Conservation Buffers
to Reduce Pesticide Losses

Conservation buffers can be used in a systems approach to help manage soils, water, nutrients, and pesticides for sustainable agricultural production which minimizes environmental impact. Buffers have long been a staple in conservation systems designed to prevent erosion and trap sediment and nutrients from field runoff. They also provide other benefits such as wildlife habitat improvement, streambank protection, and farming safety. Many studies have been conducted to document these benefits and to provide guidance in designing buffers for these purposes. But do buffers work to reduce pesticide losses?

Rainfall or irrigation can cause pesticides to run off the surface of treated fields. Edge-of-field losses can range from less than one percent of the amount applied to as much as ten percent (Wauchope, 1978). Losses are greatest when severe rainstorms occur soon after pesticide application. Edge-of-field concentrations of pesticides in surface runoff can range from less than 1 part per billion (ppb) to 1 part per million (ppm) or more.

Until recently, few studies had been conducted to measure the effectiveness of buffers in trapping pesticides in runoff. Physical properties of pesticides affect their behavior and transport. Some pesticides are highly adsorbed to soil particles and are carried primarily adsorbed to eroded sediment. Trapping of these pesticides by buffers should be very similar to sediment trapping. However, some pesticides are only moderately adsorbed to soil particles, and are carried off fields primarily dissolved in water. In order for buffers to be effective in trapping this type of pesticide, either water infiltration into the buffer must occur, carrying the chemical into the soil, or chemical must be removed from solution flowing over the soil surface by contact with soil or vegetation. Most studies indicate that an increase in water infiltration is the most important factor in trapping these pesticides.

This booklet will examine current knowledge of how conservation buffers can be most effectively used to reduce pesticide losses to water. Studies specifically measuring pesticide trapping by buffers will be reported, as well as relevant studies on effectiveness of buffers in trapping sediment and increasing water infiltration. The effectiveness of buffers in reducing pesticide losses will depend on the properties of the specific pesticide, the design and maintenance of the buffer, and local climate, weather, and soil conditions. When combined with specific local input from sources such as the National Resource Conservation Service (NRCS), this booklet will provide guidance to those providing advice and assistance to farmers and landowners installing conservation buffers. Other Best Management Practices which improve management and reduce losses of pesticides and can be used in combination with buffers will also be discussed.

-for more information on sediment and nutrient trapping-

Literature Reviews

Gilliam, J.W. et al. 1997. Selected agricultural best management practices to control nitrogen in the Neuse River Basin, North Carolina State University Technical Bulletin 311, Raleigh, NC.

Lowrance, R., et al. 1995. Water quality functions of riparian forest buffer systems in the Chesapeake Bay Watershed. U.S. EPA Publication EPA 903-R-95-004.

Bibliographies

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http://www.serc.si.edu/documents/ripzone.html

Function and design of vegetation filter strips: an annotated bibliography. Texas State Soil and Water Conservation Board, Temple, TX.
http://waterhome.tamu.edu/tsswcb/Projects/bibliography/index.html

NRCS Websites

National Handbook of Conservation Practices and Buffer Job Sheets
http://www.ncg.nrcs.usda.gov/nhcp_2.html

Naural Resources Conservation Service Homepage
http://www.nrcs.usda.gov

TYPES OF BUFFERS

Water Buffers

Within Fields

Grassed waterway: a natural or constructed vegetated channel that is shaped and graded to carry surface water at a nonerosive velocity to a stable outlet. Because of concentrated flow that normally occurs in waterways, trapping of sediment and water infiltration can be minimal. Waterways are most effective in trapping sediment and dissolved chemicals when designed to spread concentrated water flow over a vegetated filter adjacent to streams.

Contour buffer strips: strips of perennial vegetation alternated with wider cultivated strips that are farmed on the contour. Buffers are most effective in trapping pesticides when runoff enters uniformly as sheet flow. Contour buffer strips are one of the most effective buffers in trapping pesticides because there is less chance for concentrated flow and smaller areas of cultivated field deliver runoff directly, within a relatively short distance, to each strip, compared to some edge-of-field buffers.

Vegetative barriers: narrow, permanent strips of stiff stemmed, erect, tall, dense perennial vegetation established in parallel rows and perpendicular to the dominant slope of the field. These barriers function in a similar manner to contour buffer strips and may be especially effective in dispersing concentrated flow, thus increasing sediment trapping and water infiltration.

Terrace tile inlet buffer: setbacks surrounding inlets to tile-outlet terrace systems. Some herbicide labels describe leaving untreated setbacks around these inlets when tiles draining terraces outlet directly into streams. Because water ponds over these areas during runoff events, reductions in herbicide runoff have occurred only proportion to reductions in total area treated.

Edge-of-Field

Field borders: a band or strip of perennial vegetation established on the edge of a cropland field. This type of buffer reduces pesticide runoff only when runoff flows over the strip. Even when no water flow occurs over the strip, some water quality benefit may be gained due to physical separation of spraying operations from adjacent areas, reducing drift and direct application to riparian areas.

Filter strips: areas of grass or other permanent vegetation used to reduce sediment, organics, nutrients, pesticides, and other contaminants from runoff and to maintain or improve water quality. Filter strips are located between crop fields and waterbodies. Efficiency in removing pesticides can be improved by encouraging as much sheet flow as possible across the strip. This may be accomplished by combining filter strips with practices such as vegetative barriers, level spreaders, or water bars.

Set backs: untreated areas where surface runoff enters streams. Some herbicide labels describe leaving these areas untreated. Seeding these areas to perennial grass improves herbicide trapping, compared to trapping with untreated row crop.

Riparian forest buffer: an area of trees and shrubs located adjacent to streams, lakes, ponds, and wetlands. Forest buffers are often combined with perennial grass buffers. Woody vegetation provides food and cover for wildlife, helps lower water temperatures by shading the waterbody, protects stream banks, and slows out-of-bank flood flows. Deep roots of trees may intercept nitrate entering streams in shallow subsurface flow and provide soil carbon for microbial energy. Microbes can degrade pesticides and denitrify nitrate.

