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INTEGRATED MANAGEMENT OF IN-FIELD, EDGE-OF-FIELD, AND AFTER-FIELD BUFFERS[1]

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ABSTRACT: This review summarizes how conservation benefits are maximized when in-field and edge-of-field buffers are integrated with each other and with other conservation practices such as residue management and grade control structures. Buffers improve both surface and subsurface water quality. Soils under permanent buffer vegetation generally have higher organic carbon concentrations, higher infiltration capacities, and more active microbial populations than similar soils under annual cropping. Sediment can be trapped with rather narrow buffers, but extensive buffers are better at transforming dissolved pollutants. Buffers improve surface runoff water quality most efficiently when flows through them are slow, shallow, and diffuse. Vegetative barriers – narrow strips of dense, erect grass – can slow and spread concentrated runoff. Subsurface processing is best on shallow soils that provide increased hydrologic contact between the ground water plume and buffer vegetation. Vegetated ditches and constructed wetlands can act as "after-field" conservation buffers, processing pollutants that escape from fields. For these buffers to function efficiently, it is critical that in-field and edge-of-field practices limit peak runoff rate and sediment yield in order to maximize contact time with buffer vegetation and minimize the need for cleanout excavation that destroys vegetation and its processing capacity.
(KEY TERMS: water quality; runoff; erosion; sediment; nutrients; pesticides; riparian buffers.)

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INTRODUCTION

Dictionary definitions of buffers include several meanings: a cushion like device that reduces shock due to contact of railroad cars; an ionic compound that resists changes in its pH; an electronic device to provide compatibility between components; and a temporary storage area. While none of these mentions vegetation, they all have something in common with the functioning of vegetative buffers. A vegetative buffer acts to protect from impact or "cushion the blow."

Vegetative buffers come in a variety of forms (Figure 1). The U.S. Department of Agriculture-Natural Resources Conservation Service (USDA-NRCS) includes seven types of water-erosion-control buffers in its National Handbook of Conservation Practices (USDA-NRCS, 2005a) and its CORE4 buffer program. To avoid ambiguity in terminology, the USDA-NRCS buffer nomenclature and code numbers will be adopted throughout this paper. Official USDA-NRCS conservation practices standards describe each buffer type, its intended purposes, areas of application, and minimum quality criteria (USDA-NRCS, 2005a). State specific adaptations of each buffer are described in Section IV of the electronic Field Office Technical Guide (USDA-NRCS, 2005b). Tabular summaries comparing the USDA-NRCS buffer types have been presented by Lowrance *et al.* (2002) and Dabney (2003).

Three types of water erosion control buffers are applied within cropped fields and will herein be referred to as "in-field" buffers: Grassed Waterway, Code 412; Contour Buffer Strips, Code 332; and Alley Cropping, Code 311. Three others are applied at the boundaries of cropped fields and will be referred to as "edge-of-field" buffers: Field Border, Code 386; Filter Strip, Code 393; and Riparian Forest Buffer, Code 391. The seventh buffer, Vegetative Barrier, Code 601, may be used in both in-field and edge-of-field configurations. Additional practices that provide buffer functioning beyond the field edge, such as constructed

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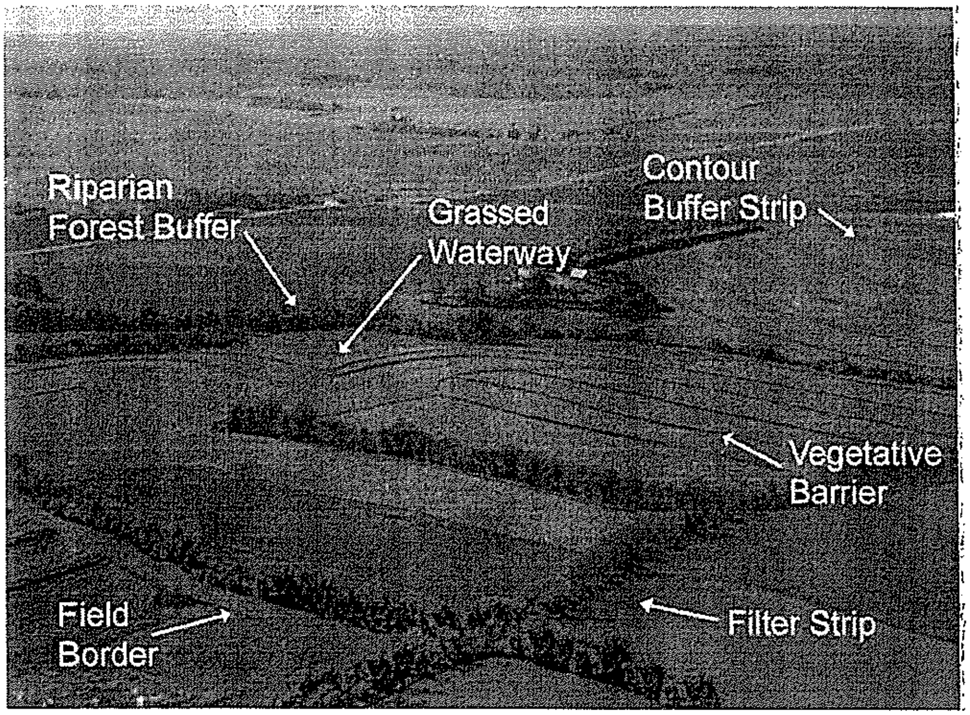

