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Ecological Engineering 24 (2005) 433–439
ECOLOGICAL ENGINEERING
www.elsevier.com/locate/ecoleng

Principles of planning and establishment of buffer zones

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Accepted 10 January 2005

Abstract

Good management of the uplands is essential and effective buffer zones along the streams draining the basin will complete the task of water quality protection. Most basin drainage moves through the riparian zones of first- and second-order headwaters streams. It is important to have continuous buffers on both sides of these streams. For larger streams, protect the flood plains. Several zones of buffer vegetation are most effective. A narrow grass strip at the upland edge traps suspended particulates and phosphorus. A wider zone of woody vegetation traps nitrate, and both cools and provides natural organic matter to the receiving waters. Contour the buffer surface to avoid concentrated storm flows and periodically remove sediment berms that develop. For a completely degraded riparian zone, it is essential to provide soils of the right porosity and organic carbon content. Sub-soils need to be permeable and to have a reasonable groundwater retention time. High organic carbon is required to develop a low redox potential. Provide short-term protection from erosion. Only add native species. Sometimes, exotic plants get established and must be eradicated. Fence livestock out. Control excessive activity by wild ungulates, voles, and beaver.

Keywords: Drainage basin management; Buffer restoration; Exotic plants; Water quality

1. Introduction

Healthy riparian buffers are highly interactive with the adjacent waterways and provide many services to these waters. Stands of native plants provide leaf litter and dissolved organic matter of the right type for desirable populations of invertebrates and microorganisms, which in turn, support fish populations (e.g. Gregory et al., 1991). Mature woody vegetation also provides a good supply of coarse woody debris, which is important to stream channel morphology and fish habitat (e.g. Harmon et al., 1986). Riparian vegetation, especially forest, also plays an important role in maintaining lower temperatures in streams (e.g. Sinokrot and Stefan, 1993). This cooling is due to the combined effects of shading and evaporative cooling and often is essential to the life of the native species of fish.

Healthy riparian buffers also provide water quality services to adjacent waters by filtering out contaminants from overland storm flows and groundwater entering laterally, and from stream channel waters flooding out into flood plains during storm events. For groundwater flows the chief benefits are removal of nitrate (see review by Hill, 1996) and the neutralization of excessive acidity (e.g. Correll and Weller, 1989). For lateral overland storm flows and out-floodings from the

0925-8574/$ – see front matter © 2005 Published by Elsevier B.V.
doi:10.1016/j.ecoleng.2005.01.007

channel into the flood plain, the chief water quality benefits are removal of suspended sediments (e.g. Cooper et al., 1987; McIntyre and Naney, 1991), pesticides (e.g. Lowrance et al., 1997), and various forms of nitrogen and phosphorus (e.g. Mander et al., 1995).

There are very few published reports of research on the water quality benefits of riparian buffer zones prior to the mid-1970s. During the 1970s and early 1980s environmental scientists began to realize that receiving water quality often was not closely related to the quality of surface and groundwater as it left the "edge of the fields". This disparity was especially evident for nitrate concentrations at three study sites in the southeastern United States. Investigators at these sites proceeded to focus their attention on the dynamics of nitrate in the riparian zones of these sites (Lowrance et al., 1984; Peterjohn and Correll, 1984; Jacobs and Gilliam, 1985). The findings at these sites, not only with respect to nitrate, but for many other parameters, quickly led to many studies in other parts of the United States and Canada, as well as in Great Britain and Europe.

Over most of the world, many riparian zones have not only been denuded of native vegetation, but the adjacent waterways have been channelized, dammed, populated by exotic biota and seriously polluted. Natural resource managers, having realized the values of healthy riparian zones, now face the challenge of restoration or recreation of functional riparian zones in many different settings. This is a rather recent challenge with relatively little experience upon which managers can rely for guidance. It is very important that land managers not make the mistake of thinking that a healthy riparian buffer zone will cure the impacts of mistaken management practices in the uplands of the watersheds. Only good management of the uplands and healthy riparian zones will completely protect the quality and functioning of the receiving waters (e.g. Correll et al., 1992; Lowrance et al., 1997).