Constructed Wetlands

Most nitrate is carried to streams by subsurface flow. Subsurface flow may also carry low concentrations of pesticides. While riparian buffers can intercept shallow subsurface flow and either cause uptake of nitrate and utilization by plants or encourage denitrification, drainage tiles bypass buffers and deliver subsurface drainage directly to streams. Wetlands constructed at tile outlets have been effective in causing denitrification of nitrate and degradation of pesticides.

Wind Buffers

Windbreak/shelterbelts: plantings of single or multiple rows of trees that are established for environmental purposes. While the primary purpose of such buffers is to protect leeward areas from troublesome winds, they may also provide separation of spraying operations from adjacent areas, reduce drift due to lowered wind speed, and intercept spray drift. Taller plantings provide the most drift protection.

Cross Wind Trap Strips: areas of herbaceous vegetation, resistant to wind erosion, and grown in strips perpendicular to the prevailing wind direction. These strips trap wind-borne sediment and nutrients and pesticides carried by sediment.

Herbaceous Wind Barriers: tall grasses, up to 5 feet, and other non-woody plants established in 1- to 2-row narrow strips spaced across the field perpendicular to the normal wind direction. These barriers reduce wind speed and wind erosion and intercept wind-borne soil particles which may carry pesticides and nutrients.

Other Barriers: other types of perennial vegetation in the landscape can serve the function of a buffer. These include CRP fields, wood lots, terrace back slopes, ditch banks, and wildlife plantings.

-pictures from NRCS of several buffers can be spread through previous section-

PESTICIDE TRAPPING BY BUFFERS

Pesticides vary in how tightly they are adsorbed to soil particles. Degree of soil binding is measured by binding coefficients or "K" values. K_{oc} (K of organic carbon) is a measure of adsorption to the organic matter content of soils, with higher values indicating more binding. While pesticides are also bound to clay particles, binding to organic matter is a useful predictor of chemical behavior and movement. K_{oc} values can be used to predict whether a specific pesticide will be carried primarily in the sediment or dissolved phase of field runoff. K_{oc} values greater than 1000 indicate that pesticides are highly adsorbed to soil. Eroded soil carries the majority of this kind of chemical leaving fields in runoff. Thus, if conservation buffers are effective in trapping sediment, they will be effective in trapping this type of pesticide.

Pesticides with lower K_{oc} values (less than 300 to 500) tend to move more with water than adsorbed on sediment. Concentrations carried on sediment are higher than concentrations in water, but because water quantities running off fields are so much greater than eroded soil quantities, water accounts for the majority of chemical leaving fields. To be effective in trapping this type of pesticide, buffers need to increase water infiltration or maximize contact of runoff with soil and vegetation which may adsorb pesticide.

Nitrate is water soluble and not adsorbed by soil particles. Usually nitrate quickly enters the soil, with little nitrate carried in runoff water. Rather, nitrate may leach to shallow ground water and be carried to streams by subsurface flow. To be effective in trapping nitrate, roots of conservation buffer plants need to intercept this subsurface flow. Conditions for denitrification present in this biologically active zone also reduce nitrate reaching streams. Similarly, some weakly adsorbed pesticides may leach to shallow groundwater in small amounts. Although subsurface flow may carry small quantities of pesticides to streams, usually quantities present in surface runoff are much greater. The NRCS maintains a current Pesticide Property Database and can provide K_{oc} values for specific pesticides.

Study Results

One of the earliest studies of the impact of buffers on pesticide runoff investigated pesticide retention by grassed waterways (Asmussen et al., 1977). Runoff from a small plot was directed into an 80-foot-long waterway. The weakly adsorbed herbicide, 2,4-D, was trapped at a rate of 70%. In a later, similar study (Rhode et al., 1980), 96% of the strongly adsorbed trifluralin was trapped when the waterway was dry before runoff and 86% when the waterway was already wet when runoff was produced.

Hall et al. (1983) studied the impact of strip cropping on atrazine runoff in Pennsylvania. Seventy-two-foot-long plots were constructed up and down a 14% slope with a 19.7-foot- wide area at the base of the slope seeded to oats (*Avena sativa* L.). Runoff of atrazine applied to corn was measured throughout the season which included a severe, once-in-100-year frequency storm in June. The oats strip trapped 91% of atrazine in runoff when the herbicide was applied at a rate of 2 lb/A.

Results of these early studies surprised some scientists who assumed that buffers would have minimal impact on runoff of moderately adsorbed pesticides like atrazine and 2,4-D. However, significant infiltration of runoff water into buffers was identified as the primary mechanism of pesticide removal in these studies.

In Mississippi, Webster and Shaw (1996) measured runoff of metolachlor and metribuzin from soybean plots with and without tall fescue (*Festuca arundinacea* Schreb.) filter strips. Plots were 13 by 72 ft with 3% slope. Filter strips were either 13 or 6.5 ft wide. Width of the filter strip did not affect herbicide trapping efficiency. Over 3 years, metolachlor loss was reduced 55 to 74% by the filter strips, while metribuzin loss was reduced by 50 to 76%. Much of the trapping of herbicides could be attributed to infiltration of runoff into the filter strips. Using similar techniques in a later study (Rankins et al., 1998), tall fescue buffers reduced runoff of fluormeturon and norfluorazon applied to cotton by at least 60% and 65%, respectively.

Several studies in Iowa have investigated herbicide trapping by smooth bromegrass (*Bromus inermis* Leysser) filter strips using either simulated or natural runoff. In some studies field runoff was simulated by adding known concentrations of herbicide to water released above filter strips while rainfall was simulated (Mickelson and Baker, 1993). Amount of solution calculated to represent runoff from a 150 foot-long area was applied to the top of 15 and 30 foot-long filter strips (thus representing source area to buffer ratios of 10:1 and 5:1). The 15 foot strip reduced atrazine runoff by 35%, while the 30 foot strip reduced runoff by 59.5%.

