ABSTRACT

HAZEL, DENNIS WILLIAM.. Effectiveness and Cost of Improving Vegetated Filter Zones by Installing Level Spreaders to Disperse Agricultural Runoff. (Under the direction of Dr. E. Carlyle Franklin)

Recent studies of agricultural watersheds have indicated that vegetated filter zones (VFZ) may not function optimally because of channelized surface runoff through the zone. One proposed solution has been to disperse channelized surface runoff in the receiving portion of the filter zone with level spreaders. An initial feasibility study demonstrated that level spreaders substantially improved filter strip performance and reduced non-point source pollution (NPSP) outputs to surface water. However, widespread adoption of level spreaders as a best management practice requires designs that are both functional and cost effective over a range of site characteristics including filter zone (FZ) condition and with varying sources of NPSP and under differing rates of loading.

The main objective of this research was to evaluate different level spreader designs and configurations for dispersing channelized agricultural runoff and to evaluate them for enhancing FZ effectiveness on several sites with greatly differing watershed characteristics. Other objectives included estimating construction and maintenance costs and developing recommendations for level spreaders for specific watershed and FZ conditions.

Level spreaders with associated instrumentation were constructed on eight watersheds from 1989 to 1997 representing a wide variety of watershed and FZ conditions. Spreaders without associated instrumentation were constructed on three watersheds.

Source areas included crops under both conventional and conservation tillage, a pasture, a dry-lot for dairy cattle, and a paved and partly-roofed cattle containment area. All spreaders tested were designed to be permanent installations. Designs tested included commercial galvanized gutters, treated wood, fabric-lined ditches with gravel just above and below the ditch, and vegetated berm and trench.

Reductions in NPSP through-puts were a function of filter zone size, input concentration, runoff volume, and season. Filter zones where FZ area was greater than two percent of source-area size generally removed a least a third of each analyte. Of the six sites with dispersed flow which did not have large unaccounted contributions to the FZ, only one failed to reduce N by 30 percent. All spreader designs improved FZ performance. Level spreaders with larger cross-sectional areas were more effective for high peak-flow events. However, spreaders with limited cross sectional such as above-ground gutters have potential where excavation of ditches or shaping of spreaders with large equipment is a problem such as in forests or on steep slopes. The most easily maintained design is a vegetated berm and trench spreader shaped from soil. However, its use is practical only where tree roots are minimum and where farm equipment can maneuver during installation. This design also allows limited vehicle traffic over the spreader.

EFFECTIVENESS AND COST OF IMPROVING VEGETATED FILTER ZONES BY INSTALLING LEVEL SPREADERS TO DISPERSE AGRICULTURAL RUNOFF

by

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DEDICATION

This writing is dedicated to my father, Robert B. Hazel, former Executive Director of the North Carolina Wildlife Resources Commission and Professor Emeritus, Department of Forestry, College of Forest Resources, North Carolina State University. Throughout my life he has taught me directly and through example respect and stewardship of our natural resources. The many childhood hours of camping, hiking, fishing, and hunting have immeasurably influenced the way I see the world in which we have been placed. His continued love for the out-of-doors and involvement in issues affecting our environment encourage me to continue to learn, grow, and maybe in a small way, make a difference.

BIOGRAPHY

Dennis William Hazel was borne in Belfonte Pennsylvania. He received his Bachelor of Science in Wildlife Biology from North Carolina State University in 1972. He received his Masters of Science in Forestry from North Carolina State University in 1978. His thesis was entitled “Deer Forage Production Associated with the Practice of Site Conversion in a North Carolina Pocosin.” After completing his Masters, he served as a Research Assistant in the Department of Forestry at North Carolina State University under the direction of Professor T.E. Maki. Research included studying the effects of stream channelization of bottomland and swamp forest ecosystems and exploring factors, including flooding, thought to be associated with southern pine beetle infestations.

From 1978 until 1980, Mr. Hazel served as a Research Assistant in the Department of Zoology at North Carolina State University where he participated in research on threatened furbearers in the North Carolina Coastal Plain. During his tenure with the Zoology, he assisted with trapping and radio telemetry of bobcats and subsequently developed habitat suitability maps using digital LANDSAT imagery. Since 1980, he has served as a Research Assistant in the Woodlot Forestry Research and Development Program in the Department of Forestry at North Carolina State University. Research involvements have included the development of technology for management of timber and other resources on private nonindustrial forest land in North Carolina. Since 1989, he has been especially associated with studies of the use and management of field-side forested filter zones for treatment of agricultural runoff.