Figure 1. Schematic Illustration of Several In-Field and Edge-of-Field Buffer Types (photo courtesy of USDA-NRCS).

wetlands, Code 656, will be referred to as "after-field-buffers."

The purpose of this paper is to describe the water erosion control buffer types used in the United States and to discuss how these buffer types can be integrated with each other and with other conservation practices to improve buffer functioning. Examples will be given to explain functioning, discuss limitations, debunk common fallacies, and highlight areas of needed additional research.

GENERAL BUFFER PRINCIPLES

In this section, four principles are presented that apply to all buffer types. These principles will be referred to in later sections to describe buffer functioning and interactions with other conservation practices.

Principle 1: Some is Much Better Than None

Buffers reduce erosion, trap sediment, and remove contaminants by slowing runoff, increasing infiltration, and facilitating the uptake and transformation of contaminants. Of these, slowing runoff is of critical importance for sediment trapping (Dabney, 2003). Buffers less than 1 m wide can trap a great deal of sediment (Abujamin *et al.*, 1985; Van Dijk *et al.*, 1996; Raffaelle *et al.*, 1997; McGregor *et al.*, 1999, Blanco-Canqui *et al.*, 2004) because much sediment deposits upslope of the buffer itself (Dabney *et al.*, 1995; Jin *et al.*, 2002). Narrow buffers can also trap a significant fraction of soluble nutrients if infiltration is increased (Eghball *et al.*, 2000). Evidence also indicates that the leading edge of buffers often performs a disproportionate share of denitrification function and that grass buffers can support as much denitrification as forested buffers (Lowrance, 1992; Schnabel *et al.*, 1996; Verchot *et al.*, 1997; Addy *et al.*, 1999; Lowrance *et al.*, 2000). It is therefore wrong to assume that narrow buffers do not improve water quality. Rather, the presence of a continuous buffer edge is critical because the first increment of buffer has a much larger impact than any subsequent increment.

Principle 2: Flow Rate Matters

Buffers treat surface runoff best with slow, shallow, diffuse flows and least well for rapid, deep, concentrated flows (Lee *et al.*, 2003). The ratio of the buffer area to the upslope source area captures one source of variability in buffer loading but does not capture the large variations caused by differences among individual storm events or due to flow concentration prior to runoff entering the buffer. The specific flow rate (i.e., the volume rate of flow per unit length of buffer perpendicular to the direction of flow) is a more fundamental way to describe flow rate through a buffer. Buffer hydrologic contact time with surface runoff is determined by specific flow rate, buffer width in the direction of flow, and buffer hydrologic roughness (Dabney, 2003).

Principle 3: Buffers Retard, Retain, and Process Pollutants

Buffer phyloplanes and soils have enhanced capacities to retard, retain, and metabolize pollutants where geomorphic features cause hydrological contact between buffers and contaminant flows. Trapping of sediment or sediment bound nutrients is often greater than trapping of soluble constituents (Daniels and Gilliam, 1996). Trapping of pathogens is greater for protozoa than for smaller microbes (Tate *et al.,* 2004). Periodic removal or harvest may be needed if conserved contaminants accumulate to excessive levels. On the other hand, processing of labile pollutants such as nitrate, pathogens, and pesticides may not involve an accumulation of mass. Buffers attenuate pollutants by limiting drift, increasing deposition of sediment bound materials, increasing infiltration, increasing sorption on plant residues, increasing nutrient uptake by plants, increasing soil and rhizosphere microbial populations and enzymatic activity, and accelerating metabolism and cometabolism (Locke *et al.,* 2006). Surface soils under vegetative buffers often contain higher organic C and have greater capacity for labile pollutant sorption, degradation, or attenuation than adjacent field soils (Staddon *et al.,* 2001; Locke *et al.,* 2003; Shankle *et al.,* 2004).

Principle 4: Buffers Are Particularly Valuable on Shallow Soils

Runoff is generated soonest, and seepage forces that encourage erosion are greatest, on the shallowest soils in a watershed. These are therefore the zones that need the greatest protection. They are also among the least productive areas from an agricultural point of view. Shallow soils ensure that ground water plumes have hydrological contact with (do not pass beneath) the riparian root zone, increasing potential for buffering nutrient fluxes through denitrification and for nutrient uptake (Tabacchi *et al.,* 1998). In such areas, buffer vegetation with aerenchymous roots (Clark *et al.,* 1998; Braendle and Crawford, 1999) that can extend below periodically high water tables is better able to survive drought periods and can therefore provide improved buffer functioning at all times.

