four-fold increase in denitrification in the surface 50 cm of soil when compared to crop field soils of the same mapping unit.
5. Tracer tests and isotope evidence shows that denitrification is the major groundwater nitrate removal mechanism in the buffers.
6. Stratigraphy below buffers can determine the effectiveness of nutrient removal from shallow groundwater. With a shallow confining layer of till below a loamy root zone buffers can remove up to 90% of the nitrate in groundwater. When the confining layer is found well below the rooting zone and porous sand and gravel are found between the till and the loam, residence time and contact with roots is dramatically reduced and buffers are unable to remove much nitrate from the groundwater. The difficulty in describing the stratigraphy below buffers makes it difficult to quantify the role that specific buffers might play in remediating agricultural chemicals in groundwater.
7. Buffered stream banks lose up to 80% less soil than row cropped or heavily grazed stream banks.
8. Riparian buffers can reach maximum efficiency for sediment removal in as little as 5 years and nutrient removal in as little as 10–15 years.
9. Streamside buffers cannot remove materials from field drainage tiles. But an acre of tile–intercepting wetland can remove 20–40 tons of N over a period of 60 years.
10. Stream segments with extended buffers exhibit greater stream substrate and fish species diversity. Vole and mouse species common to the region strongly prefer riparian forest buffers with prairie grass and forb zones instead of introduced cool-season grass zones. Riparian forest buffers support five times as many bird species as row-cropped or heavily grazed riparian areas.
11. To have a significant effect on stream water quality continuous riparian buffers should be placed high up in the watershed.

12. Eighty percent of farmers and town's people agree that buffers are an effective tool for improving stream water quality. These same persons believe that water quality in streams should be improved by 40%.
13. Ninety percent of financial agents who appraise agricultural land and lend money to farmers believe buffers are a net asset when considering market (financial) and nonmarket (conservation, aesthetic, environmental, etc.) benefits and government assistance. When market benefits exclusively are considered, only 46% think that buffers are 'a net asset.'
14. Buffers enhance recreational opportunities. Fishing, hunting and watching wildlife are popular uses.

Conclusion

Based on the studies that have been conducted in the Bear Creek watershed, riparian buffers are effective at reducing the impact of non-point source pollutants on stream and ground water in a small order watershed. These studies have also demonstrated, however, that there is great variability in rates of the important biological and physical processes that are responsible for these improved conditions. Statements about general buffer effectiveness over a wide range of landscapes must be made carefully and further research must be conducted to establish the range of process rates in other ecoregions around the country and the world.

It has been difficult to demonstrate the impact of over 6 km of buffer on the water quality in Bear Creek, itself, because about a third of the watershed lies above the buffered portion of the creek and that part of the watershed contains about twice as many kilometers of channel as the buffered reach. Yet at the field scale buffer efficacy has been demonstrated. This points to the need for buffering watersheds in a systematic manner beginning in the headwaters and moving down stream.

While this chapter has only dealt with the design and role of riparian buffers in improving stream water and ground water quality, it must be realized that they are just one of a number of conservation practices that may be needed to make up a riparian management system. Stream bank bioengineering, in-stream flow control structures, constructed wetlands and intensively managed grazing systems along with a host of upland conservation practices may all be needed to round out an effective pollution control system within a watershed.

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