Other similar studies with smooth bromegrass buffers (Misra et al., 1996) showed less difference between buffer sizes. When comparing 15:1 and 30:1 source area to buffer ratios, atrazine removal was 31.2% and 26.4%, respectively. Concentrations of herbicides in simulated runoff were applied at either 0.1 ppm or 1.0 ppm. A higher percentage of herbicide was trapped by buffers when inflow had higher concentrations. When inflow had 1.0 ppm herbicide, 15:1 area ratio buffers trapped 50%, 47%, and 47% of atrazine, metolachlor, and cyanazine, respectively. When inflow concentrations were 0.1 ppm, these buffers trapped 31%, 32%, and 30% of atrazine, metolachlor, and cyanazine, respectively. Infiltration of runoff water into buffers accounted for most herbicide trapping.

In other studies natural runoff from a treated area was collected and distributed to replicated smooth bromegrass buffers 66 feet long (Arora et al., 1996). Runoff was distributed to represent source area to buffer ratios of 15:1 and 30:1. Efficiency of herbicide trapping was determined for six runoff events over a 2 year period. Trapping of atrazine, cyanazine, and metolachlor ranged from a low of 8% to a high of 100%, depending largely on the timing and intensity of rainfall and antecedent soil moisture conditions. Herbicide trapping was least efficient when soil was saturated due to previous rains. For most events there were only small differences in herbicide trapping efficiency between area ratios. Averaging results for all herbicides and area ratios over the six events, 62% of herbicide contained in runoff was trapped by buffers. Infiltration of runoff into buffers was determined to be the major mechanism of herbicide removal. While sediment retention ranged from 40 to 100%, only about 5% of total herbicide retention was due to sediment trapping.

Analysis of soil within the buffer strips confirmed that herbicides were being trapped and held by soil within the strips (Fawcett et al, 1995). Concentrations declined during the growing season, presumably due to degradation. No phytotoxicity was observed on buffer grasses.

Bermudagrass (*Coynodon dactylon* L.) and wheat (*Triticum aestivum* L.) buffers were studied in Texas (Hoffman, 1995). Three 30-foot-wide buffers were equally spaced within a 435 wide watershed planted to corn. Hydrologic data showed that water runoff was reduced 57% by bermudagrass and 50% by wheat. Total atrazine loss was reduced 30% by bermudagrass and 57% by wheat in one year, and by 44-50% by all buffers in another.

Patty et al. (1997) studied ryegrass (*Lolium perenne* L.) buffers in France under natural rainfall conditions. Buffer widths were varied from 20 to 59 ft. Runoff volume was reduced by 43 to 99.9%, suspended solids by 87 to 100%, lindane losses by 72 to 100%, atrazine and metabolite losses by 44 to 100%, isoproturon losses by 99%, and diflufenican losses by 97%.

The ability of bermudagrass buffers to trap runoff of turf pesticides was studied in Oklahoma (Cole et al., 1997). Buffers 16 feet wide trapped from 90 to 100% of dicamba, from 89 to 98% of

2,4-D, from 89 to 95% of mecroprop, and from 62 to 99% of chlorpyrifos in runoff. In most instances buffer mowing height (3.3 in or 9.7 in), buffer length (7.9 or 16 feet), and tine aeration did not significantly affect pesticide trapping efficiency.

The effectiveness of a three zone riparian buffer in trapping herbicide runoff was studied in Georgia (Lowrance et al, 1997). Total buffer width was 164 feet, with a 26-foot-wide grass buffer adjacent to the crop field, a managed pine forest down slope from the grass, and a narrow hardwood forest containing the stream channel. More than 90% of atrazine and alachlor in field runoff was trapped by the buffer. Most herbicide trapping was accomplished by the grass strip, with 60 to 70% of herbicide in runoff trapped. Grass was a mixture of bahaigrass grass (*Paspalum notatum* Flugge), bermudagrass, and perennial ryegrass.

The impact of untreated setbacks around tile inlets in tile-outlet terrace systems was studied in Iowa, Nebraska, and Missouri (Mickelson et al.; Franti et al.). In all studies, setbacks provided no reductions in herbicide runoff into inlets beyond what would be expected due to reduced area treated. This result is not surprising, since these terraces are designed to pond water around inlets, causing sediment to settle and increasing water infiltration. Much of the untreated setback area would be under water during runoff events and could not be expected to increase infiltration or sediment trapping beyond that caused by normal functioning of the terrace system. The studies' authors concluded that alternative BMPs such as herbicide incorporation and no-till production were more effective in reducing herbicide runoff into inlets. Based on this research, USEPA allowed label changes on atrazine and cyanazine-containing products. Three alternative BMPs are now described on these labels for use in tile-outlet terrace systems: 1) 66 foot untreated setback around inlet; or 2) incorporation of herbicide in areas draining to inlet; or 3) no-till production with high crop residue levels in areas draining to inlet.

The importance of water infiltration as a mechanism of trapping moderately adsorbed pesticides is illustrated by some studies which have shown that buffers do little to reduce concentrations of this type of pesticide in runoff. In Nebraska (Yonts et al., 1996) smooth bromegrass or intermediate wheatgrass buffers did not significantly reduce concentrations of alachlor, cyanazine, 2,4-D, or atrazine present in furrow irrigation runoff water, although concentrations of the strongly adsorbed chlorpyrifos were reduced.

In contrast, some studies have shown significant reductions in concentrations of moderately adsorbed pesticides caused by buffers. In Mississippi (Tingle et al., 1998), tall fescue buffers as narrow as 1.6 feet at the base of 72 foot plots reduced concentrations of metolachlor and metribuzin in runoff by almost 50%.

Biological and physical conditions, which develop in buffers planted to grasses and/or trees, favor increased water infiltration and subsequent attenuation of nutrients and attenuation and degradation of pesticides. Bharati (1997) compared infiltration and soil properties under a multi-species riparian buffer in Iowa to adjacent cultivated fields and a grazed pasture. Average cumulative water infiltration was five times greater under the buffer than the cultivated field and pasture sites. Soil bulk density was also consistently lower under the buffer. Wood (1977) compared hydrologic characteristics of forested land to adjacent sugarcane, pineapple, or pasture land of the same soil series at 15 sites in the Hawaiian islands. Infiltration rates were higher under forest cover at 14 of the 15 sites. Mean weight diameters of the surface soil aggregates were larger for forested soils.