IN-FIELD BUFFERS

In-field buffers offer the best opportunities to encounter sheet flows and therefore can most effectively (Principle 2) reduce runoff and control erosion and pollutant transport close to the source. In-field buffers are complementary to edge-of-field and after-field buffers. In-field buffers may be oriented either close to the contour (contour buffer strips, alley cropping, vegetative barriers) or up-and-down slope (grassed waterways) (USDA-NRCS, 1999).

As the name implies, contour buffer strips are laid out close to the contour of the land. On rolling terrain, however, it is not feasible to keep uniformly wide and equally spaced buffers on the contour. Even if the key (central) strip is placed perfectly on the contour, moving upslope or downslope a fixed distance will cause greater vertical changes on steeper parts of the field than on flatter parts. In order to keep the upslope edge of each buffer close to the contour while having cropped strips of uniform width, the buffer strips must be wider on flatter portions of a field and narrower where slopes are steeper (Figure 1). Narrow buffer strips can still function effectively to control erosion and trap sediment (Principle 1).

Where flow concentrates in tilled agricultural fields, ephemeral gullies may form in the same place year after year due to topographic or seepage (Principle 4) properties, only to be filled in again by tillage. When a farmer converts to no-tillage farming, these ephemeral gullies may grow into classic gullies that are too large to be crossed or filled with conventional farm equipment (Figure 2a). Stabilization can be achieved with a grassed waterway or, for small contributing areas, by a series of vegetative barriers (Figure 2b). Both of these buffer solutions require maintenance.

It is commonly assumed that most runoff that reaches a buffer enters the buffer and flows through it except for a portion that infiltrates in the buffer. In reality, tillage performed parallel to contour buffers and perpendicular to waterways inevitably forms berms at the edges of these buffers (Dabney, 2002). Berms at buffer edges act as oriented linear roughness elements that interact with topography and soil properties and may alter runoff patterns. To avoid these berms, contour buffer strips must be periodically renovated (USDA-NRCS, 1999). Berms that cause runoff to flow parallel to a grassed waterway must also be eliminated to avoid the formation of a "W-ditch" caused by erosive flows cutting channels outside of, but parallel to, the waterway. To avoid this, side slopes feeding a waterway should have a slope of at least 1 percent perpendicular to the axis of the waterway (USDA-NRCS, 1999). In contrast, vegetative barriers can be designed to control runoff by using these berms as miniature gradient terraces to redirect runoff to a stabilized concentrated flow outlet (USDA-NRCS, 1999).

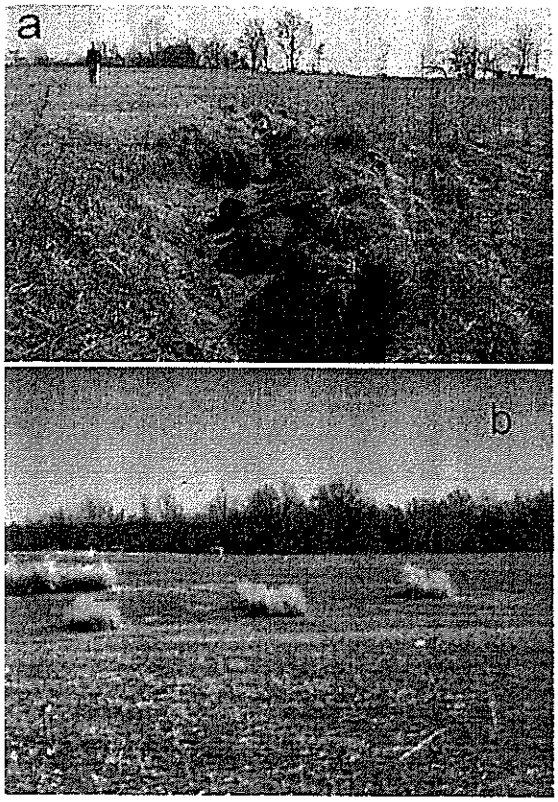

Figure 2. (a) An Ephemeral Gully That Grew Into a Classic Gully When a Soybean Field Was Converted to No-Till Management and (b) Was Controlled With a Series of Vegetative Barriers (Meyer *et al.*, 1999).