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I want to express my deep appreciation to my wife Debbie and to my two daughters Abigail and Lauren who have endured a much too protracted period of having their husband and dad gone collecting water samples, fixing ill-tempered data collection systems, and taking classes. I especially appreciate them allowing me to do my homework instead of helping with theirs.

I want to thank the many people who have contributed to the project from which this writing was drawn. Mr. Gene Nocerino has again brought his penchant for quality work and his ability to see how to do that which seems undoable to the job of installing level spreaders and constructing the associated structures. Mr. Pete Russell, Mr. John Coulston, Mr. T.R. Clark, and Mr. Hunter Gibbs have all loaned their hands and back to the job of construction while pursuing their undergraduate or graduate education. Mr. Morgan Wood, Mr. Tommy Fisher, Mr. Luke Wood, and Mr. Adrian Moon all spent time in the “trenches” helping with construction between receiving their undergraduate degrees and starting permanent career employment.

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Ms. Kathleen Summit is owed a large “thanks” for development of figures for this document. Her dogged determination to sort her way through any problem will serve her well as she continues to carry on her own research in natural resources. Ms. Tracie Roark superbly handled accounting and correspondence with funding agencies and added tremendous moral support. Ms. Salina Kovach prepared many of the text and appendix tables.

I appreciate the interest and faith in our research expressed by the funding agencies. The initial projects at the Oxford Tobacco Research Station were funded by the University of North Carolina Water Resources Research Institute and by the United States Geological Survey. The bulk of data from which this research was drawn was funded by the North Carolina Division of Water Quality through their US EPA Section 319 Nonpoint Source Program.

I greatly appreciate the support provided by the staff of the research sites at which this research was conducted. Mr. Bill Clements, Superintendent of the Oxford Tobacco Research Station, and his staff have enthusiastically contributed to the series of water-quality studies which we began in 1989. Mr. Ken Snyder, Superintendent of the NCSU Lake Wheeler Road Field Laboratory, and his staff have provided materials, labor, and equipment for our installations there. Mr. Eddie Pitzer, current Superintendent of the Center for Environmental Farming Systems and Mr. Rex Sasser, former Superintendent, and their staff have contributed greatly to site development there. Dr. George Naderman

has graciously accommodated our research on the Tillage Systems Research portion of The Center for Environmental Farming Systems.

I am especially grateful to my Committee members for their wisdom and patience. Dr. James D. Gregory, Dr. John E. Parsons, and Dr. Wayne P. Robarge have greatly contributed to both my personal and intellectual growth. I want to express my sincere and deepest thanks to my Chairman, Dr. E. Carlyle Franklin, who has provided me encouragement and a rich and diverse research environment in which to work and grow. His perpetual enthusiasm and unusual energy has made the many years of working for him in the Woodlot Forestry Research and Development Program seem quite short.

Funding for the bulk of this research was received from the North Carolina Division of Water Quality US EPA Section 319 Nonpoint Source Program. This funding was used to construct level spreaders and install associated instrumentation on six sites in the Piedmont and Coastal Plain of North Carolina. Data from previous studies at the Oxford Tobacco Research Station in Granville County funded by the University of North Carolina Water Resources Research Institute were also used.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF TABLES

Chapter II Pages

LIST OF TABLES (continued)

Chapter III.

APPENDIX

LIST OF TABLES (continued)

LIST OF TABLES (continued)

LIST OF TABLES (continued)

LIST OF FIGURES

Chapter II.

Chapter III.

Chapter IV

CHAPTER I

INTRODUCTION

Background

The substantial contribution by agriculture to nutrient and sediment loads of streams, rivers, and lakes has long been recognized (Smolen and Shanholtz 1980). Ten southeastern states have reported that agricultural NPS pollution affected greater than 50% of their waters (Neary *et al*. 1989). In response, best-management practices (BMPs) have been developed and implemented for southeastern agricultural lands to reduce these inputs including use of vegetated filter zones (VFZ). In particular, field-side forest filter zones (FFZ) provide an especially good opportunity to reduce NPSP from agricultural runoff, and some research has indicated that FFZs may be more effective than grassed filter zones. Within the past 15 to 20 years agronomists and foresters recognized the importance of these as valuable filters for agricultural runoff.

