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Design, Function, and Management of Integrated Riparian Management Systems

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Abstract

A challenge for resource managers in intensively modified agricultural landscapes is the development and implementation of restoration-based management approaches that build upon traditional pollution control efforts. The creation or restoration of vegetative buffer zones is one approach to enhance soil and water quality protection while also enhancing the chemical, physical, and biological integrity of terrestrial and aquatic systems. To demonstrate the benefits of properly functioning riparian zones in the heavily row-cropped midwestern U.S., an integrated riparian management system was constructed along a central Iowa stream beginning in 1990. The system consists of three components: a constructed, multi-species riparian buffer strip; soil bioengineering technologies for streambank stabilization; and constructed wetlands to intercept and process nonpoint source pollutants in agricultural drainage tile water. The multi-species riparian buffer strip consists of four or five rows of fast-growing trees placed closest to the stream, then two shrub rows, and finally a strip of switchgrass *(Panicum virgatum)* established next to the agricultural field. Long-term monitoring has demonstrated the significant capability of these components to intercept eroding soil from adjacent crop land, intercept and process agricultural chemicals moving in shallow subsurface water, stabilize stream channel movement, and improve instream environments, while also providing valuable wildlife habitat. While not a true restoration in the strict definition of the term, important ecosystem functions associated with a healthy and diverse riparian zone are being restored. The integrated riparian management system model has the potential to increase the biotic integrity of the aquatic ecosystems in this region by reducing sediment and chemical loading, modifying flow regime by reducing discharge extremes, improving structural habitat, and restoring energy relationships through the addition of organic matter and reduction in temperature and dissolved oxygen extremes.

Introduction

The Western Corn Belt Plains Ecoregion which covers most of Iowa and parts of surrounding states can be characterized as extensive cropland on level to gently rolling dissected glacial till plains, hilly loess plains, and morainal hills with broad smooth ridgetops (Griffith et al. 1994). This landscape has been largely converted to agricultural uses with extensive acreage in corn, soybeans, and forage for livestock. Modification of the local and regional hydrology has been an essential part of this conversion. Creation of extensive networks of subsurface tile drains, excavation of surface drainage ditches, and channelization of many perennial streams have facilitated the conversion of nearly all wet prairie and wetland acreage to agricultural uses.

This large scale modification of regional hydrology and native ecosystems has had profound impact on the biological integrity of the surface waters of the region. Menzel (1983) reviewed the natural structure and function of stream ecosystems of the "Corn Belt" region with special reference to the impacts of past and present agricultural management practices. He concluded that impacts on water quality were not the sole problem, and that aspects of water quantity, habitat structure, and energy transfer are often profoundly affected by agricultural land use practices. Such alteration of the physical, chemical, and biological processes associated with the water resource will result in a reduction in the biological integrity of the aquatic system (Karr 1991).

In recognition of the inadequacy of traditional chemical control approaches to protect water resources, many states are adopting biological criteria for surface waters to improve water quality standards (Griffith et al. 1994). Ambient monitoring of biological integrity is being recognized as a direct, comprehensive indicator of ecological conditions and thus, desired quality of a water resource. Also emerging is the recognition that rivers and their floodplains are so intimately linked that they should be understood, managed, and restored as integral parts of a single ecosystem (National Research Council 1992). Placement, maintenance, or enhancement of riparian vegetation or "streamside filter strips" are recommended to reduce sediment and chemical loading, modify flow regime by reducing discharge extremes, improve structural habitat, and restore energy relationships through the addition of organic matter and reduction in temperature and dissolved oxygen extremes.

This paper describes a model for integrated riparian zone management designed to reduce nonpoint source pollution in regions of intensive row crop agriculture, while facilitating restoration of the ecological functions associated with the riparian zone. A six year old riparian zone restoration site located on Bear Creek in North Central Iowa is used to illustrate the success that can be achieved over a short time period.