Another common assumption is that the hydraulic roughness of buffer vegetation can be characterized by a roughness parameter, such as Manning's n, that is a constant whose value depends on vegetation characteristics such as height and stem density. In reality, Manning's n depends on both vegetal characteristics and flow regime. For extremely shallow flows, soil surface roughness determines n. As flow increases from very low levels, n increases with specific discharge as vegetation becomes involved and emergent stems and leaves exert drag on the flow (Figure 3). If vegetal density is uniform with height, as with the idealized buffer composed of bristle bunches (Figure 3), Manning's n increases with increasing flow rate as depth increases but velocity remains constant. At some depth, the flow encounters less dense areas of vegetation or even begins to overtop vegetation, after which n decreases with increasing discharge, as shown in Figure 3 for the standard grassed waterway design curves labeled A through E (Temple *et al.*, 1987). Only when vegetation is deeply submerged can n be considered constant and independent of flow rate. Vegetative barriers of vetiver grass (*Vetiveria zizanioides*) or switchgrass (*Panicum virgatum*) have unusually high hydraulic roughness, particularly when loaded with plant residues (Figure 3).

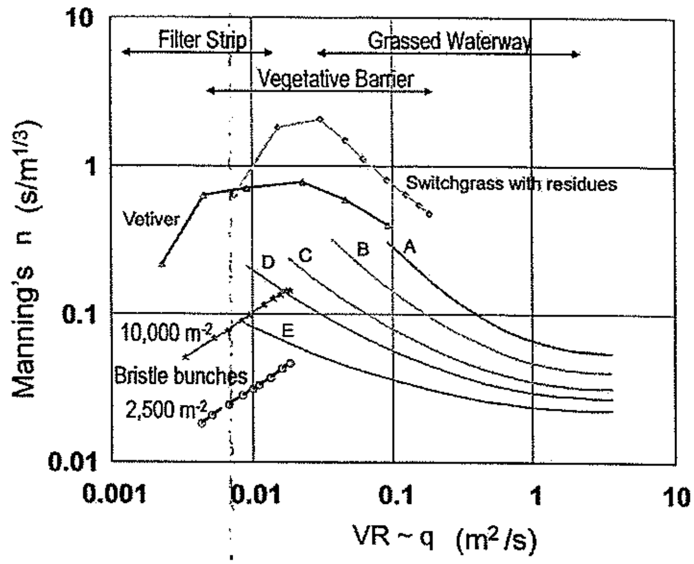

Figure 3. Variation of Hydraulic Roughness of Buffers as a Function of the Product of Average Flow Velocity (V) and Hydraulic Radius (R, flow area divided by wetted perimeter). For Wide Channels, R is approximately equal to depth so the VR product is approximately equal to the specific flow fate (q) (after Dabney, 2003).

EDGE-OF-FIELD BUFFERS

On flatlands, buffers that impede drainage within agricultural fields are impractical. In these areas, edge-of-field buffers are more practical and may take several forms: field borders (Code 386), filter strips (Code 383), vegetative barriers (Code 601), and riparian forest buffers (Code 391). Another edge-of-field practice that acts as a buffer, though not a vegetative buffer, is a flow restricting drop pipe structure built under the practice termed grade stabilization structure (Code 410).

Field borders are vegetated strips that surround fields (Figure 1). These strips can be used for turning equipment or managed for enhanced wildlife habitat (USDA-NRCS, 1999). Filter strips, in contrast, are located only on the downslope edge of fields and have specific grade requirements (USDA-NRCS, 1999). Riparian forest buffers are designed with three zones. Zone 1, a 5 m forested strip adjacent to the waterbody, receives little disturbance. Zone 2 is a managed forest area beyond Zone 1. Zone 3 of a riparian forest buffer is a filter strip; it is optional and used mainly adjacent to agricultural land to trap sediment (USDA-NRCS, 1999).

Tillage induced berms (discussed in the In-field Buffers section above) can have a profound impact on edge-of-field buffer functioning, For example, Locke *et al.* (2003) monitored fluometuron movement down rows of cotton to an edge-of-field buffer. Significant concentrations of fluometuron were measured in the turn-row areas where runoff flowing down the rows converged and collected (Figure 4b). During heavy rain, water ponded in these areas. Their finding of relatively little fluometuron in adjacent grass areas was probably due to both transport limitations and enhanced sorption and degradation within the buffer (Principle 3).

Recognizing the importance of flow redirection caused by edge-of-buffer berms, the national practice standard for filter strips specifies that the gradient along the edge of the filter strip must be less than 0.5 percent, and it calls for the field upslope of the filter strip to have a slope steepness of between 1 and 10 percent. The latter requirement cannot be met on flatlands with overall grades less than 1 percent, so this requirement is relaxed in some state Filter Strip practice standards. Figure 4 illustrates the result. Figure 4a shows a riparian forest buffer including a grass filter strip located between a cotton field and an oxbow lake in Leflore County, Mississippi, where the slope of the field is approximately 0.5 percent, and the edge of the buffer deviates from the contour with a gradient of approximately 0.06 percent. Figure 4b shows a small tillage induced berm redirecting irrigation return flow along the edge of the buffer. Flow is from the south toward an ephemeral channel located where indicated in Figure 4a and shown in Figure 4c. Much runoff passes though this and similar channels rather than entering the buffer as dispersed sheet flow. Installation of a grade control pipe, shown in Figure 4c and 4d, can improve the functioning of a riparian forest buffer in flatland areas, as discussed below.