Farmers own much of the private forest lands in the southeast, much of it bordering fields. These forested borders are usually forested because they are too steep or wet for agriculture, but fortuitously they can serve well as FFZs. The Conservation Reserve Program is adding to these lands, providing financial incentives for erodible farmland to be planted with trees.

Filter Zones Reduce Sediments and Nutrients

Researchers using various approaches have concluded that nutrients and sediments in agricultural runoff may be substantially reduced in VFZs. For example, Hill (1981) measured phosphorous (P) output from 22 watersheds but did not directly measure field runoff. He found positive correlations between crop area and P concentrations in surface water, and negative correlations of P concentrations with the amount of forested area. In a case study of the Chowan River watershed in North Carolina, Craig and Kuenzler (1983) estimated that swamp forests removed 83% of the total nitrogen (N) and 51% of the total P.

Other researchers, particularly those in the North Carolina Coastal Plain, have demonstrated the effectiveness of filter zones (FZ) by examining the drainage patterns and directly measuring volumes of runoff through the FZ. Jacobs and Gilliam (1983) found that a 16-meter-wide zone was effective in one instance in removing nitrate. Whereas fields with natural drainage lost almost all nitrate from runoff before water left the field, fields with drain tiles and ditches passed most of their nitrate to surface waters. Gilliam *et al.* (1978) used flashboard riser structures in drainage ditches and found that this procedure was somewhat successful in reducing nitrate entering receiving waters by promoting denitrification.

In another North Carolina study, Cooper (1985) measured Cesium-137 from soil profiles along transects across two Coastal Plain streams to study sediment redistribution within the last 20 to 25 years. He found that 15 to 50 cm of sediment had been deposited at the forest edge while less than 5 cm had been deposited in the flood plain. About 80% was deposited within 100 m of the field edge. This was particularly significant, since many nutrients, especially P and other chemicals, are bound to soil particles. Cooper also measured P in the transects and found that 50% of the P remained in the sediments within riparian areas while 50% left the watershed in streams. Other researchers have also demonstrated that FFZs significantly reduced sediments and nutrients: (Franklin *et al.* 1992, Verchot *et al.* 1997a,b,c; Peterjohn and Correll 1984, Lowrance *et al.* 1984a, Lowrance *et al.* 1984b, Jacobs and Gilliam 1983, Parsons *et al.* 1990, Phillips 1989, and Doyle *et al.* 1975).

Forested Versus Grassed Filter Zones

Whereas, forested filter zones (especially riparian) have been determined to be effective in reducing NPSP from agricultural sources, results regarding grassed VFZs are mixed (Madgette *et al.*, 1989, Daniels and Gilliam, 1989; Dillaha *et al.* 1989) with results suggesting that grassed zones may be effective for particulate and sediment-bound nitrogen (N) including organic and adsorbed NH_4-N and relatively ineffective for dissolved N (NH_4-N and NO_3-N). In addition, grass can be quickly submereged by stormflow rendering these zones ineffective (Hayes *et al.* 1983). Others have felt that grassed FZs may offer specific characteristics which may compliment other types of vegetation when used together in FZs.

Schultz *et al*. (1995) noted deficiencies in grassed FZs compared with FFZs and proposed designed FZs consisting of trees, shrubs, and grasses to take advantage of the different above- and below-ground structures of different plant forms. Welsch (1991) proposed a designed three-zone FZ system where channelized runoff would be distributed within the grassed field-edge FZ approximately 6 m in length (up-slope to down-slope). Nutrient "trapping" would primarily be accomplished by a two-zoned FFZ. The up-slope FFZ would be approximately 18 m in width and would have periodic timber harvesting to remove sequestered nutrients. The second and stream-side FFZ would be about 5 m in width and would not be harvested.

Verchot (1997b) noted that when grassed FZs and FFZs are adjacent, attenuation of NO_3-N in sub-surface flow due to denitrification occurs under the forested rather than grass portions due to higher concentrations of dissolved organic carbon deeper in the soil profile.