The extensive root growth in buffers and superior soil structure likely explain observed water infiltration increases. This root growth also impacts biological activity, supplying an organic carbon energy source to soil microorganisms. These microorganisms in turn are responsible for degrading pesticides and denitrifying nitrate. Such untilled areas also attenuate atmospheric carbon dioxide in tree and grass vegetation and soil organic matter. Tillage and crop production often deplete soil organic matter (Reicosky et al., 1995). Increased soil organic matter in buffers serves to better adsorb pesticides in runoff. Nutrients are taken up by vegetation and stored in living tissue. Periodic harvest may be desirable to prevent later rerelease. Pesticides are also taken up by roots and may be metabolized in plants. In addition, vegetation at the soil surface adsorbs pesticides during runoff events. In Iowa (Fawcett et al., 1995), atrazine concentrations in plant residue collected in buffers ranged from 80 ppb to 740 ppb depending on collection date, and were similar to concentrations found in surface buffer soil.

Few studies have investigated pesticide trapping by constructed wetlands. Some pesticides are relatively short-lived in water. Thus degradation occurring while runoff or tile effluent is sequestered in wetlands reduces contaminants reaching streams. Wetlands can also serve to ameliorate pulses of concentrated runoff before it enters streams. Some pesticides are relatively persistent once they reach water. However, the high organic matter content of wetlands sediments binds these pesticides, removing them from water. Matter (1993) used intact freshwater wetland sediment microcosms to study the behavior of atrazine. Atrazine was removed from the overlying water column at a rate of 15.8%/day for 3 days after introduction. After 10 months, 88% applied atrazine was unextractable from sediment and none was recovered from the overlying water.

Considering buffer research to date, under controlled conditions, buffers have been effective in trapping both highly adsorbed and moderately adsorbed pesticides. Table 1 is a summary of buffer studies showing trapping efficiency for specific pesticides and pesticide K_{oc} values. Highly adsorbed pesticides were trapped at rates of from 62 to 100%. Trapping of moderately adsorbed pesticides was more variable and ranged from 8 to 100%. Lowest percent pesticide retention by buffers occurred when buffer soil was saturated due to previous rains. Many studies found pesticide trapping efficiencies of 50% or more.

Table 1. Summary of buffer studies measuring trapping efficiencies for specific pesticides. K_{oc} values listed for each pesticide are from the NRCS Field Office Technical Guide Section II Pesticide Property Database.

Pesticide	K_{oc}	Study Reference	Range % Pesticide Trapped
	Highly	Adsorbed Pesticides	
Chlorpyrifos	6070	Cole et al. 1997	62-99
Diflufenican	1990	Patty et al. 1997	97
Lindane	1100	Patty et al. 1997	72-100
Trifluralin	8000	Rhode et al. 1980	86-96
	Moderately	Adsorbed Pesticides	
Alachlor	170	Lowrance et al. 1997	91
Atrazine	100	Arora et al. 1996 Hall et al. 1983 Hoffman 1995 Lowrance et al. 1997 Mickelson & Baker 1993 Misra et al. 1996 Patty et al. 1997	11-100 91 30-57 97 35-60 26-50 44-100
Cyanazine	190	Arora et al. 1996 Misra et al. 1996	8-100 30-47
2,4-D	20	Asmussen et al. 1977 Cole et al. 1997	70 89-98

Dicamba	2	Cole et al. 1997	90-100
Fluormeturon	100	Rankins et al. 1998	60
Isoproturon	120	Patty et al. 1997	99
Mecoprop	20	Cole et al. 1997	89-95
Metolachlor	200	Arora et al. 1996 Misra et al. 1996 Webster & Shaw 1996 Tingle et al. 1998	16-100 32-47 55-74 67-97
Metribuzin	60	Webster & Shaw 1996 Tingle et al. 1998	50-76 73-97
Norflurazon	600	Rankins et al. 1998	65

Do results of these controlled studies predict what will happen in the real world? Nearly all of these studies (with the exception of early grassed waterway studies) were designed to encourage sheet flow across buffers. Therefore, they represent the maximum trapping expected. In the real world, concentrated flow often occurs across buffers, reducing their effectiveness. In order to maximize trapping of both sediment-adsorbed and dissolved pesticides, sheet flow needs to be encouraged through proper buffer design and maintenance.

Dillaha et al. (1989) analyzed 33 existing buffers in Virginia for sediment trapping efficiency. They found sediment trapping was often poor either due to concentrated flow where topography was hilly, or due to sediment that accumulated in the buffer, causing runoff to flow parallel to the buffer until a low point was reached, where concentrated flow occurred.

Excessive sediment load in runoff may not only change flow patterns due to accumulation in buffers, but may also reduce water infiltration, making buffers less effective in trapping dissolved pesticides. In an Iowa simulation study (Misra, 1994), runoff with and without suspended sediment was introduced into buffers. In absence of sediment, buffers removed over 80% of atrazine, cyanazine, and metolachlor. When sediment at 10,000 mg/L was included in runoff, trapping of the three herbicides fell to about 50%. Accumulation of sediment apparently caused surface sealing, reducing total water infiltration from 83% in absence of sediment to 30% with sediment. It is thus critical that soil conservation methods be used above conservation buffers to reduce amounts of sediment entering buffers.

DESIGNING BUFFERS FOR MAXIMUM PESTICIDE TRAPPING EFFICIENCY

Location

All buffers can provide some measure of protection of water bodies if they are sited between pesticide-treated fields and water. Physical separation of spraying operations and water reduces the chances for direct application to water when spray booms overhang water when turning at field ends and can reduce spray drift into water. However, to act in trapping pesticides contained in runoff and drift, buffers must be sited so that water runs over or wind passes through the buffer area. Often, by the time field runoff reaches stream banks, concentrated flow is prevalent. Natural berms may develop along banks preventing overland flow into streams. This phenomenon was illustrated by a study in Nebraska, where water runoff patterns were characterized between field edges of watersheds and streams (Eisenhaurer et al., 1997). In one watershed, about 51% of the area had runoff pathways that experienced sheet flow, but only 22% of the area had sheet flow distances greater than 10 feet. Thus buffers adjacent to water may be limited in their ability to trap pesticides unless land can be shaped to encourage sheet flow.