On flatland areas, "slotted-inlet" pipes (Figure 4d) are routinely designed and installed with a "pad" or terrace that provides temporary storage for 100 to 150 mm of runoff from the contributing area. Unlike in hill regions, where significant temporary storage is not feasible, the pipes on flatlands are not sized large enough to carry the peak runoff rate. Rather, pipes are sized to avoid crop damage from flooding by allowing drainage of 100 to 150 mm of runoff within 24 hours. The USDA-NRCS WinTR-55 Small Watershed Hydrology model (USDA-NRCS, 2005c) was used to illustrate how the effect of runoff from a 100-year storm falling on a 17 ha cotton field differs from discharge through a pipe like the one shown in Figure 4c. The pipe/pad combination reduces peak flow rate by about a factor of 10 (Figure 5). Note the difference between the small diameter of the pipe compared to the dimensions of natural riparian channel (Figure

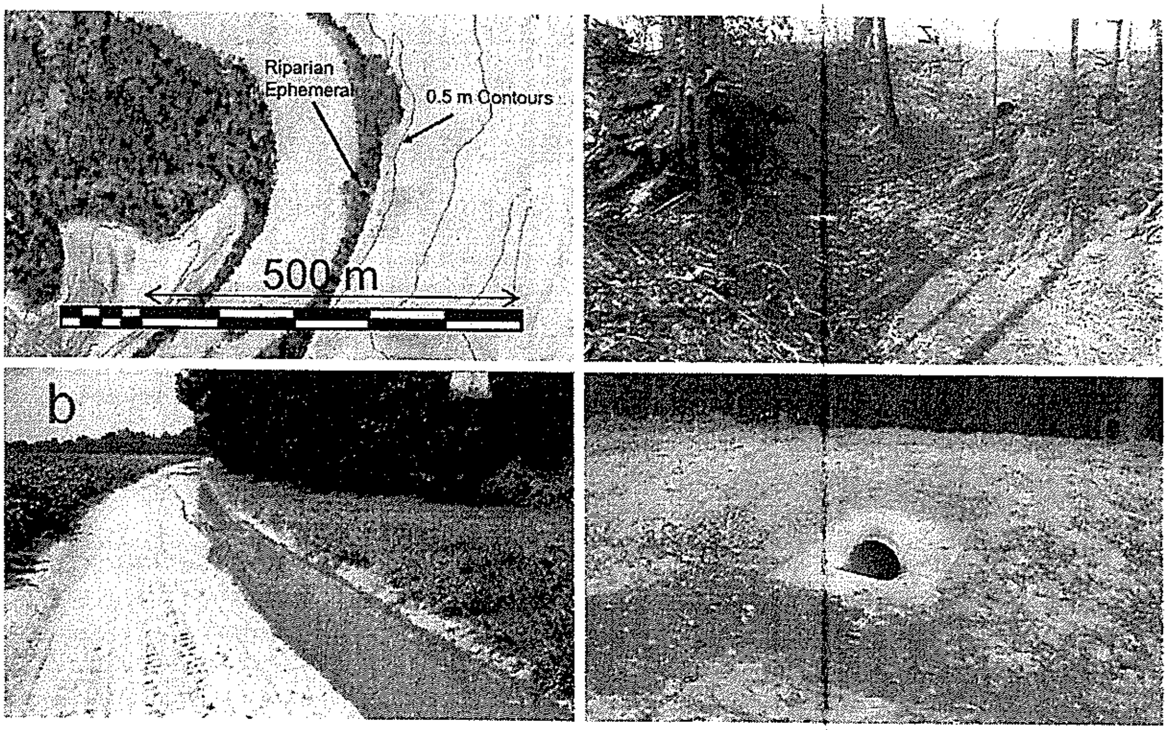

Figure 4. Runoff Reaching (a) a Riparian Forest Buffer Surrounding an Oxbow Lake in the Mississippi Delta was (b) Redirected by a Small Tillage Berm to (a and c) a Riparian Ephemeral Flow Channel. Stormflow through this channel was controlled by (c and d) a slotted-inlet pipe and associated earthen pad or berm.

4c). Because of the flat terrain, water ponded 0.3 m deep at the pipe would create a backwater extending 60 m into the field. A great deal of sediment could fall out in this temporarily ponded area and be retained in the field (Dabney *et al.,* 1995), thereby improving water quality. The backwater would also overtop the tillage berm and bring the edge-of-field buffer into action. If the pad were designed with a level top at some distance away from the ephemeral channel, the pad could act as a level spreader, ensuring sheet flow through the riparian buffer, creating opportunities for more infiltration, denitrification, and even greater water quality improvements. In a very real sense, grade control pipe/pad combinations buffer runoff flows.