Riparian versus Upland Forests as Filter Zones

Much FFZ research has focused on riparian forests (*e.g.* Ambus and Lowrance 1991, Cooper and Gilliam 1986, Cooper *et al.* 1987, Fail *et al.* 1987, Gilliam 1994, Jacobs and Gilliam 1985, Jordan *et al.* 1993, Lowrance 1992, Lowrance *et al.* 1983, Lowrance *et al.* 1984c, Lowrance and Shirmohammadi 1985, Lowrance *et al.* 1985, Peterjohn and Correll 1984, Schultz *et al.* 1995). Indeed, on most streams in the eastern U.S., riparian forests exist as narrow bands on either side of streams (Gilliam 1994). They are forested because they are too steep or too wet for tillage. Regardless of their size or shape, they exist and therefore can serve as FFZs. Gilliam (1994) characterizes them as "wet areas" that "are the result of either (i) restricted surface and subsurface drainage or (ii) water received from higher elevation." Gilliam (1994) additionally distinguishes riparian areas from flood plain swamps and interstream divides and states that riparian areas are "the most important areas for preserving water quality..." Lowrance *et al.* (1985) refers to riparian ecosystems as a "special class of wetlands" and characterizes them as generally having high clay content, organic matter, water-holding capacity, and fertility. Although several authors acknowledge that truly "riparian" forests (from Latin *rip* meaning "bank" of a stream) may include upland-type soils and species, clearly most authors are referring to the wetter and often more poorly drained soils of stream-side forests.

Riparian areas do have special characteristics which often make them unique including a high degree of connectiveness to other ecosystems including aquatic and upland ecosystems (Lowrance *et al.* 1983). However, more upland forest zones exist with their own characteristics which in many cases make them more suitable for FFZs than riparian zones. An often distinguishing characteristic of riparian versus upland FZs is depth to an aquiclude (Jordan *et al*. 1993) with upland soils being deeper and having better year-round infiltration. However, the higher riparian water tables bring subsurface nitrates into contact with the rhizosphere where dissolved organic carbon (DOC) and the presence of denitrifiers promote denitrification (Ambus and Lowrance 1991, Correll 1994, Hanson *et al*. 1994, Peterjohn and Correll 1984, Jordan *et al*. 1993, Lowrance 1992, Verchot *et al*. 1997b,c).

Franklin *et al*. (2000) studied two Piedmont FFZs for four years. One FFZ, although not immediately adjacent to a stream, had riparian characteristics including shallower soils to an aquiclude, wetland-type forest vegetation, and seepage during winter and early spring months. The second site, although closer to a perennial stream, had upland characteristics including deeper better-drained soils and upland forest vegetation. The second site proved more effective in treating surface agricultural runoff when compared to the first site, especially in winter months. This difference was largely attributed to the better infiltration year-round of the better-drained more-upland soils. Although upland FZs may in many cases have greater soil depth to an aquiclude and may not be periodically inundated like riparian flood-plain FZs, Dillaha (1989) recommended avoiding the use of uplands which promote erosion due to steeper slopes.

Hall and Eshleman (1993) in a study of a Virginia Coastal Plain watershed concluded that riparian wetlands are dominant contributors of both baseflow and stormflow, whereas uplands are associated with ground water recharge. Verchot *et al*. (1997a) noted that in portions of the year such as winter and early spring, wetland FFZs can be net contributors of surface N, largely due to low infiltration and due to seepage of surface flow with higher concentration of dissolved organic nitrogen (DON).

Several general conclusions can be reached from these studies regarding riparian versus upland FFZs. Riparian FFZs exist over the length of most streams in the eastern United States. Because of higher water tables during winter and spring when nitrate concentrations are often elevated in subsurface flow, denitrification is promoted because of higher DOC levels in the rhizosphere and because of reduced conditions at or near saturation. However, because of low infiltration during winter spring or wet portions of other seasons, riparian FFZs are less effective than upland FFZs for dissolved and adsorbed nutrients in surface water. Because of their higher infiltration, upland soils can be expected to better reduce stormflow through the FFZ thus promoting better "buffering" of sediments and sediment-adsorbed nutrients and pesticides. However, a choice of FFZ “type” may not exist for most fields. Existing field-side forest land must be used, and may be enhanced by establishing through planting on available field-side soils. In most cases, the most pertinent question is how can the function of any VFZ be enhanced?

The Need to Disperse Channelized Flow and the Concept of Level Spreaders

Several recent studies of agricultural watersheds indicated that filter zones may not function as well as some plot-scale research results suggest because of channelized flow through the riparian areas (Nutter and Gaskin 1989). In a simulated feedlot study, Dillaha *et al*. (1986a) observed that grassed filters with channelized flow were much less effective than those with shallow uniform flow. Dillaha *et al*. (1986b) visited 33 Virginia farms and found that most sites had topographic limitations which limited FZ performance by concentrating field runoff in natural drainageways before it reached the FZ. Dillaha *et al*. (1989) concluded that operational VFZs were not as likely to be as effective as experimental ones because of channelized flow.

