Proceedings

TECHNICAL WORKSHOP
ON SEDIMENTS

February 3-7, 1992 • Corvallis, Oregon

Sponsored by

Terrene Institute
U.S. Environmental Protection Agency
U.S. Department of Agriculture
Forest Service

September 1993
Issue Identification and Definition

Areas that function as buffer zones have been referred to as filter strips, riparian zones (Karr and Schlosser, 1978; Todd et al. 1983; Corbett and Lynch, 1985; Conner and Day, 1989; Gresham, 1989) and streamside management zones (Cummins, 1980; Nutter and Gaskin, 1989; Smith, 1989). However, these areas can also be defined as transitions between two different land uses to protect one from changes in the other (Brown et al. 1978; Brown and Schaefer, 1987).

Buffer zones function by acting as barriers or treatment areas that protect adjoining areas from off-site disturbance effects. Phillips (1989) described them as "one of the most effective tools for coping with nonpoint source pollution. A buffer zone allows runoff and associated pollutants to be attenuated before reaching surface waters via infiltration, adsorption, uptake, decay, filtering, and deposition."

Wetlands have been defined by the U.S. Fish and Wildlife Service (as cited in Mitsch and Grosselink, 1986) as

... lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. ... Wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes; (2) the substrate is predominantly undrained hydric soil; and (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year.

Considering this definition, wetlands comprise a diverse group of landscapes. "Wetlands," as used in this presentation, refer mainly to swamps, marshes, bogs, and bottomlands surrounding perennial streams. Wetlands also include peatland and sloughs. These terms are defined in more detail by Mitsch and Grosselink (1986).

The intensity of forest management is manifested in several forms, ranging from remote wildlands and protected wild forests to domesticated forests (Stone, 1975). Within the context of the more intensive management practices, many commercial species regenerate well, grow best, are easiest to manage, and are least expensive to harvest under even-aged management. Where soil is intentionally cultivated, this type of management generally results in maximum site disturbance.

The degree of disturbance, long-term effects of disturbance, and off-site effects to aquatic systems have been and continue to be studied and debated.
Concerns about the effect of forestry practices on adjacent aquatic ecosystems and wetlands have not been adequately addressed over the South's many physiographic regions. Long-term hydrological and ecological research at the Coweeta Hydrologic Laboratory has produced the most information in the South (Dils, 1953; Douglass and Swank, 1975; Monk, 1975; Neary and Currier, 1982; Neary et al. 1986b; Neary and Swift, 1987; O'Hop and Wallace, 1983; Swift 1984a, 1984b, 1986; Tebo, 1955). However, this research represents mainly the Appalachian Mountain subregion, although some Coweeta research in the late 1970s and 1980s did include the Piedmont (Douglass and Goodwin, 1980; Douglass and Van Lear, 1983; Neary et al. 1986a; Van Lear et al. 1985). More recently, other research projects have been established in different physiographic regions (Riekerk et al. 1989) to broaden understanding of the effects of forestry practices on wetlands and aquatic ecosystems.

Interest is increasing in preserving wetlands and maintaining them in their more natural state. Questions that regulatory agencies are asking include the following:

• What effect will forest operations have on the plant community structure and stability in wetlands?

• Will nutrient, sediment, or increased water loads cause short- or long-term changes in wetlands?

• What is the nature of these changes?

• What type and intensity of forest management are compatible with maintaining wetlands in their current state?

Inherent in the answer to these questions are two other questions:

• If, and how well do, buffer zones function to protect riparian ecosystems?

• Do well-functioning buffer zones prevent or ameliorate any adverse impacts of forest management?

Protecting riparian zones in this context is relatively new because wetlands have been viewed as creating buffers between upland anthropomorphic activities and adjoining river, stream, and lake ecosystems (Nutter and Gaskin, 1989). For this reason, the effectiveness of buffer zones in protecting the stability of adjoining wetlands is a topic with few substantial field studies (Nutter and Gaskin, 1989). Even the more obvious conflicts between farming and adjoining wetlands have not been thoroughly studied. But, a series of studies draw inferences about agricultural buffer zones. A reasonable assumption is that properly functioning buffer zones will have a common set of characteristics. However, their effectiveness is a function of individual site conditions. For example, Brown and Schaefer (1987) set out to develop a single buffer width for a landscape association. But, recognizing the variability in the landscapes, they eventually developed guidelines based on each site’s physical attributes.