Historical Setting

The Bear Creek watershed is located in the Des Moines Lobe Subecoregion of the Western Corn Belt Plains Ecoregion, one of the younger and flattest ecological subregions in Iowa (Griffith et al. 1994). In general, the land is level to gently rolling with a poorly developed stream network. This region was once part of the vast tallgrass prairie ecosystem, interspersed with wet prairie marshes in topographic lows and gallery forests associated with larger order streams and rivers. The total length of Bear Creek is 34.8 km with 27.8 km of major tributaries. The integrated riparian management demonstration site is located approximately 19.3 km upstream from Bear Creek's confluence with the Skunk River. At this point, Bear Creek can be described as a third order perennial stream (Strahler 1957) with average discharge rates varying between 0.3 and 1.4 m^3 sec^{-1}.

Description of the presettlement landscape and drainage history of the Bear Creek watershed is the subject of an ongoing study by members of Leopold Center for Sustainable Agriculture's Agroecology Issue Team (Andersen and Bishop in prep.). This research is using original land survey notes (circa 1847) and accompanying field plat maps to describe the presettlement landscape. Early county atlases, original drainage district maps, and historical accounts of early settlers provide a historical perspective of changes in watershed hydrology and modification of the ecosystem. Clearly dramatic changes have occurred since European settlement of the region.

The townships through which Bear Creek flows originally were surveyed in 1847. These surveys suggest that prior to settlement, the watershed was "rolling prairie" with "first rate soil" with a substantial portion being "low and marshy." Native forest was limited to the larger Skunk River corridor into which Bear Creek flows. No perennial stream channel was identified in the township where the riparian management demonstration site is located. It is more likely that this area was low, wet prairie connecting more defined marshes and would contain intermittent or seasonal flow. Again, Bear Creek at this location is now a third order perennial stream with many vertical streambanks of one meter or more in height.

Subsequent changes in watershed hydrology have resulted in the change from a low, wet prairie landscape to a perennial stream. Conversion of the land from native vegetation to row crops, extensive subsurface drainage tile installation, and dredge ditching have resulted in substantial stream channel development. Records suggest that artificial drainage of marshes and low prairie in the upper reaches of the Bear Creek watershed was completed about 1902, with ditch dredging completed shortly thereafter. While the main stream pattern appears to have remained about the same since that time, significant channelization continued into the 1970s. Modern stream patterns also indicate development of intermittent flow drainages throughout the watershed. Ground surveys show that these are typically grass waterways associated with agricultural row crops.

The conversion of this landscape to production agriculture has produced many benefits such as great quantities of high quality and inexpensive food stuffs and industrial raw materials. The production-oriented function of this landscape has also produced unintended and undesirable consequences that include a reduction in soil quality, nonpoint source pollution, a decrease in wildlife habitat and biodiversity, and a reduction in the biological integrity of aquatic habitats. A significant challenge for resource managers in these landscapes is the development and implementation of restoration-based approaches that build upon traditional pollution control efforts. Managing the landscape by creating or restoring buffer zones is one such approach that is viewed as a promising way to increase the effectiveness of efforts to protect soil and water quality while also enhancing the chemical, physical, and biological integrity of the terrestrial and aquatic systems (National Research Council 1993).

An Integrated Riparian Management System

While a considerable body of evidence confirms that existing vegetated riparian zones have considerable ecological value and can be effective sinks for nonpoint source (Castelle et al. 1994, Osborne and Kovacic 1993, Lowrance 1992, Cooper et al. 1987, Jacobs and Gilliam 1985, Lowrance et al. 1985, Lowrance et al. 1984, Peterjohn and Correll 1984), little information is available for restored or constructed riparian buffer systems. To demonstrate the benefits of properly functioning riparian zones in the heavily row-cropped Midwest, the Agroecology Issue Team of the Leopold Center for Sustainable Agriculture and the Iowa State Agroforestry Research Team (IStART) are conducting research on the design and establishment of integrated riparian management systems. The purpose of these systems is to restore the essential ecological functions that these riparian areas once provided. Specific objectives of such buffers are to intercept eroding soil and agricultural chemicals from adjacent crop fields, slow flood waters, stabilize streambanks, provide wildlife habitat, and improve the biological integrity of aquatic ecosystems.