Smolen *et al*. (1993) proposed level spreaders to disperse channelized runoff and published design criteria, although none had been constructed and tested. Their design functioned by impounding water above a soil structure constructed across the ephemeral channel. Franklin *et al.* (1992) first tested the feasibility of dispersing channelized runoff in the upper portion of the receiving FZ using level spreaders. Their design differed from that of Smolen *et al*. (1993) in that the spreader was essentially an open channel on contour designed to maintain velocities in the spreader to avoid sediment build-ups within the spreader. In a continuation of their feasibility study, Franklin *et al*. (2000) showed that dispersing channelized field runoff in the upper (receiving) portion of FFZs using level spreaders alters the hydrodynamics of overland flow including: greater sheet flow, less channel flow, increased filtration, reduced peak flow rates, and flow detention. Outputs of total phosphorus (TP), orthophosphate (OP), nitrate nitrogen (NO_3-N), ammoniacal nitrogen (NH_4-N), total Kjeldahl nitrogen (TKN), and total suspended solids (TSS) from the FFZs were reduced by dispersing flow.

By dispersing a given volume of stormflow over a large surface area, both surface retention (microdepressional ponding which eventually infiltrates) and surface detention (ponding which eventually moves to adjacent areas) can be increased. Increased surface retention and detention and greater soil contact will result in higher infiltration. Rajbhandari (1995) used a series of standardized artificial events on two Piedmont FFZs and indirectly determined that volumes of runoff infiltrated into the FFZs were substantially increased by dispersing channelized flow. Dispersion in the upper portion of the FFZ will increase preferential flow (pipeflow and macropore) and microdepressional flow - both components of near-surface interflow. By producing lower surface runoff peak flows and more baseflow through greater infiltration, streamflow may be more even.

By converting channelized flow to sheet flow at lower velocity, hydraulic transport capacity is reduced and sediments and organic particulates "drop out" sooner and at higher rates. Franklin *et al*. (2000) found that on the average 46% of total suspended solids were deposited in a riparian-type filter zone when flow was dispersed compared with 28% for channelized events. On a second somewhat larger upland type FFZ, 73% of total suspended solids on a areal basis were deposited in a riparian-type FZ when flow was dispersed compared with 46% for channelized events. Reductions in TSS output from the FFZs were equally significant when only the largest few events, which contributed 80% of the TSS for all events, were considered, indicating the FFZs were effective in trapping TSS, even for large events.

Verchot *et al.* (1998) compared denitrification potential in FFZs receiving dispersed agricultural runoff with those in adjacent forested soil receiving no runoff and concluded that denitrification potential in surface layers was increased by dispersing runoff.

Although the feasibility of dispersing channelized stormflow with level spreaders has been well demonstrated, previous published studies (Franklin *et al.* 1992, Franklin *et al.*

2000, Rajbhandara 1995, Rueda 1993, Verchot *et al.* 1996) were all based on research on only two Piedmont agricultural watersheds in Granville County North Carolina. Widespread adoption of level spreaders will require demonstration of their effectiveness when used in a variety of NPSP-contributing watersheds. Data are also needed on effectiveness and costs (both construction and maintenance) of different level spreader designs.

CHAPTER II

EFFECTIVENESS OF FILTER ZONES WITH LEVEL SPREADERS

History

In the late 1980's, the North Carolina State University (NCSU) College of Forest Resources Woodlot Forestry Research and Development Program under the leadership of Dr. Carlyle Franklin began to investigate the role of VFZs, especially FZZs, in reducing NPSP from fields and pastures. Our feeling then and now was that forested filter zones (FFZs) could be managed for reduced NPS agricultural outputs to surface waters. In 1989 Dr. Franklin, Dr. Jim Gregory of the NCSU Department of Forestry and Dr. Mike Smolen received a one-year grant from the University of North Carolina Water Resources Research Institute (UNC WRRI) to determine the feasibility of using level spreaders to disperse channelized agricultural runoff. Much of the impetus for the project came from Dr. Smolen's experience at Virginia Polytechnical and State University where a team led by Dr. T. A. Dillaha determined that channelized runoff in many VFSs greatly limited their function. Level spreaders and associated instrumentation were constructed on two agricultural watersheds on the Oxford Tobacco Research Station in Granville County North Carolina (Franklin *et al.* 1992).