2. Materials and methods

This paper is a review and is based largely on the published riparian buffer zone literature. This literature may be found in an annotated and indexed bibliography on the riparian web page, http://www.riparian.net/. I am the author of this bibliography and the current, 10th edition of the bibliography contains 780 references. The bibliography may be downloaded, without charge, onto your personal computer using your word processing software. Bibliography users are urged to send me copies of relevant articles not cited in the bibliography.

For this article I have also made use of some personal knowledge of the problems experienced at various locations, when riparian restorations were attempted. Since it is difficult to publish negative results, these problems remain largely unpublished. However, I believe that warnings about these problems will be helpful to organizations that are initiating riparian restorations.

3. Results and discussion

3.1. Hydrology and soils

When planning the establishment of riparian buffer zones, the first concern should be to understand the hydrology of the site (Burt, 1997; Woessner, 2000). If the site is a first or second order (small) stream, then one is dealing with lateral flows of overland storm flow and groundwater. The buffer must be located so as to include the stream bank and areas where the water table is near the surface. Groundwater often surfaces in these areas as seeps. If the site is on a larger stream, then one must also plan for interactions with waters flooding out from the channel during storms. Many of the characteristics of the flood plain are controlled by factors such as the frequency and depth of these flooding events (Burke et al., 1999; Clausen et al., 2001). One should also place specific sites into the context of the entire watershed, considering the cumulative impacts of all upland and riparian activities on the basin (Johnston et al., 1990; Correll et al., 1992).

Soils in undisturbed natural riparian buffer zones are the long-term result of the geology, hydrology, and biota. It is important to remember that pedogenesis is a very slow process. After humans have disrupted and disturbed a buffer zone, reestablishment of a functional buffer zone may require the placement of appropriate sub-soils and top-soils before planting the site. Subsoils must have an appropriate hydraulic conductivity for shallow groundwater to move with a reasonable transit time (e.g. Bosch et al., 1994). Both surface and subsurface soils need enough organic matter to support high rates of microbial activity so that a low oxidation/reduction potential is attained in the groundwater (e.g. Seitzinger, 1994; Pinay et al., 1995). Land planners often assume that if they contour and plant the site, the soils will take care of themselves. To some extent this might be true, but the time scale required would be at least a few centuries. If a timely response in the riparian buffer is desired, proper attention to soils is required.

3.2. Placement and zoning of vegetation in buffer zones

What do we know about priorities for location of riparian buffers on a watershed? We know that most of the water entering most receiving waters enters via first- and second-order headwater streams. We also know that the most efficient place to remove pollutants and nutrients from watershed discharges is in riparian zones before it enters a stream channel. Thus, we know in general that the most important locations to protect and restore riparian buffers are along these headwater streams. Of course it is desirable to have healthy riparian buffers along all waterways. Something a little less obvious is that it is more effective for such benefits as nitrate removal from groundwater to have continuous but narrow riparian buffers, than wider, but intermittent buffers (Weller et al., 1998).

A hypothetical watershed and a lake or wetland that receives its drainage (Fig. 1) illustrates these points. Please note on the diagram that about half of the first order streams have no riparian vegetation. This is a common defect in watershed management plans. These small headwater streams will be major pollution sources, especially in wet weather. In this situation it would be advisable to restore riparian buffers at these sites, even if that required the narrowing of areas on larger streams that now have wider buffers. Also note that although the buffers on the shore of the lake are desirable, they are less important than those on the streams. In planning, it is very common for managers to assume that these buffers on the lake or other large receiving water are the most important. In many cases these lake shore lands are the most valuable real estate on the watershed for development and a plan that only protects them will fail to protect the water quality of the lake.