The system consists of three components: a constructed, multi-species riparian buffer strip; soil bioengineering technologies for streambank stabilization; and constructed wetlands to intercept and process nonpoint source pollutants in agricultural drainage tile water (Figure 1). The research is being conducted on a private farm located along Bear Creek in a highly developed agricultural region of central Iowa. Project establishment began in 1990.

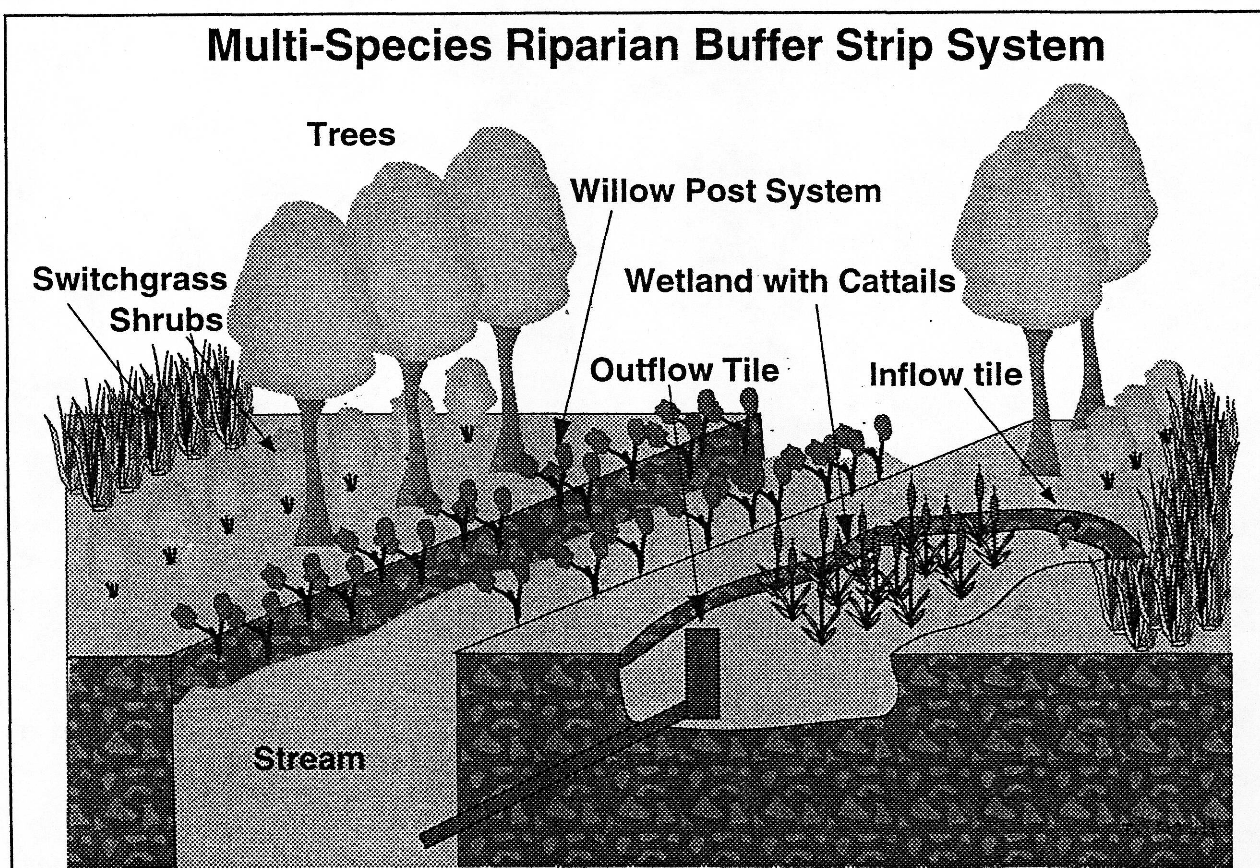

Figure 1. Riparian management system model which integrates a multi-species buffer strip, streambank stabilization technologies, and constructed wetlands.