After the initial feasibility study was complete, a follow-on study by Drs. Franklin and Gregory of the NCSU Department of Forestry and Dr. John Parsons of the NCSU Department of Biological and Agricultural Engineering was funded by UNC-WRRI and the USDI Geological Survey (Franklin *et al.* 2000). Two graduate students were instrumental in carrying out the follow-on study. Dr. Narayan Rajbhandari (1995) studied hydrology of FFZs with and without dispersed flow through natural and artificial events. Mr. Juan Rueda (1993) modified and validated the ANSFOR model to accommodate dispersed flow.

An additional grant was received by Dr. Franklin and Dr. J. Wendell Gilliam of the NCSU Department of Soil Science from UNC-WRRI to study nitrogen fates within the two Oxford watersheds. On this project, Dr. Lou Verchot developed N budgets for the grass and forested FZs as part of his dissertation. Results indicated that infiltration was essential for removal of nitrogen pollutants from surface runoff. The major N influxes through surface runoff from the agricultural fields occurred during the spring. During this period, leaching losses were low due to presence of a high water table. Nitrogen retained by the FFZ during this period was taken up by the vegetation. Denitrification was the primary process that accounted for nitrate removal from subsurface water. The efficiency of nitrate removal via denitrification was closely associated with dissolved organic carbon which was more associated with soils under the FFZ than with soils under the grassed field border. Dispersal of agricultural runoff enhanced denitrification potential within the FFZ, suggesting that this practice had a favorable effect on the soil microbial population.

The above series of studies conducted from 1989 to 1995 demonstrated the feasibility of dispersing channelized agricultural runoff with level spreaders and thereby improving FFZ function. However, we recognized that before level spreaders become a recommended Best Management Practice (BMP) by state and federal regulatory agencies, estimates of costs and maintenance requirements would be required as well as design criteria. Agency personel, such as those with the USDA Natural Resources Conservation Service, must also have the means to collect relatively simple data on field and FFZ conditions to determine whether level spreaders should be used and how they should be deployed. In 1996, Drs. Franklin and Gregory received US EPA Section 319 funding through the North Carolina Division of Water Quality (NC DWQ) to evaluate the cost and effectiveness of several level spreader designs and configurations.

Objectives

The main objectives of this research were to:

1. Evaluate the effectiveness of vegetated filter zones in reducing NPS pollution from a agricultural runoff from a variety of agricultural sources and watershed characteristics.
2. Evaluate the potential for enhancing FZ effectiveness with level spreaders.
3. Estimate the reductions in NPS pollution of VFZs with level spreaders with varying sources of agricultural NPS pollution.

Methods

To estimate the reductions in NPS pollution of VFZs with level spreaders with varying sources of agricultural NPS pollution, data from the six sites developed with NCDWQ funding and the two Piedmont sites studied by Franklin *et al.* (1992), Franklin *et al.* (2000), Rajbhandari 1995, Rueda 1993, and Verchot *et al.* 1998 were evaluated. The two sites in Granville County were located at the Oxford Tobacco Research Station (OTRS) and were constructed such that runoff could be directed into the original ephemeral channel as before site development or runoff could be directed into the level spreaders thereby using a larger and somewhat different portion of the available FFZ (Franklin *et al.* 1992). Because event data were collected with both channelized and dispersed flow, the sites at OTRS effectively provided four sites for purposes of evaluating FZ size (Table 1).

Table 1. Location and characteristics of watersheds and filter zones on which level spreaders were constructed and evaluated from 1989 to 1998

Site Name	County	Physiographic Province	Watershed Cover	Filter Zone Condition
OTRS Watershed I*	Granville	Piedmont	Conventional row crops	Mature forest
OTRS Watershed II	Granville	Piedmont	Conventional row crops	Mature forest
LWFL Pasture**	Wake	Piedmont	Established grass pasture	Wetland forest
LWFL Drylot	Wake	Piedmont	Compacted dry lot, pavement	Mature forest
LWFL Detention Basin	Wake	Piedmont	Paved areas, detention basin	Former pasture
CEFS Boundary Ditch***	Wayne	Coastal Plain	Mixed tillage row crops	Grass, low plants
CEFS Access Road	Wayne	Coastal Plain	Mixed tillage row crops	Grass, low plants
CEFS River Floodplain	Wayne	Coastal Plain	Mixed tillage row crops	Mature forest