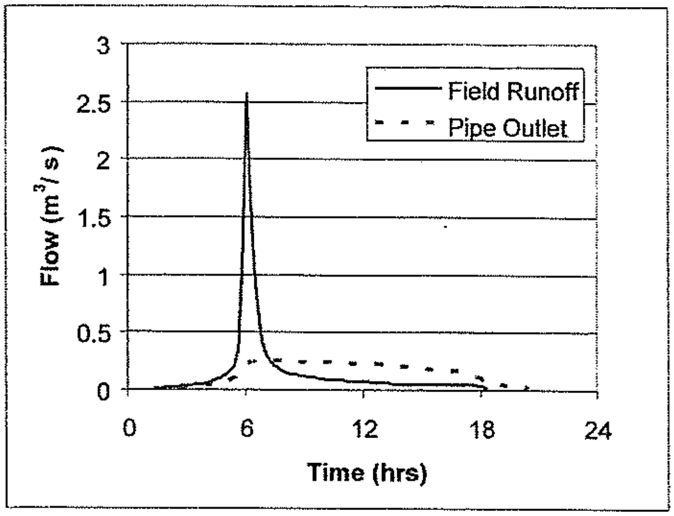

Figure 5. Runoff Predicted by TR-55 for a 17 ha Cotton Field (CN = 78) and That From a 0.41 m Diameter Pipe for a 100-Year Storm (218 mm rainfall) in Leflore County, Mississippi.

The buffering capacity of grade control pipes operates only during storms large enough to cause hydraulically limiting full pipe flow. For small flows, such as that illustrated in Figure 4b, there is no buffering action because everything reaching the pipe is quickly transported through it. In fact, the slotted inlet pipe end (Figure 4d) is designed to increase drainage rates of flows that do not cause full pipe flow by allowing the pipe to run half-full with very little backwater into the field. In an effort to improve the buffering capabilities of grade control structures at low flows, Dabney *et al.* (2004b) proposed a hybrid practice in which a vegetative barrier is planted around the pipe inlet (Figure 6). To maximize buffering of low flows, the length of the vegetative barrier surrounding a pipe inlet should be as short as possible without limiting the full pipe discharge needed to drain the temporary impoundment created by large storms within 24 hours. A shorter barrier has increased specific discharge (Principle 2) and hence increased backwater depth, ponded area extent, and pollutant trapping. Based on stage/discharge relationships reported by Temple and Dabney (2001), 10 m of vegetative barrier would be needed for each m^3/s of design full pipe discharge. Thus, for the scenario illustrated in Figure 5, a semicircular vegetative barrier about 3 m long would be needed. For small drainage areas, up to 3 ha, vegetative barriers can control the extension of edge-of-field gullies beyond the riparian forest (Dabney *et al.,* 2004a). Inside shaded forest, where vegetative barriers may not grow, check dams can be constructed using concrete sacks. With both vegetative barrier and concrete checks, tile drains such as those illustrated in Figure 6 allow the crest of the check dams to be placed at a higher elevation, thereby improving pollutant trapping efficacy while maintaining adequate drainage to assure field accessibility and practice acceptability in flatland areas.

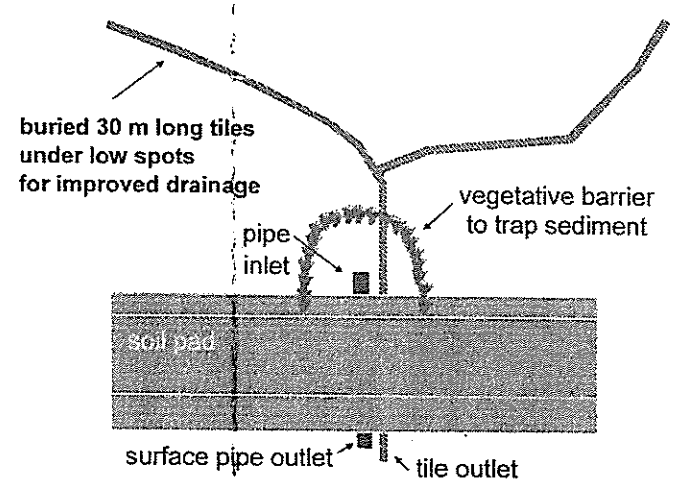

Figure 6. Schematic Diagram (plan view) Indicating Placement of a Vegetative Barrier Around a Grade Control Pipe Inlet (see Figure 4d) to Increase Hydraulic Resistance to Low Flows Without Reducing the Conveyance of the Pipe at Design Discharge, and of Subsurface Tiles Located Under Thalwegs of Surface Drains to Alleviate Wet Spots.

AFTER-FIELD BUFFERS

Even after runoff has left the field and passed through edge-of-field buffers, water quality can be improved by after-field buffers such as channel bank vegetation (Code 322) or constructed wetlands (Code 656). These practices are particularly effective for treating low flows, such as irrigation return flows that can bypass edge-of-field buffers and pass through grade control structures unabated as illustrated in Figure 4b.