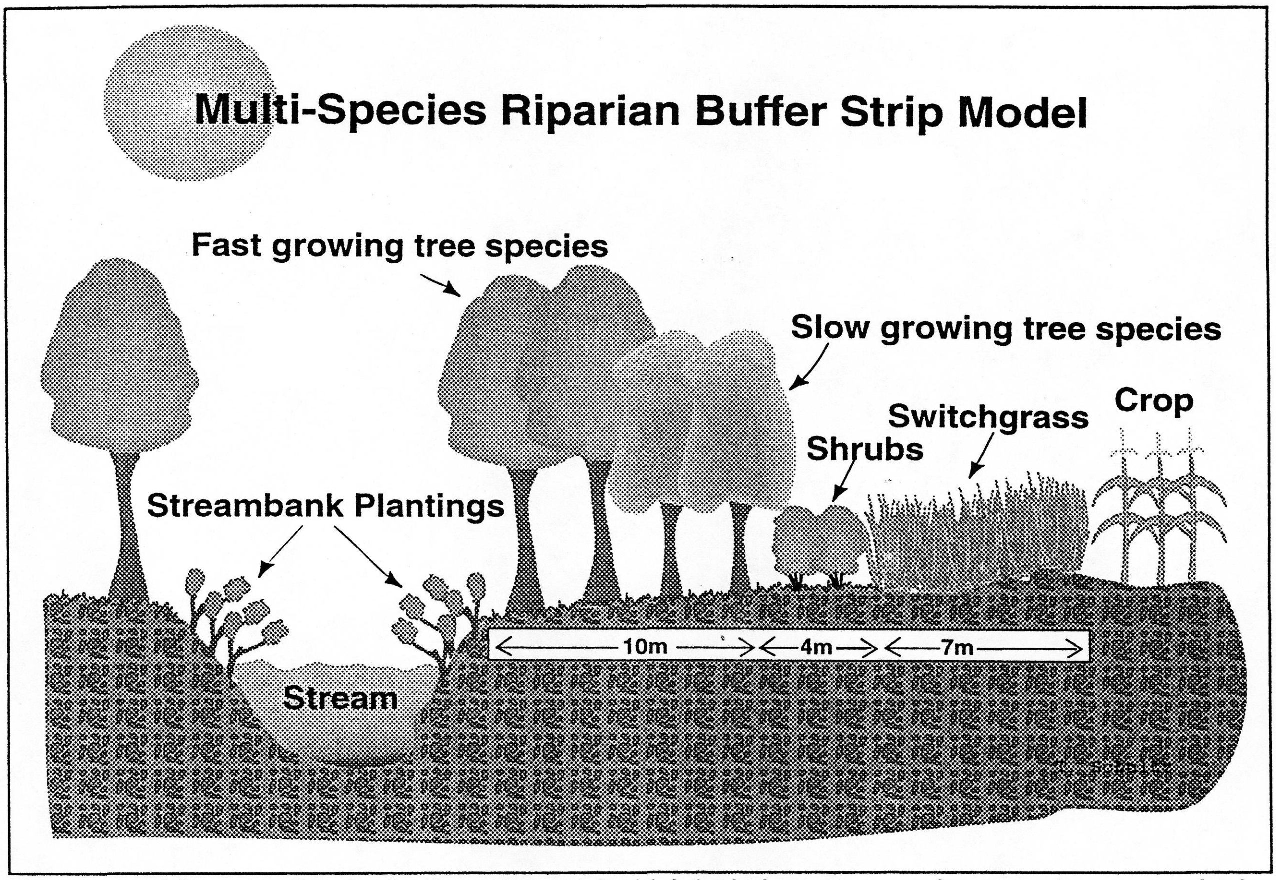

Figure 2. Multi-species riparian buffer strip model which includes tree rows closest to the stream, shrubs, and a strip of switchgrass adjacent to the cropland.

Multi-Species Riparian Buffer Strip

The general multi-species riparian buffer strip layout consists of three zones (Figure 2). Starting at the creek or stream bank edge, the first zone includes a 10 m wide strip of 4-5 rows of trees, the second zone is a 4 m wide strip of 1-2 rows of shrubs, and the third zone is a 7 m wide strip of native warm-season grass. This design is important because the trees and shrubs provide perennial root systems and long-term nutrient storage close to the stream, while the grass provides the high density of stems needed to dissipate the energy of surface runoff from the adjacent cropland.