There is a lack of information on forestry buffer zones. It is appropriate to outline how they function, what plant and soil properties affect them, and draw conclusions based on the more abundant literature concerning the effectiveness of buffer zones in protecting adjoining wetlands and open waters from the effects of farming practices. Thus, this review will:

• synthesize research results in current literature on buffer zones,

• determine the utility of buffer zones in protecting forested wetlands and surface waters from the sediment nonpoint source pollution impacts of silvicultural operations, and

• identify information gaps and research needs.

Current Situation and Program Needs and Trends

Processes Important to a Functioning Buffer Strip

This synthesis starts from the premise that buffer zones are able to change the character of the water entering them with regard to its quantity and quality (e.g. sediment load, nutrient content, and pesticide loading). It also assumes that buffers provide an edge effect to maintain the wetland temperature regime. In all these ways, buffer zones affect wetland plant community structure and stability.

All factors relating to the effect of buffer zones on water quality depend on the concept that water flows more or less uniformly (above and below ground) through the buffer zone. Any channelized flow (above or below ground) will reduce the effect-
tiveness of the buffer zone. Flow rates as high as 2 cm s\(^{-1}\) have been reported in steeply sloped forested soils and ascribed to flow through root channels and similar pathways (Mosley and Rowe, 1984). In some landscapes, flow tends to be dominated by channelized flow toward the base of slopes (Nutter and Gaskin, 1989). Rapid water movement in ephemeral drainage channels and large soil macropores can quickly move sediments across and through buffer zones. The main effect of ephemeral channels and macropores is that they reduce the time available for retention processes. In most instances, research on buffer zones has not isolated the effects of rapid channelized flow from slower, more uniform, mass flow across buffer zones.

**Conceptual Framework**

A myriad of processes affect the utility of buffer zones in ameliorating the effects of forest management. Processes relating to sediment are discussed below and summarized in Figure 1 as a conceptual framework.

- **Sediment.** Forested lands constitute the vast majority of the headwaters of the South's important watersheds. These watersheds are the source of much of the region's high quality water. Streams originating in forested lands have the lowest concentrations of nonpoint source pollutants and usually meet sediment water quality standards. Natural sediment yield from forested watersheds in the South's 27 physiographic sub-regions range from 0.004 to 0.022 Mg\(^{-1}\) ha\(^{-1}\) yr\(^{-1}\) (Maxwell and Neary, 1991). By contrast 6.5 million ha of cropland in the region have erosion rates that exceed the soil loss tolerance (Larson et al., 1983). Erosion rates on these lands range from 5 to 12.5 Mg\(^{-1}\) ha\(^{-1}\) yr\(^{-1}\).

An analysis of sediment yields from Federally owned forested lands in the South (Maxwell and Neary, 1991) indicated that a great deal of variability exists between forestry management practices over physiographic subregions. Moderate mechanical site preparation techniques (chopping, shearing, and piling) produce about 50 percent more erosion than prescribed moderate fires and broadcast herbicide applications. Severe fires and raking produce 7.5 times more sediment, and disking produces about 30 times more. Mean erosion from all sources averages 50 to 60 times greater in the steep Blue Ridge Mountains landscape than in the level Atlantic Coastal Plain flatwoods. Human-induced increases in sediment yields above natural rates vary from 5 to nearly 500 percent.

---

**Figure 1.—Sediment movement through a buffer strip.**
Some interesting patterns were noted by Maxwell and Neary (1991):

- In watersheds with over 20 percent private land, 70 to 90 percent of the human-induced sediment comes from private land, notably agriculture and roads.

- In most mountain watersheds, forestry practices produce 2 to 20 percent of the human-induced sediment.

- In Coastal Plain and Piedmont watersheds, roads produce <40 percent of the human-induced sediment. In watersheds with 2 to 9 percent cropland, nearly 50 percent of the sediment increases come from cropland.

- Intensive vegetation management on forested lands contributes only 1 to 7 percent of the human-induced sediment yields.

Often, the main reason for using buffer zones is to reduce sediment movement in runoff (Omernik et al., 1981). A buffer zone should function as a physical filter by removing sediment from transiting water. The effectiveness of the vegetation in trapping sediments, as indicated by Karr and Schlosser (1978), depends on:

- **Velocity of Water Flow:** All other criteria listed below in some way affect flow velocity. The argument for reducing flow velocity is obvious. The size of a particle moved by water is a function of the water velocity as seen in the following equation:

  \[
  \text{Competence} = C \times v^6.
  \]

  Competence is the size of the particle moved by water and C is a constant (Hewlett and Nutter, 1969). If the velocity is reduced 50 percent, the particle size carried by water drops by a factor of 64. Small velocity reductions can make drastic changes in the particle type that can be carried. Reduced flow rate also decreases the channel-cutting power of runoff (Baver et al. 1972).