Buffers are most effective in trapping pesticides when located as close to treated fields as possible. Contour buffer strips and vegetative barriers are most effective in trapping pesticides because they are located within fields and are on the contour, thus maximizing sheet flow across the buffer. Herbaceous wind barriers and cross wind trap strips perform the same close proximity function for wind eroded particles that have attached pesticides. Typically the ratio of runoff source areas to buffers is smaller for this type of buffer than most edge-of-field buffers, also increasing efficiency of trapping. Grassed waterways intercept both sheet and concentrated flow from fields and also have the opportunity to intercept pesticides close to the source. Wider grass strips encourage more sheet flow and infiltration as runoff enters the edges of waterways.

Stream networks are designated by using stream orders. First order streams have no tributaries. A second-order stream starts at the confluence of two first-order streams. The confluence of two second-order streams is a third-order stream and so on. Most experts conclude that stream-side conservation buffers are most effective on first- and second-order streams at the "top" of watersheds. The greatest volume of runoff water and therefore pollutant volume enters most stream systems from these small streams. Thus, ephemeral as well as first and second order perennial streams require greater amounts of vegetative buffer protection. Often there is little "new" water entering third- and fourth-order streams over banks. Conservation buffers along these larger streams have other benefits such as wildlife habitat and streambank protection, but have less opportunity to intercept pesticides and improve water quality. In watershed planning, likely sources of pesticides based on cropping patterns can also be identified in order to prioritize placement of conservation buffers.

Concentrated flow is the nemesis of pesticide trapping by buffers. Natural berms often develop along field edges from deposition of sediment. Such berms become barriers to sheet flow off fields and should be removed when possible. Land can also be shaped to encourage sheet flow. New techniques have been developed to disperse concentrated flow. Level spreaders are constructed to laterally disperse runoff uniformly across a slope (Figure 1). They consist of a long, narrow trench with an outlet lip of uniform elevation constructed in stable, undisturbed soil. The outlet area should have uniform slope and be well vegetated. Small berms or "water bars" (Figure 2) may be constructed to break up concentrated flow and redirect it as sheet flow across buffers. Strategically located vegetative barriers perpendicular to the flow can serve the same purpose to slow runoff velocity and redirect runoff across an associated grass buffer as shallow sheet flow.

- Figure of Level Spreader from Gilley pub here-

- Figure or photo of Water Bar if available-

How Wide is Wide Enough?

There is considerable debate over appropriate widths for conservation buffers. Widths are defined here as flow length across the buffer. Effectiveness of buffers per unit area are affected by the flow rate and depth of runoff as well as by conditions within the buffer such as soil type and antecedent moisture, which affect water infiltration. Amount of runoff is affected both by source area size and properties, as well as rainfall intensity and quantity. Often selecting an appropriate buffer size may involve consideration of several desired functions, site conditions, and what is economically or politically practical.

Many studies have investigated sediment trapping efficiency of grass buffers. Dillaha et al. (1989) found that 30 foot and 15 foot strips of orchardgrass trapped 84 and 70% of incoming solids, respectively. The source area of runoff was 60 feet or 4 times as wide as the 15 foot buffers. Magette et al. (1989) found that 30 foot and 15 foot strips of fescue trapped 75% and 52% of incoming solids, respectively. The source area was 72 feet deep or 4.8 times as wide as the 15 foot buffers. Castelle et al. (1994) reviewed literature on buffer size requirements and concluded that a range of buffer widths from 10 to 650 feet was found to be effective, depending on site-specific conditions. A buffer width of at least 50 feet was found to be necessary to protect wetlands and streams under most conditions.

Adequate buffer widths will depend on field slopes and source areas. A draft NRCS Conservation Practice Standard for Filter Strips requires a minimum flow length of 30 feet for the purpose of reducing sediment and sediment-adsorbed contaminant loadings. It also sets ratios of filter strip area to field areas based on Universal Soil Loss Equation R factor values (rainfall amount and intensity) of regions: “The ratio of the field or disturbed area to the filter strip area shall be less than 70:1 in regions with USLE R factor values 0-35, 60:1 in regions with USLE R factor values 35-175, and 50:1 in regions with USLE R factor values of more than 175.” Be sure to consult local NRCS Field Office Technical Guides for filter strip standards, as these criteria will vary depending on local conditions. Additional criteria may apply to reduce dissolved contaminants in runoff. The draft national standard states: “Filter strip flow length required to reduce dissolved contaminants in runoff shall be based on management objectives, contaminants of concern, and the volume of runoff from the filter strip drainage area compared with the filter strip’s area and infiltration capacity.”

Several site characteristics may dictate wider buffers, especially when trying to maximize water infiltration and trapping of dissolved pesticides. Fine-textured soils slow water infiltration rates. Or a high water-table underlying buffers may limit infiltration. Iowa studies found that water infiltration and trapping of dissolved herbicides by buffers was least effective when previous rains saturated soils. Vegetation within the buffer improves surface soil conditions, improving infiltration rates and internal soil drainage.

NRCS guidelines use Soil Hydrologic Groups to aid in sizing buffers. Soils are classified into Hydrologic Groups based on speed of water infiltration and transmission when soils are wet. Groups A and B have the fastest infiltration and transmission. Groups C and D have slower infiltration and transmission. NRCS recommends larger buffer areas for Group C and D soils.

The specific pesticide studies reported on in this publication found that buffers as narrow as 1.6 feet were effective in trapping significant quantities of pesticides. Increasing buffer width did not always significantly improve pesticide trapping. Narrow buffers have sometimes been effective in trapping pesticides. Tingle et al. (1998) compared tall fescue buffers measuring 1.6, 3.2, 6.6, 9.8, and 13.1 feet wide placed below 72 foot-long soybean plots. No significant differences in pesticide trapping efficiencies were found between buffer widths. Runoff of metribuzin was reduced by at least 73%, and runoff of metolachlor was reduced by at least 67% by all buffer widths.