Fast growing trees are recommended to provide a functioning multi-species riparian buffer strip in the shortest possible time. It is especially important that rows 1-3 (row 1 is closest to the streambank edge) in the tree zone include fast-growing, riparian species such as willow *(Salix sp.)*, cottonwood *(Populus deltoides)*, silver maple *(Acer sacharinum)*, hybrid poplars *(Populus sp.)*, green ash *(Fraxinus pennsylvanica)*, and box elder *(Acer negundo)*. Other moderate-growth species include black ash *(Fraxinus nigra)*, river birch *(Betula nigra)*, hackberry *(Celtis occidentalis)*, shellbark hickory *(Carya laciniosa)*, swamp white oak *(Quercus bicolor)*, Ohio buckeye *(Aesculus glabra)*, and sycamore *(Platanus occidentalis)*. The key to tree species selection is to observe native species growing along existing natural riparian zones and select the faster growing species. If height from the top of the streambank to the water level at normal flow (summer non-flood stage) is more than 1 m and soils are well drained, species such as black walnut *(Juglans nigra)*, red oak *(Quercus rubra)*, white oak *(Quercus alba)*, white ash *(Fraxinus americana)* or even selected conifers can be planted in rows 4 and 5. The slower growing species will not begin to function as nutrient sinks as quickly as faster growing species. Other selections could be made based on species growing in neighboring uplands.

Shrubs are included in the design because of their permanent roots and because they add biodiversity and wildlife habitat. Their multiple stems also function to slow flood flows. The mixture of species that have been used by IStART include ninebark *(Physocarpus opulifolius)*, redosier *(cornus stonifera)* and gray dogwood *(Cornus racemosa)*, chokecherry *(Prunus virginiana)*, Nanking cherry *(Prunus tomentosa)*, hazel *(Corylus americana)*, and nannyberry *(Viburnum lentago)*. Other shrubs can be used, especially if they are native species and provide the desired wildlife/aesthetic objectives. These other species could include speckled alder *(Alnus rugosa)*, serviceberry *(Amelanchier arborea)*, silky dogwood *(Cornus obliqua)*, hawthorns *(Crataegus sp.)*, wild plum *(Prunus americana)*, pin cherry *(Prunus pensylvanica)*, peachleaf willow *(Salix amygladoides)*, sandbar willow *(Salix interior)*, buffalo berry *(Sheperdia argentea)*, and blackhaw *(Viburnum prunifolium)*.

The grass zone functions to intercept and dissipate the energy of surface runoff, trap sediment and agricultural chemicals in the surface runoff, and provide a source of soil organic matter for microbes which can metabolize the nonpoint source pollutants. A minimum width of 7 m of switchgrass *(Panicum virgatum)* is recommended because it produces a uniform cover and has dense, stiff stems that provide a highly frictional surface to intercept surface runoff and facilitate infiltration. Other warm season grasses, such as Indian grass *(Sorghastrum nutans)* and big bluestem *(Andropogon gerardii)* and native perennial forbs also may be part of the mix. Because of its structure, switchgrass should be used where surface runoff is most severe.

The multi-species riparian buffer strip model presented here prescribes a zone of trees, a zone of shrubs, and a zone of prairie grass. Although these species combinations provide a very effective plant community, they are not the only combinations that can be effective. Site conditions (e.g. soils, slope), major buffer strip biological and physical function(s), owner objectives, and cost-share program requirements should be considered in specifying species combinations and placement.

Although the model that IStART has developed is 20 m wide on each side of the creek, stream, or river, a multi-species riparian buffer strip may have different widths that can be adapted to fit each site and land ownership. The total width of the buffer strip depends in large part on the major functions of the buffer strip 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 percent. If excess nutrient removal also is an important function, a width of 20–30 m would be necessary depending on the kind and quantity of agricultural chemicals applied and the soil and cultivation system used. If rowcrops are found adjacent to the buffer strip, both the sediment and chemical removal functions would be important. If increased wildlife habitat is an objective of the buffer strip, widths of 30–100 m would provide a more suitable wildlife corridor or transition zone between the upland agricultural land and the aquatic ecosystem (Castelle et al. 1994).