Agricultural drainage ditches are constructed primarily to facilitate removal of excess surface and shallow ground water. They range in size from small intermittently flooded ditches draining individual fields to higher order permanently flooded channels with nearly riverine capacities (Bouldin *et al.*, 2004). Moore *et al.* (2001) demonstrated that when these ditches are vegetated, they may significantly attenuate the movement of nutrients and pesticides through them. To illustrate the potential impact, consider the "Thighman" study described by Moore *et al.* (2004) that was conducted in a vegetated ditch segment 650 m long upstream of Thighman Lake in Sunflower County, Mississippi. A dilute solution containing the pyrethroid insecticide lambda-cyhalothrin (Karate®) was introduced at the upstream end of the segment over a period of 90 minutes. Its concentration in ditch water, vegetation, and bed sediments was then monitored for the next 44 days. At the time of the test, water in the ditch was about 0.3 m deep and was about 2.8 m wide at the water surface. The average center line velocity of the flow was 2.8 cm/s, yielding a specific flow rate of about 0.01 m^2/s. This flow rate is lower than that usually encountered by a grassed waterway but is within the range associated with flow through filter strips (Figure 3), so the functioning of ditch vegetation in this test may be similar to that of a very long filter strip. Ditch vegetation was a mixture of rooted *Ludwigia* sp. (yellow primrose, 115 g/m^2) and floating *Lemna* sp. (70 g/m^2).

Three hours after the initiation of pyrethroid addition, close to 100 percent of the added pesticide was recovered in ditch water (90 percent), plants (8 percent), and bottom sediments (1 percent) (Figure 7a). Recovery declined rapidly to only 21 percent (10 percent in water, 11 percent in plants) by 12 hours after initiation. Ditch water sampling indicated that little insecticide ever reached the end of the ditch. The time of appearance of elevated ditch-water pesticide concentrations (Figure 7c) indicated that the average velocity of the flow was about 0.01 m/s, somewhat less than the measured center-line velocity. This value may be used in the one-dimensional advective dipersion equation (Chapra, 1997)

$$c(x,t) = \frac{m_p}{2\sqrt{\pi E t}} e^{\frac{(x-Ut)^2}{4Et}} \tag{1}$$

where c is the concentration (mg/l) at any distance, x (m), and time, t (s), after pesticide introduction (assumed instantaneous), m_p is the initial plane source strength (g/m^2), U is the flow average velocity (m/s), and E is a dispersion coefficient (in m^2/s of order 0.1 m^2/s). The equation predicts that after 12 hours the peak of a plume of a nonreactive species

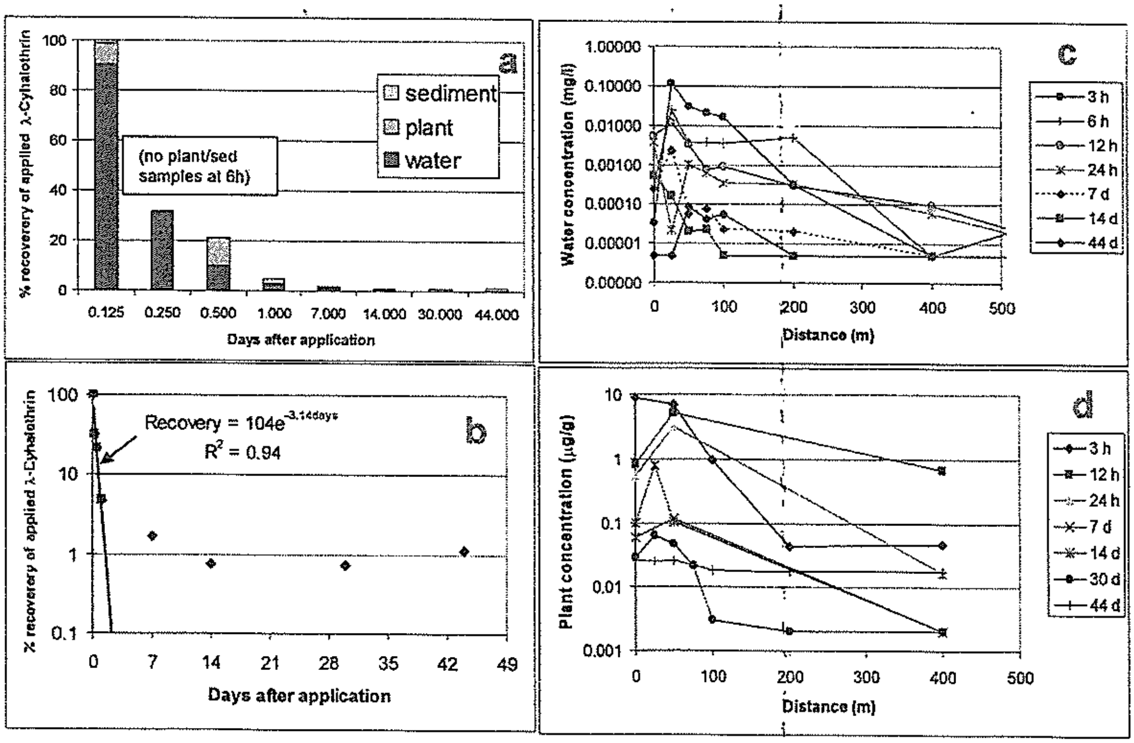

Figure 7. Changes in Pyrethroid Insecticide (Lambda-Cyhalothrin) Recovery and Partitioning among Water, Plants, and Ditch Sediments (a and b) With Time and (c and d) With Distance From the Point of Injection.