- **Distribution of Incoming Sediments:** As demonstrated above, if the incoming sediments are dominated by large particles, buffer zones should be quite effective in removing the sediment. However, if the sediment is predominantly colloidal, the effect of velocity reduction is less certain.

- **Slope and Length of Slope Before Reaching the Buffer:** Both of these control runoff velocity as well as the surface area that contributes sediment. The steeper and longer the slope, the greater its runoff velocity.

- **Buffer Zone Slope and Length:** A reduction in slope would reduce runoff velocity just as increased slopes have the potential to increase the flow rate of runoff. The slope length simply defines the "time" the buffer zone has to affect the sediment. Of the two, slope is thought to be more important (Baver et al. 1972).

- **Vegetation Characteristics:** In addition to reducing the runoff velocity, sediment can also be trapped by the site's physical features. The characteristics of the vegetation can promote sediment trapping. For example, a forest floor (Nutter and Gaskin, 1989) or a thick, low understory can physically filter sediment and reduce flow velocity. Both examples increase the the flow path's "roughness", reduce runoff rate, and promote sedimentation (Schlosser and Karr, 1981).

- **Water Depth and Vegetation Height:** If the buffer zone is a wetland, the timing of runoff relative to the hydroperiod could influence sediment movement to the protected area. When disturbance coincides with the hydroperiod's peak, the beneficial effect of vegetation is reduced.

- **Water Quantity:** The theory of hillslope hydrology has been reported by Whipkey and Kirby (1978), Chorley (1978), Hillel and Hornberger (1978), and Burt and Trudgill (1985). Six flow components occur on a hillslope, and flow may occur either singly or as a combination of these components. The following components are listed in the order of expected rapidity of hydrograph response during measurement of runoff water:

  - infiltration-excess overland flow,
  - saturated overland flow,
  - return flow,
  - saturated subsurface flow,
  - unsaturated subsurface flow, and
  - groundwater flow.

  At the beginning of a rainfall event on a sloping surface, some water infiltrates vertically into the soil cover. This process tends to increase the soil's water content. Some water will be removed by the surface and subsurface runoff mechanisms previously listed and some by evapotranspiration; the remainder will be stored in the soil or will move below the surface hydrologic regime.

  The ratio of the rainfall intensity and the topsoil's hydraulic conductivity will largely determine the nature of this water movement. Low intensity
D.G. NEARY, N.B. COMERFORD, & L.W. SWIFT JR.

(intensity less than the saturated conductivity of the surface soil) tends to promote unsaturated subsurface flow or groundwater flow. At moderate storm intensities, the saturated subsurface flow often becomes more important, particularly in soils with distinct horizons. At high storm intensities, the surface soil can become saturated, and excess overland flow may dominate. Saturation of the surface soil results in maximum soil water storage such that incoming water tends to accumulate at the surface and move downslope as surface runoff.

The presence of bare soil or low permeability subsurface layers (such as compacted zones, day layers, hardpans, or bedrock) are often a prerequisite for promoting saturated subsurface flow on a sloping soil surface under most rainfall conditions because these layers minimize infiltration. Surface runoff is a common occurrence for sloping surfaces with subsurface horizons of limited hydraulic conductivity. For local depressions or flat topography, such as in cypress wetlands, ponding may result at the surface of soil profiles with horizons of low permeability.

Infiltration of water on hillslopes is known to be inhibited by

- layering within the soil profile;
- anisotropy and limiting values of hydraulic conductivity for the surface soil at water saturation;
- convergence of the soil surface;
- steep slopes;
- high-intensity rainstorms; and
- subsurface soil layers with very low permeability.

Such limitations to infiltration result in surface runoff somewhere along the hillside.

The effect of buffer zones on water quantity must be considered in the context of the mechanisms operating in a buffer zone that affect the water yield from an area. The effect on runoff amount is primarily related to soil storage available in a buffer zone. By maintaining actively growing vegetation, water is used, which increases the soil storage capacity (Baver et al. 1972). The ultimate effect this increase will have on water yield depends on the vigor of the plant community, the water storage capacity of the soil in question, the position of the buffer area in the landscape (receiving or supplying water), and the size of the buffer area relative to the area that is the source of water. When buffer areas are small relative to the water source area, the effect of the buffer zone on water yield is minimal. In a wetlands buffer, the soil water storage will probably also be limited by a subsurface water table, so the potential of the buffer zone to change water yield will have minor importance. The major effect of vegetation is to reduce the runoff velocity, not runoff amount (Baver et al. 1972).