Streambank bioengineering

Several authors have estimated that greater than 50 percent of the sediment yield in small watersheds in the Midwest is the result of channel erosion (Roseboom and White 1990). This soil usually consists of small silt and clay particles which are ultimately deposited in rivers, lakes or backwater areas, choking these areas with sediment and diminishing their value as habitat for fish and aquatic macroinvertebrates (Frazee and Roseboom 1993). This problem has been exacerbated by the increased erosive power of streams as result of stream channelization and loss of riparian vegetation. The typical solution is to buttress blocks of concrete, wood or steel along the stretch of the bank which is eroding (Frazee and Roseboom 1993). Such solutions are costly to build and maintain and provide little aquatic habitat. An alternative streambank stabilization technique is the use of locally available natural materials such as willow posts or other live plant material, often in combination with revetments of rock, cut cedar, or other woody material. These techniques often are referred to as soft engineering or soil bioengineering.

Several different soil bioengineering techniques have been employed by IStART. On vertical or actively cutting streambanks, combinations of willow "posts" and/or anchored dead tree revetments are used to slow bank collapse. These plant materials provide a frictional surface for absorbing stream energy and trapping sediment. The goal of these plantings is to change the streambank angle from vertical to about 50 degrees to allow other vegetation to become established. Willow *(Salix sp.)* cuttings are collected during the dormant season, cut into 0.3–2 m sections, and stored in a cooler until planting. Small cuttings with diameters between 0.6 cm–5 cm can be manually installed. Large diameter cuttings should be hydraulically installed using an auger mounted on a backhoe.

One or two rows of the largest cuttings are placed into the stream bed at the base of the streambank at spacing of 0.6 x 0.6 m between posts. An additional 2–4 rows of small diameter cuttings should be planted into the bank above the low water line. Small wing dams of willow posts can be extended into the stream by placing double rows of 3–4 posts at right angles or pointed slightly downstream.

Where there is a concern for active undercutting of the bank, the toe of the bank can be stabilized using rock. Alternatively, bundles of Eastern red cedar *(Juniperus virginiana)* or small hardwoods (5–6 year old), silver maples, willows, etc. can be tied together into 2–4 tree bundles. A row of these bundles is laid horizontally along the bottom-most row of willow posts with the bottoms pointed upstream and the bundles anchored into the bank.

Constructed Wetlands

A characteristic of the Des Moines Lobe Subecoregion of the Western Corn Belt Plains Ecoregion is the presence of an extensive network of subsurface tile drainage. Such tile drains provide a direct path to surface water for nitrate or other agricultural chemicals that move with the shallow groundwater. In such instances, constructed wetlands that are integrated into new or existing drainage systems may have considerable potential to remove nitrate from shallow subsurface drainage (Crumpton and Baker 1993, Crumpton et al. 1993).

To demonstrate this technology, a small (500 m^2) wetland was constructed to process field drainage tile water from a 4.9 ha cropped field. The wetland was planted with cattail rhizomes *(Typha glauca)*. The subsurface drainage tile was rerouted to enter the wetland at a point furthest from the stream, maximizing residence time of drainage tile water within the wetland. In general, the nitrate removal efficiency of freshwater wetlands can be maximized by providing ample residence time for contaminant laden water to come into contact with microbially active surfaces. In addition, as vegetation and litter accumulate over time, nitrate removal efficiencies can be expected to increase. Models of areal nitrate flux that can be combined with models of wetland hydrology to produce general models of nitrate loss and assimilative capacity for freshwater wetlands now exist (Crumpton and Baker 1993).

System Effectiveness

The recommendations discussed above provide a integrated riparian management system that effectively intercepts and treats nonpoint source pollution from the uplands. However, it should be stressed that a riparian management system cannot replace upland conservation practices. In a properly functioning agricultural landscape, both upland conservation practices and an integrated riparian system contribute to achieving environmental goals and improved ecosystem functioning.