While site characteristics, such as large source areas, or slow permeability soils, may dictate larger buffers for high efficiency trapping of pesticides, relatively small buffers should provide significant water quality benefits. Typical buffer widths of about 50 feet can be effective in reducing pesticide runoff by 50% or more if sheet flow occurs.

-for more information-

Local Field Office Technical Guide on file with NRCS will give guidance on buffer widths required in the local area.

Selecting and sizing buffer practices for the conservation buffer initiative.
http://www.ftw.nrcs.usda.gov/tpham/buffer/akey.htm

Species Selection

Conservation buffers can be planted to perennial grasses, legumes and forbs, woody plants, or a combination of the three. Some annually harvested crops such as small grains or legume-grass forages can serve the purpose of buffers, either when planted adjacent to water courses or in strip cropping systems - alternating strips of row crop and densely planted crops. In Texas (Hoffman, 1995), wheat was more effective in trapping herbicides than bermudagrass when planted in contour strips below a corn field.

Perennial grasses. Many buffer studies have used common forage grass species such as bromegrass, orchardgrass, fescue, and bermudagrass. While these species have performed satisfactorily, researchers are investigating other species, including native warm season grasses. To date few studies have compared the effectiveness of grass species in trapping pesticides. Rankins et al. (1998) compared giant reed (*Arundo donax* L.), eastern gammagrass (*Tripsacum dactyloides* L.), big bluestem (*Andropogon gerardii* Vitman), Alamo switchgrass (*Panicum virgatum* L.), and tall fescue planted in filter strips below cotton treated with fluormeturon and norflurazon. All species were similar in effectiveness. The native warm season grass, switchgrass, was compared to cool season grasses bromegrass, timothy (*Phleum pratense* L.), and fescue in ability to trap sediment and nutrients in Iowa (Lee, 1997). Switchgrass filter strips removed significantly more sediment, total N, nitrate-N, total P, and PO_4-P than cool season grass filter strips.

Ideally, buffer grasses should produce dense vegetation with stiff, upright stems near the ground level. Species that form sods rather than clumps should provide more uniform coverage. Because increased infiltration and percolation of water into buffers is an important mechanism of removal of pesticides, species with deeper rooting patterns may be more effective. Upright growth and stiff stems can slow velocity of runoff and increase sediment drop and infiltration. Weak-stemmed species may be pushed over by runoff, mat on the soil surface, and decrease infiltration. Because buffers will trap considerable quantities of sediment, buffer species should be able to tolerate deposition of sediment over crowns.

Stiff-stemmed grass species have received recent attention for use as narrow hedges. Meyer et al. (1995) found a 19 inch wide hedge of switchgrass or vetiver [*Vetiveria zizanioides* (L.) Nash.] ponded runoff to a depth of 10 inches and trapped more than 90% of sediment coarser than 125 µm (fine sands and coarser). Such hedges can be used in contour strips. Over time trapped sediment will form natural terraces. Or short hedges could be integrated with other buffers to break up concentrated flow and direct it across buffers. Vetiver is not winter hardy, but switchgrass is adapted to both northern and southern climates and is being widely used as a general conservation buffer planting, as well as for grass hedge applications. Warm season grasses such as switchgrass and big bluestem are also tolerant to triazine herbicides which may be present in field runoff.

Conservation buffer grass species and varieties will need to be adapted to local conditions. Check local information sources such as NRCS and Extension before making selections. These sources can also provide guidance as to seeding rates and procedures. Some cost sharing programs may also have specific seeding requirements.

Woody species. Trees and shrubs can aid in trapping sediment, nutrients, and pesticides, as well as providing wildlife habitat and streambank protection. The deep roots of trees also help to intercept subsurface water flow containing nitrate and introduce organic matter into deep soil, facilitating denitrification of nitrate and acting as a carbon source for pesticide-degradiing microorganisms.

Trees and shrubs are often used in combination with a grass buffer located adjacent to crop fields. Schultz et al. (1995) describe a 3-zone buffer with a 23 foot-wide strip of perennial grass (switchgrass preferred) adjacent to the crop field, two rows of shrubs next downgradient, and four or five rows of trees adjacent to the stream, for a total width of 66 feet. Gilliam et al. (1997) describe a 50 foot wide buffer with half in perennial grass and half forest species. Welsch (1991) describes a 3-zone riparian buffer where Zone 1 is permanent woody vegetation immediately adjacent to the stream bank, Zone 2 is managed forest occupying a strip upslope from Zone 1, and Zone 3 is an herbaceous filter strip upslope from Zone 2.

Selection of appropriate shrubs and trees for these riparian buffers will depend highly on climate and site conditions, including soil type and depth to water table, as well as the intended uses (possible harvest), species of wildlife desired, and tolerance of the vegetation species to the pesticides contained in the runoff.

-for more information-

Banks & Buffers A Guide to Selecting Native Plants for Streambanks and Shorelines: Available on CD-ROM from Tennessee Valley

Authority. Call 423-751-7338.

Plants for Conservation Buffers. USDA NRCS.

Maintenance

Sediment removal. Intensive management of conservation buffers is required to maintain pesticide-trapping efficiency. Sediment trapped by buffers changes land shape and may cause runoff to flow parallel to buffers rather than across them. Similarly, sediment trapped in the center of grassed waterways may cause runoff to flow along the edge of waterways, eroding gullies and increasing concentrated flow. Sediment will have to be removed periodically from these areas and vegetation reestablished when necessary. It is critical that sediment loads flowing across buffers be limited as much as possible by soil conservation practices applied to source fields. The draft NRCS Conservation Practice Standard for Filter Strips requires that average sheet and rill erosion above the filter strip shall be less than 10 tons per acre per year.

Mowing. Buffers may require mowing for weed control or aesthetic reasons. Mowing can both positively and negatively affect pesticide trapping efficiency. Mowing can encourage some grass species to tiller and produce denser vegetation at the soil surface. Mowing too short, especially with stiff-stemmed species, may reduce the flow retardence of the vegetation. Actively growing vegetation will be more biologically active, absorbing and degrading pesticides, and supplying carbon for microbial degradation.