would have been located about 400 m from its injection point, and the peak concentration at that point would have been reduced by up to a factor of 10, depending on dispersion coefficient assumed. In contrast, data show much greater attenuation with time and distance than can be explained by convection and dispersion without reaction. After 12 hours the highest water concentrations remained close to the point of injection (Figure 7c) rather than 400 m down the channel. Furthermore, at 400 m, maximum observed concentrations were at least three orders of magnitude lower than the concentration observed 25 m downstream of the injection point three hours after initiation of addition.

During the first 24 hours, the recovered pesticide mass displayed an exponential decay with a time constant of about eight hours and a half-life of about 5.6 hours (Figure 7b). Vegetation is important to the rapid decline of the pesticide concentrations, as other studies have shown much more rapid attenuation of pesticides in both space and time in vegetated channels compared with unvegetated channels (Moore *et al.*, 2002; Schulz *et al.*, 2003; Milam *et al.*, 2004). In the Thighman study, less than 2 percent of the applied pesticide was ever recovered in association with the ditch sediments. After 14 days most of the persistent pesticide was associated with bottom sediments, but this represented only about 1 percent of the material applied. Once pesticides are associated with sediments, their fate may be affected by the water regime. Weaver *et al.* (2004) reported differential effects of flooding on the persistence of the herbicides atrazine and fluometuron mixed with soil from a recently established constructed wetland. Fluometuron was much more persistent under flooded versus 12 percent air filled pore space incubation, while atrazine was rapidly incorporated into soil bound components in both circumstances.

Thus, the mechanism of the contaminant processing in vegetated ditches is not clear but is likely associated with leaves, stems, and roots providing additional surfaces for deposition, adsorption, absorption, and the activity of associated microorganisms. Properly managed vegetated ditches can function as a special class of constructed wetlands, and both of these landscape features can function as buffers.

INTEGRATION

Intuitively, water quality outcomes are most positive when all the buffer types and related conservation practices are used together. In-field buffers can reduce and slow runoff amounts and lower sediment loads, thereby helping to make edge-of-field buffers work more efficiently. Additional in-field practices such as residue management, cover crops, and crop rotations can further enhance the effectiveness of conservation systems. There is a considerable edge effect in buffer sediment trapping efficiency since much sediment is deposited upslope if the buffer edge is continuous (Principle 1). Residue management reduces runoff amounts, slows flow velocities, and provides mulch to be trapped on buffers that increases buffer edge density and effectiveness (Jin *et al.*, 2002; Dabney, 2003). Vegetative barriers placed where flow concentrates upslope of contour buffer strips, filter strips, or riparian forest buffers can help to retard and spread runoff, thereby protecting the buffers from excessive sediment deposition and improving their functioning.

Rather than short circuiting flows through buffers, properly engineered pipe structures and associated land grading and pad construction can actually reduce ephemeral bypass flows through riparian gullies and help make flatland riparian buffers function more efficiently during large storms. Vegetative barriers can be used to slow velocity and filter contaminants from low flows that would pass unimpeded through grade control pipes: irrigation return flows, smaller storms, and the "first flush" of large storms that frequently carry a disproportionate fraction of pollutants. Subsurface tile drains placed for a short distance upslope from the edge of the field can alleviate the wet spots that might be created where vegetative barriers slow drainage at the end of a hydrograph.

While drainage ditches have been used to drain wetlands, when properly designed, vegetated, and managed, drainage ditches can function as a special class of constructed wetlands. In-field and edge-of-field buffers, together with grade control structures, can reduce peak runoff rates and keep sediment from clogging ditches. Lowering peak runoff rates by storing excess water on the fields for up to 24 hours reduces flooding downstream, allows vegetated ditches to have adequate conveyance, and improves vegetated ditches' ability to process contaminants (Principle 2 and Principle 3). Less sediment deposition in ditches reduces the frequency of ditch cleanout, thereby preserving ditch vegetation and maintaining after-field buffer functioning.

In a properly integrated system, receiving waters are protected by field buffers (and residues, tiles, pads, and pipes), ditches, and wetlands. Wetlands, in turn, are protected by field buffers and ditches. Ditches are protected by field buffers, residue management, and flow control structures. Acting together, all these practices act as buffers. They protect each other and the environment – they all "cushion the blow."

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