Long-term monitoring has demonstrated the significant capability of these systems to intercept eroding soil from adjacent crop land, intercept and process agricultural chemicals moving in shallow subsurface water, stabilize stream channel movement, and improve instream environments—while also providing wildlife habitat, biomass for energy, and high quality timber (Schultz et al. 1995). The buffer strip traps much the sediment carried in surface runoff and has reduced nitrate and atrazine concentrations moving through the soil solution by over 90 percent, with resulting concentrations well below the maximum contaminant levels specified by the U.S. EPA (Figure 3). The constructed wetland also has proven to be very effective in processing nitrate and other nonpoint source pollutants moving in the agricultural tile drainage water. Wildlife benefits also have appeared in a very short time with a nearly five fold increase in bird species diversity observed within the buffer strip versus an adjacent, unprotected stream reach. Figures 4 and 5 show the dramatic changes that can take place in as little as four growing seasons after establishment of the integrated riparian management system.

Summary

Restoration has been defined as "the return of an ecosystem to a close approximation of its condition prior to disturbance." (National Research Council 1992). While a noble objective for managing ecosystems, the opportunities for true aquatic ecosystem restoration in areas such as the Western Corn Belt Plains Ecoregion will be limited by the extensive modification of system hydrology. True restoration in this ecoregion would often require removal of extensive subsurface and surface drainage networks, restoration of thousands of hectares of wetlands, and replacement of countless river meanders.

Under this strict definition, the integrated riparian management model described here cannot be considered restoration. The model recommends the placement of woody plant material (trees and shrubs) into areas where they did not exist prior to European settlement. Modification of watershed

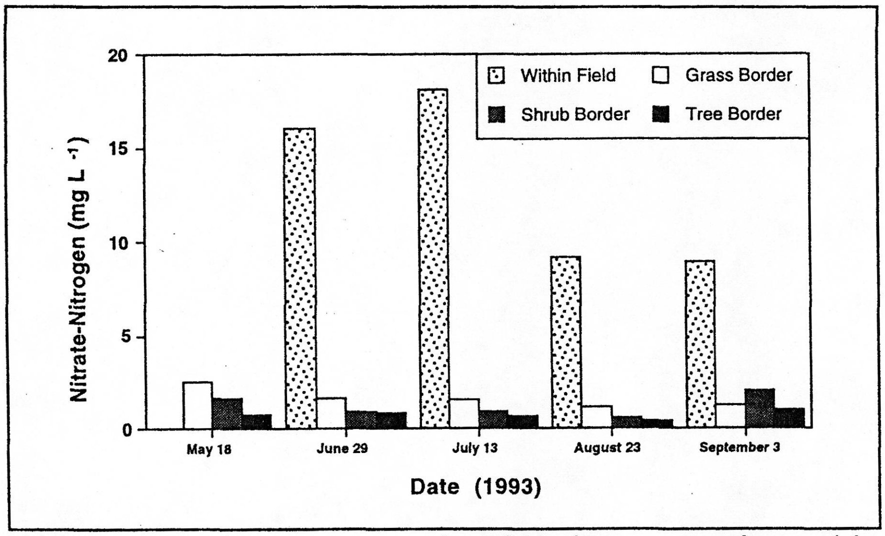

Figure 3. Nitrate-nitrogen concentration within the unsaturated zone of the cropped field and within the three zones of the multi-species riparian buffer strip on several dates in 1993. The cropped field was in corn. Notice the dramatic reduction in nitrate-nitrogen concentration through the buffer strip.

Figure 4. Bear Creek riparian management site 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.