Harvest of grass or trees. One of the functions of conservation buffers is to trap nutrients such as nitrogen and phosphorus. Periodic harvest of buffer vegetation removes trapped nutrients from the system, preventing eventual release to the soil and potential movement to water.

Impact of trapped herbicides. Herbicides trapped by buffers are degraded in the soil by microbial and chemical processes. Some herbicide may be taken up by buffer plants either by roots or through foliage and metabolized. However, it is possible that excessive loads of certain herbicides could injure buffer plants. Some preemergence herbicides have little impact on established plants. However a few, such as the triazines, can injure grasses if present in high enough concentrations. Most buffer studies have reported either no injury to buffer grasses or only slight injury. In Iowa, bromegrass in buffers grew more vigorously nearest source areas, apparently due to nutrients trapped by the buffer (Arora et al., 1996). Atrazine, cyanazine, and metolachlor trapped by the buffers did not harm the grass. Grass seedlings are most sensitive to herbicides in runoff. Thus, the greatest chance for harmful impact of herbicides in runoff would appear to occur in the seeding year. Warm season grasses such as switchgrass, big bluestem, and bermudagrass are tolerant to triazine herbicides and would not be injured by runoff.

Avoid overspray. While herbicide concentrations in runoff are usually tolerated by buffers, direct application or drift of some herbicides can be harmful to grasses or woody plants. Nonselective herbicides used as burndown treatments in no-till production systems and on some herbicide tolerant crop varieties can be especially damaging to buffer vegetation. Care should be taken to turn off spray booms and use control drip nozzles when driving over buffers, or when booms extend over buffers when turning. Squaring up cropland areas by varying buffer widths along irregular streams or field borders makes application of herbicides easier, with fewer "point rows" and chances for overspray over buffers.

Turning on buffers. While buffers at the edge of fields make convenient turning areas, driving heavy equipment on buffers can cause damage, compacting soil and reducing water infiltration, and causing ruts when soil is wet. Ruts may then encourage concentrated flow which bypasses filtering ability of the buffer. Driving on buffers should be avoided as much as possible, especially under wet soil conditions.

Livestock grazing. Grazing reduces buffer efficiency by causing compaction and reducing grass heights. Woody species may also be injured. Livestock may also cause significant stream bank degradation and directly contaminate water. Some livestock producers would like to allow livestock access to fields adjacent to buffers for limited times without having to fence buffers, such as to allow gleaning of waste grain following harvest. Planning a grazing system that allows quick, intensive foraging under good soil moisture conditions is essential. Removing livestock when soils are wet reduces potential damage to buffers.

Weed control. Buffers may harbor weeds requiring control. Vigorous grass growth prevents growth of many annual weeds, but some perennial weeds may require either mowing or spot treatment with herbicides. Noxious weeds must be controlled in the buffer.

Insect concerns. Buffers may harbor insect pests which move into crop fields. In some cases, such grassy areas are sprayed with insecticides to prevent damage to adjacent crops. If necessary, such treatments should be selected considering potential risks to adjacent aquatic ecosystems. Buffers also can be a safe harbor for beneficial insects. Populations of these insects can build up within the buffer areas and stay outside the cropland area treated with insecticides. Vegetation and buffer maintenance are tailored to promoting beneficial insect populations within buffer areas.

Regional Considerations in Buffer Design and Maintenance

Appropriate buffer design will depend on many local factors including climate, soils, hydrology, and farming practices. Buffer species need to be adapted to the region and appropriate for other functions such as wildlife habitat. Climate can greatly affect buffer function. For example, winter rains on frozen soil in northern areas produce runoff which cannot be processed by buffers. Rainfed agriculture produces different runoff patterns than agriculture dominated by irrigation. For these reasons, it is essential that those planning installation of buffers get local input to benefit from local experience and research. In addition, specific buffer design specifications are often required to qualify for cost sharing programs.

Local NRCS offices can provide design specifications for your area. In addition, Extension is also a source of expertise and information. Many State Extension Services have developed publications on buffer design and maintenance.

- examples of Extension publications –

Landowner’s Guide to Managing Streams in the Eastern United States. Publication 420-141. Virginia Cooperative Extension.

Vegetative Filter Strips: Application, Installation, and Maintenance. Publication AEX-467-94. Ohio State University Extension.

Buffer Strip Design, Establishment, and Maintenance. Publication

Pm-1626b. Iowa State University Extension.

IMPACT OF BUFFERS ON LEACHING OF PESTICIDES AND NITRATE

Because buffers increase water infiltration, concern has been expressed that leaching of pesticides and nitrate might be increased, possibly to shallow groundwater. When examining this possibility, it is important to consider the properties of pollutants normally present in field runoff. Because nitrate is water soluble and not adsorbed to soil particles, it quickly moves off the soil surface and into the soil with rainfall. In most settings runoff contains little nitrate. As discussed previously, nitrate is carried to surface water primarily be subsurface flow. Similarly, weakly adsorbed pesticides (which would have the greatest leaching risk) often are not detected at significant concentrations in runoff, as they quickly move into the soil. Pesticides detected in runoff are primarily strongly adsorbed compounds attached to suspended sediment and moderately adsorbed compounds both adsorbed to sediment and dissolved in water.

Strongly adsorbed pesticides have very low leaching potential due to adsorption to soil. Moderately adsorbed pesticides can sometimes leach below the root zone in small concentrations.

However, quantities leaching are normally as much as 1,000 times less than quantities carried off fields by runoff. Parts per million concentrations of some products can be detected in runoff at the field edge, while concentrations detected in shallow groundwater are often only a few parts per billion, if detected at all. Because of landscape positions of many buffers near streams, pesticides or nitrate leaching into buffers would likely be carried by subsurface flow to streams. Cycling runoff through buffer soil prior to discharge to streams by subsurface flow is much better than allowing surface runoff to directly enter streams. Pesticides can be adsorbed and degraded and nitrate taken up by plants or denitrified within buffers.