When land adjacent to waterways has a premium value and landowners wish to use a minimum area of land to accomplish their water quality goals, they should consider using a three-zone approach when establishing riparian buffers on small streams. A narrow zone along the stream bank should be planted with native forest trees and never logged. The primary water quality purpose of this zone is to: (a) provide shade and cooling of the stream; (b) provide stream bank stability; and (c) act as a source of large woody debris as well as leaf litter. A second, wider zone should extend from the edge of the first zone through any land that has the water table at or near the surface. This zone should be planted in native forest tree species, but they may be cropped for income. The primary purpose of this zone is to treat shallow groundwater by removing nitrate and acidity. Finally, a third narrow zone should extend a short distance up-slope from the edge of the second zone. This zone should be carefully contoured to create sheet surface flows during storms and it should be planted in grass or other plants with similar stature and function. The primary purpose of this third zone is: (a) to trap suspended sediments along with adhering nutrients and pesticides; (b) to assimilate available dissolved nutrients into the plants; and (c) to bind dissolved pesticides. Often significant infiltration of overland flow occurs in this zone. This zone must be intensively maintained by mowing and, when a berm of trapped sediment develops, it should be re-contoured and replanted. There is an extensive literature on grass buffer strips, most of which is relevant to applications in riparian buffers. There are no comprehensive recent reviews of this literature, but it is included in my riparian bibliography and can be readily subject searched (see Section 2).

The U.S. Forest Service recommends that the first zone be about 4.5 m wide, the second zone about 18 m wide and the third zone about 6 m wide (Welsch, 1991). However, these dimensions may need modification in various settings. Several research sites have tested the efficacy of partially or completely restored three-zoned buffers (Vellidis et al., 1993; Schultz et al., 1995; Daniels and Gilliam, 1996).

In the case of larger streams and rivers, appropriate modifications of this zoned approach need to be implemented. The flood plains of these large streams need to be protected or restored to flood plains in cases where they have been diked. The normal vegetation of flood plains is forest, usually composed of native species of hardwood trees. In the case of these larger streams there are two banks, the stream channel bank

Fig. 1. A small lake or wetland and its drainage basin. Riparian buffers are present in shaded areas.

and the bank between the flood plain and river terraces or other upland formations. If we modify the three-zone approach to these situations, the first zone would still be a fairly narrow area of mature forest, which should not be harvested, along the banks of the channel (including channels that dissect the flood plain). The rest of the flood plain and the bank of the flood plain would constitute zone two. Here, the geomorphology determines the width of zone two. Zone three would then be a narrow grass strip between zone two and the uplands as was the case for small streams. As in the case of smaller stream buffers, the second and third zones may be harvested for income (e.g. Lockaby et al., 1997). In these larger streams, beginning with third order streams (e.g. Jordan et al., 1993), the buffer zone is designed to both intercept lateral flows and waters flooding out from the stream channel during storm events. In the case of zone two a new major function is the trapping of suspended sediments and dissolved substances from the channel waters that flood out into the forest during storm events (Mitsch et al., 1979; Elder, 1985; Kleiss et al., 1989; Spink et al., 1998; Villar et al., 1998).

3.3. Exotic plants

Even without the intervention of humans, riparian buffers are sometimes invaded by exotic species, which impair the healthy functioning of the buffer (Tabacchi et al., 1998). All over the world, more and more such cases are unfolding. When one attempts to establish a healthy riparian plant community in locations where none has existed for a long time, it is very likely that problems with aggressive exotic plants will ensue. In these cases there is no seed bank of native species in the soils. Certainly, it would be unwise to plant non-native species, although this is a common practice. It is usually necessary to plant young tree seedlings or larger plants, which have either been raised in a nursery, or transplanted from other sites. Before carrying out these plantings it may be wise to eradicate all existing plants on the site, by herbicide treatment if necessary. In one case I know of, after a major effort of planting hardwood seedlings, the exotic multiflora rose took over and forced the use of herbicides and another planting. When aggressive exotics are first observed to be invading a site that has been planted, a proactive effort to prevent the spread of the exotics is recommended.