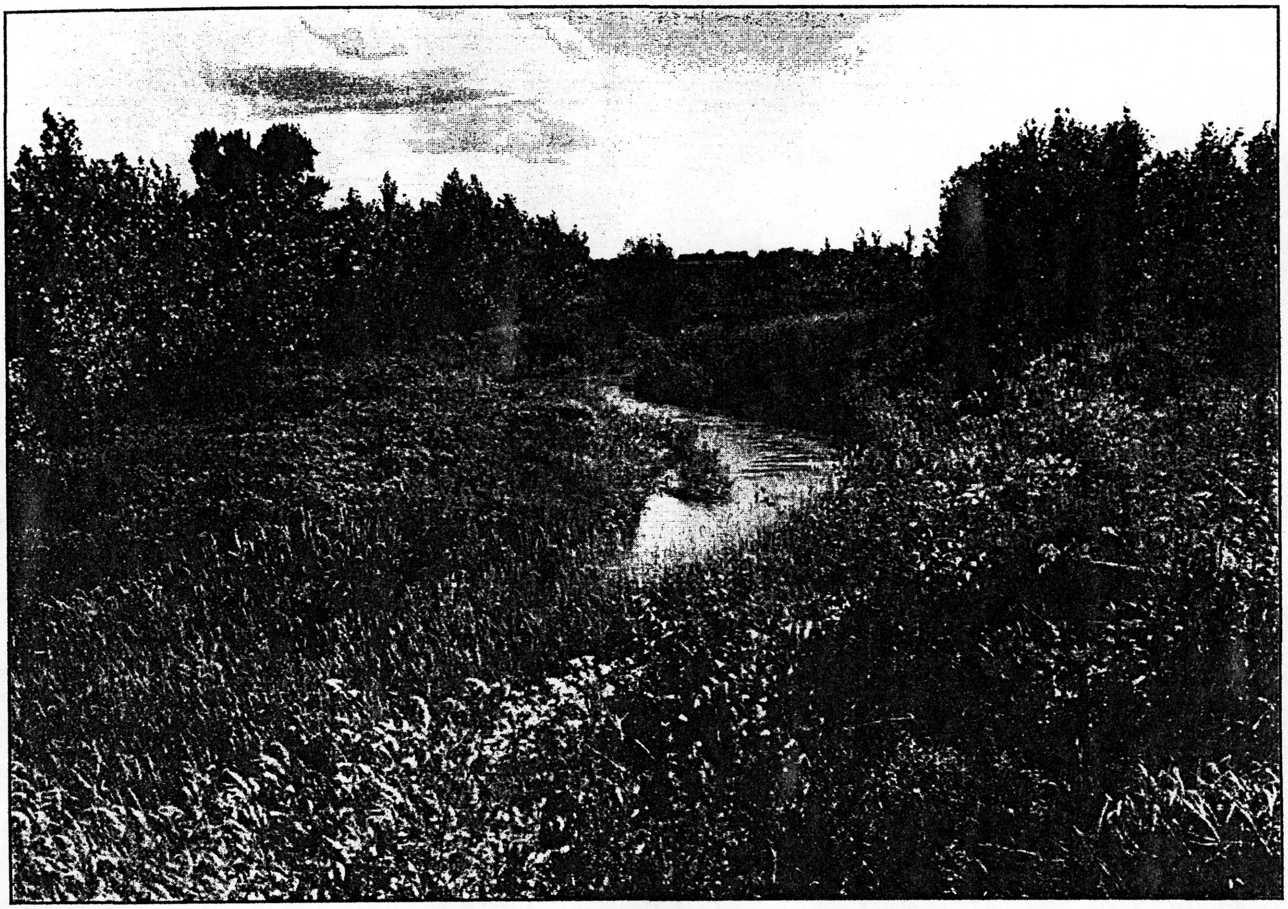

Figure 5. Bear Creek riparian management site in June 1994. Notice the rapid growth of the riparian vegetation and the dramatic improvement in the condition of the streambanks after only five seasons since establishment of the riparian management system.

hydrology has resulted in the development of stream channels in areas which were formerly wet prairie or wetlands. Little or no woody vegetation was present throughout the watershed. What is being restored, however, are the important ecosystem functions associated with a healthy, vegetated, riparian habitat.

Over time it can be expected that implementation of the integrated riparian buffer strip model on sufficient length of stream will improve the biotic integrity of the aquatic ecosystem. Water quality will be improved through the reduction of sediment and chemical loadings. Flow regime will be moderated by the reduction of discharge extremes. Structural habitat will be improved through the addition of coarse woody debris to the stream and through overhanging vegetation. Finally, important energy relationships will be restored through the addition of particulate organic matter and the moderation of temperature and dissolved oxygen fluctuations by reducing direct solar radiation. Such changes can only result in the modification of the resident biological community for the better, and improve the biotic integrity and overall sustainability of the agroecosystem.

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