**Literature Evidence for Effectiveness of Buffer Zones**

The literature that specifically examines the function of buffer zones to protect wetlands is quite sparse. Existing information concerns the use of buffers to affect water quality, water quantity, and wildlife. Only a small part of the literature deals with the effect of forest management activities, and virtually none addresses protection of wetlands. Commonly, a wetland is the buffer zone used to protect the stream's quality. The effects of buffers on maintaining stream and river quality have been summarized in several papers (Swift and Baker, 1973; Horton and Campbell, 1974; Karr and Schlosser, 1978; Howard and Allan, 1989).

This section examines the role of buffer zones in ameliorating the negative impacts of management on the quality and quantity of water passing through riparian zone buffer strips. A few studies provide rather comprehensive data on the role of these riparian areas in mitigating sediment movement (Omernik et al. 1981; Lowrance et al. 1986; Cooper and Gilliam, 1987; Cooper et al. 1987; Petersjohn and Correll, 1984).

**Sediment Removal by Buffer Zones**

Data on sediment removal by forest buffer zones suggest that two main actions occur. First, the forest edge environment promotes sediment removal from runoff. Presumably, this effect occurs because vegetation filters the sediment from the runoff and slows the runoff rate. Second, the sediment is sorted as it moves through the vegetation filter.

The first case is best described by the work of Cooper and Gilliam (1987) shown in Table 1. Using the depth of the sediment as an index of buffer zone effectiveness, the forest edge is obviously in an effective position for sediment accretion.

The second action — sorting — results from the filtering process and decreased water flow rate. The particle size distribution of the data presented in Table 1 was dominated by the sand fraction (75 percent) at the forest edge, where incoming sediment was only 59 percent sand (Cooper et al. 1987). Because the smaller size fraction continues to move
Table 3.—Summary of literature recommendations for buffer zone sizes and streamside management zones for fisheries and wildlife.

<table>
<thead>
<tr>
<th>WIDTH IN METERS</th>
<th>PURPOSE</th>
<th>SOURCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>Fisheries management</td>
<td>Seehom, 1987 (as cited in Howard and Allan, 1988)</td>
</tr>
<tr>
<td>104</td>
<td>Water quality and wildlife habitat (large streams and rivers)</td>
<td>U.S. Fish Wildl. Serv. 1988 (as cited in Howard and Allan, 1988)</td>
</tr>
<tr>
<td>400</td>
<td>Maintain wild and scenic values of rivers</td>
<td>Wild and Scenic Rivers Act P.L. 90-452 (as cited in Howard and Allan, 1988)</td>
</tr>
<tr>
<td>110–244</td>
<td>Protect wildlife habitat</td>
<td>Brown et al. 1990 (based on minimum habitat requirements for target species and dependent on landscape association)</td>
</tr>
</tbody>
</table>

Table 4.—Minimum filter strip width in meters for gravelled forest roads in the southern Appalachian Mountains.

<table>
<thead>
<tr>
<th>FILTER STRIPS</th>
<th>PERCENT SLOPE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 10 20 30 40 50 60 70 80</td>
</tr>
<tr>
<td>Without brush barrier</td>
<td>14 19 24 28 33 37 42 47 51</td>
</tr>
<tr>
<td>With brush barrier</td>
<td>11 12 13 15 16 17 19 20 21</td>
</tr>
</tbody>
</table>

Future Prospects for the Issue

Public interest, legal requirements, and political focus on wetlands and riparian zones expanded rapidly in the 1980s and continues to do so. The current debate over wetland and riparian area definitions, wetland function preservation, and the issue of "no net loss" makes this topic a high national priority. Research must be aggressive in providing information on wetland protection to provide sound scientific guidance to regulatory and management interests.

Science Questions

Science questions involve the understanding of hillslope, riparian zone, and channel sediment transport processes and how these processes interact with other riparian zone processes. These processes and concepts include:

1. Sediment routing from the upland generation zones through the interface of a riparian/buffer zone:
   A. Understanding the partitioning of sediment transport into deposition zones or preferential flow in surface drainages or macro pores; and
   B. Development of process models to route sediment through buffer and riparian zones.

2. Functional definition of riparian/buffer zone size needed to reduce sedimentation to maintain riparian function and health;

3. Interactions of channel dynamics with sediment deposited in riparian zones and wetlands; and

4. Interactions of sediment deposited in the riparian zone with other riparian zone or wetland functions.

Research Needs

Research is needed to answer these science questions for individual forest management practices, physiographic regions, and geomorphic settings. Basic data are needed to develop models of sediment transport and partitioning processes within riparian zones. Research efforts are needed to link hillslope sediment generation processes with riparian zone sediment transport models and channel/watershed sediment routing models. Linkages between sediment deposition and other wetland functions and processes need to be quantified.

References