3.4. Problems with herbivores

There are at least two categories of herbivore problems when establishing and maintaining riparian buffer zones. The first is grazing and trampling by domestic livestock (for reviews see Kaufman and Kreuger, 1984; Belsky et al., 1999). While this can be simply remedied by fencing out the livestock, there is a loss of grazing area and the cost of fencing.

The second category of herbivore problem involves wild animals. Some of the common examples include browsing by ungulates such as deer, girdling of the planted trees by voles (especially in the winter), and the cutting of riparian trees for food and dam building by beaver. Tree girdling can sometimes be prevented by the use of tree tubes. Beaver can have a long-term beneficial effect on forested landscapes (e.g. Naiman et al., 1988), and beaver ponds can have their own water quality benefits (e.g. Correll et al., 2000). However, in landscapes where riparian forests are the only remnants of native forest, beaver can be devastating. I know of a number of projects in the United States where major efforts to re-establish native hardwoods in riparian zones were defeated by deer, voles, and/or beaver. Once deer and beaver are re-introduced into such landscapes their populations must be vigorously managed.

3.5. The use of models and geographic information systems

Although there have been simple conceptual models for some time, there are few simulation models for complete riparian buffers. There have been simulation models for grass buffer strips (zone three) for a considerable time (e.g. Tolner et al., 1982; Flanagan et al., 1989; Munoz-Carpena et al., 1999). Its seems that the best developed and tested overall model for multi-zone riparian buffer water quality functions is the Riparian Ecosystem Management Model (REMM; Inamdar et al., 1999a,b). This model is for the small stream riparian buffer situation and holds promise, but is yet to be fully developed and tested under a variety of conditions. A model for larger rivers and their flood plains (Van der Peijl and Verhoeven, 1999; Van der Peijl et al., 2000) shows promise and has been tested in a variety of systems, but at this time seems to be too general for many applications.

Geographic Information Systems (GIS) have been used as a tool in overall watershed management planning for some time. Specific applications to the management of riparian buffer zones and for helping to estimate their cumulative impact at the drainage basin level are relatively new and few in number. For the small stream case, remote sensing data often lack the needed spatial resolution as well as an adequate classification of vegetation types. When one is dealing with larger rivers and flood plain forest, this is less of a problem (e.g. Bren, 1998; Basnyat et al., 2000). Another problem is the lack of good, well-tested riparian zone simulation models suitable for coupling to the GIS data. One pioneering attempt to accomplish this is that of Xiang (1996).

3.6. Case studies of riparian buffer restoration

At present most research on riparian buffer zones has been carried out on sites where restoration was not needed. Thus, we know much more about the general water quality functions of riparian buffers than we know about how to restore buffers or how quickly and effectively they regain their functions after restoration. We know that the hydrology and soils of riparian buffers are basic to their functions and must be attended to when restoring the buffers. With respect to spatial priorities, we believe that buffers along the small headwater streams are most important and that a continuous buffer is more important to overall waterway protection than a wide, but intermittent buffer. The most efficient use of the lands adjacent to the smaller waterways seems to require at least three vegetation zones, managed differently. For the larger streams we know that it is important to protect and restore the flood plains. We also know that aggressive exotic plants and herbivorous animals are often a problem during the restoration process. But these are generalities and, in truth, we do not know very much about the details of successful restorations of functionally healthy riparian buffer zones.

However, there are some success stories. These case studies are examples where well-planned riparian buffer zones have been restored and shown in research findings to be effective in preventing pollutants from entering waterways. At the smallest spatial scale, experimental three-zoned riparian buffers have been restored on sections of small streams in Georgia (Lowrance et al., 1995). In Illinois, on a larger river, artificial riparian wetlands have been constructed and tested (Hey et al., 1989). In Iowa, a significant sized watershed has had its riparian zones restored as buffers (Schultz et al., 1995). Finally, in Australia, considerable riparian buffer restoration has been accomplished and tested on a larger watershed (Williamson et al., 1996). Many, many more projects have restored or established riparian buffers on other sites, but the projects and their results have not been reported in the technical literature.

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