Because of the relatively low concentrations of pesticide trapped in buffers, leaching risk from buffers should be much less than leaching risk from source fields. For example, in an Iowa study, atrazine concentrations in a source corn field were 4,800 ppb in the surface 2 cm of soil after the first runoff event of the season (Fawcett et al., 1995). Atrazine concentrations in the buffer strip were 750 ppb. Use of BMPs to reduce pesticide runoff from source fields not only reduces pesticide loads ultimately reaching surface water, but also reduces loads trapped by buffers.

Conservation buffers have been shown to cause degradation of pesticides and to attenuate pesticide concentrations in subsurface water flow. In Iowa (Schultz et al., 1997) atrazine concentrations in soil water 2 feet below a corn field were 13 ppb. Atrazine concentrations beneath an adjacent grass and woody vegetation buffer were only 0.2 ppb. In a Georgia study (Lowrance et al., 1997) no atrazine was detected in shallow groundwater beneath a 3-zone buffer for the first two years of the study. In the third year of the study a large rain event soon after herbicide application resulted in atrazine detections in monitoring wells 6.6 foot deep. A concentration of 6 ppb was detected at the field edge. At the downslope edge of a 26 foot-wide grass strip adjacent to the field, atrazine concentrations declined to 2 ppb. At the downslope edge of the tree strip at the stream edge, atrazine was detected at only 0.2 ppb.

Considering the relatively small load of pesticide intercepted by buffers compared to that applied to crop fields, and the adsorption and degradation of pesticides by soil and vegetation in buffers, increased leaching of pesticides does not appear to be a significant risk from conservation buffers.

INTEGRATING BUFFERS WITH BMPs

Conservation buffers can trap and degrade a portion of pesticides that run off fields either adsorbed to sediment or dissolved in water. However, buffers are seldom effective in trapping all pesticides in runoff. Buffers have been described as "the last line of defense" or as acting to "polish" runoff after it has been treated by other practices. Other BMPs are needed in a systems approach in order to adequately protect water quality. Many practices can be used to reduce off site movement of pesticides. These practices can be selected and integrated into cropping systems where appropriate and effective. Although not an exhaustive list, some common pesticide BMPs and descriptions are listed here.

Integrated Pest Management. IPM systems utilize pesticides in concert with non-chemical pest management techniques. Pest populations are determined and pesticides or other techniques used only when populations exceed economic thresholds. The lowest pesticide rate which is effective is used, and pesticide products selected based on specific pests present and safety to nontarget organisms.

Pesticide Selection. Pesticides applied at low rates reduce amounts available to run off. Products which are strongly adsorbed are less likely to move off fields dissolved in runoff.

Pesticide Application Timing. Risk of pesticide runoff is greatest when heavy rains closely follow pesticide application. Application should be avoided if heavy rain is imminent. Sometimes long-term weather records can identify application times when heavy rains are less likely. Postemergence applications result in less runoff than soil applications, as the crop and weeds behave in the manner of a buffer, increasing infiltration and pesticide adsorption by soil and foliage.

Banded Application. Application of herbicides in bands over crop rows, combined with cultivation to control weeds between rows, reduces total amounts of chemical applied compared to broadcast applications.

Soil Incorporation. Some herbicides and insecticides are effective when mechanically incorporated into the soil (in the case of herbicides) or placed in crop furrows (in the case of insecticides). Placing some of the applied chemical below the soil surface protects it from surface runoff.

Conservation Tillage. Surface crop residue reduces erosion and often increases water infiltration, reducing pesticide runoff. No-till, especially after practiced for several years, has sometimes dramatically reduced pesticide runoff.

Contour Planting. Contour rows reduce erosion, slow runoff, and increase infiltration. Orientation of rows adjacent to buffers may need to be adjusted to direct runoff as sheet flow across buffers.

Strip Cropping. When strips of densely planted crops such as forages or small grains are alternated with strips of row crops, the densely planted crop acts as a buffer. When the strips are planted on the contour, runoff and erosion are reduced and more runoff water enters the soil.

Crop Rotation. Rotation of crops can disrupt life cycles of insects, diseases, and weeds, and reduce the necessity for pesticide treatments. Pesticides can be rotated as the crop is rotated, thus reducing the amount of any one pesticide used on that field.

Terraces/Detention Ponds. These structures shorten slope length, trap sediment, and increase water infiltration, reducing pesticide runoff.

Irrigation Timing. Irrigation after application of soil-applied herbicides moves the chemical off the soil surface, improving weed control and protecting the chemical from later rainfall-runoff events. PAM increases infiltration.

Irrigation Water Management. Improved management of the rate and amount of irrigation water can reduce deep percolation, tailwater, and soil movement.

Compaction Reduction. Correcting compaction problems encourages water infiltration and reduces runoff.

Subsurface Drainage. High water tables can result in excessive runoff and pesticide loss. Improvement of drainage increases water infiltration and reduces pesticide runoff. As subsurface drainage carries nitrate to streams, treatment of tile effluent in a constructed wetland or buffer area may be desirable.

SUMMARY

Conservation buffers are an effective tool to reduce losses of pesticides to water when used in conjunction with other BMPs. Trapping of pesticides is most efficient when sheet flow rather than concentrated flow occurs across buffers. Sheet flow can be encouraged by proper buffer design, including innovations such as level spreaders, water bars, and stiff grass hedges. As sediment is trapped, water flow patterns are changed. Thus, maintenance of buffers will be critical. Sediment will need to be periodically removed and buffers reshaped to maintain effectiveness. This problem illustrates that other soil conservation practices will need to be used in conjunction with buffers to prolong the effective buffer life.

Conservation buffers provide many other benefits, including trapping sediment and nutrients, providing wildlife habitat, streambank protection, and farming safety. By varying buffer width along irregular streams or field borders, cropped areas can be "squared up", reducing sprayer overlaps and making fields more compatible with Global Positioning Systems controls used in Precision Farming. There are many buffer types which can be selected to match site conditions and desired benefits. Appropriate buffer species should be selected to match local conditions. Research into buffer effectiveness in pesticide trapping is a relatively new field. As research continues, buffer designs and maintenance procedures will undoubtedly be refined to maximize effectiveness.

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