* OTRS is the Oxford Tobacco Research Station

** LWFL is the NCSU Lake Wheeler Field Laboratory

*** CEFS is the Cherry Hospital Farm Center for Environmental Farming Systems

Determination of Potential versus Effective Filter Zone

On each site, level spreaders were installed on contour laterally from the ephemeral channel or ditch. Where topographic or land-use limitations did not restrict either the installation of level spreaders on both sides of the channel or the use of VFZs on both sides, spreaders were installed on contour on both sides. Otherwise, level spreaders were installed only on one side. Micro-topographic variation within available VGZs prevented dispersed runoff from covering all potential filter zone. Even where the VFZ was nearly a plane, small relief variation caused some rechannelization. Thus, direct contact with the vegetative cover, litter, and soil surface occurred on less than the full down-slope area. The potential filter zone was considered to be a polygon defined by the following features: (1) the level spreader; (2) the lower wing-wall and/or collection berm which was constructed immediately above the stream or at the point of nearly complete rechannelization due to topography; and, (3) runoff flow paths from the ends of both spreaders down-slope to the lower wing-wall in VFZs where spreaders were installed on both sides of the channel, or in VFZs where spreaders were installed only on one side, the flow path from the end of the spreaders served as one boundary feature and the ditch or channel served as the feature on the opposite side. Areas which due to topography may not have received runoff within these boundary features were not excluded.

These features were mapped using a mapping-grade global positioning system (GPS) receiver. These data were differentially corrected and included in a geographic system (GIS) data-base and areas determined.

In some cases, as discussed in more detail below, level spreaders were not fully functional due to limited cross-sectional area. In these cases or where reconcentration greatly excluded large areas of the potential FZ, perimeters of the actual flow path were observed during events and then mapped with GPS receivers for inclusion in the GIS. The resulting area is considered to be the effective FZ area.

Sites

Level spreaders with associated instrumentation were constructed on eight watersheds from 1989 to 1999 representing a wide variety of watershed and FZ conditions (Table 1). The first sites on which level spreaders were constructed were at the Oxford Tobacco Research Station (OTRS) in Granville County. During four years of data collection, fields were in conventional-tillage crops including tobacco and minimum-tillage small grains, depending on the year and season. Six additional sites were developed with a grant from the North Carolina Division of Water Quality under their Section 319 Nonpoint Source Program. Three sites were developed at the dairy unit of the North Carolina State University Lake Wheeler Field Laboratory (LWFL) in Wake County in the Piedmont. Watersheds included a pasture, a dry-lot, and effluent from a detention basin into which livestock waste is scraped. Three Coastal Plain sites were developed at the Cherry Hospital Farm Center for Environmental Farming Systems (CEFS). All three sites were located on the tillage-systems portion where a variety of tillage systems are compared on several plots. Watersheds for each of the three CEFS sites had a mixture of crops and tillage systems. Runoff from each of the three watersheds drained into the

Little River upstream from its confluence with the Neuse River. The Neuse River is considered nutrient-sensitive and has been the focus of recent efforts to reduce both nutrient and sediment loading. During much of the period from January through April of 1998, the filter zones on the three CEFS sites were flooded when the Little River flooded from *El Nino*-associated rains.

Prior to construction of the level spreaders, runoff for each of the eight watersheds was channelized in natural channels or excavated ditches. Therefore, opportunities for removal of pollutants from runoff prior to reaching surface waters were minimal.

Oxford Tobacco Research Station Watersheds I and II: Two adjacent watersheds at the Oxford Tobacco Research Station in Granville County, North Carolina were used in this study (Figure 1). Each watershed contained several small fields from which stormflow drained to a grassed waterway which collected and emptied channelized storm-flow into the adjacent forest. In the receiving forested zone, storm-flow normally remained channelized in an ephemeral channel until it discharged into Lake Devin from Watershed I (OTRS I) or into a perennial stream from Watershed II (OTRS II), a short distance upstream from Lake Devin. The area of fields, waterways, and grassed field edge totaled 1.38 ha on Watershed I and 1.26 ha on Watershed II (Table 2).

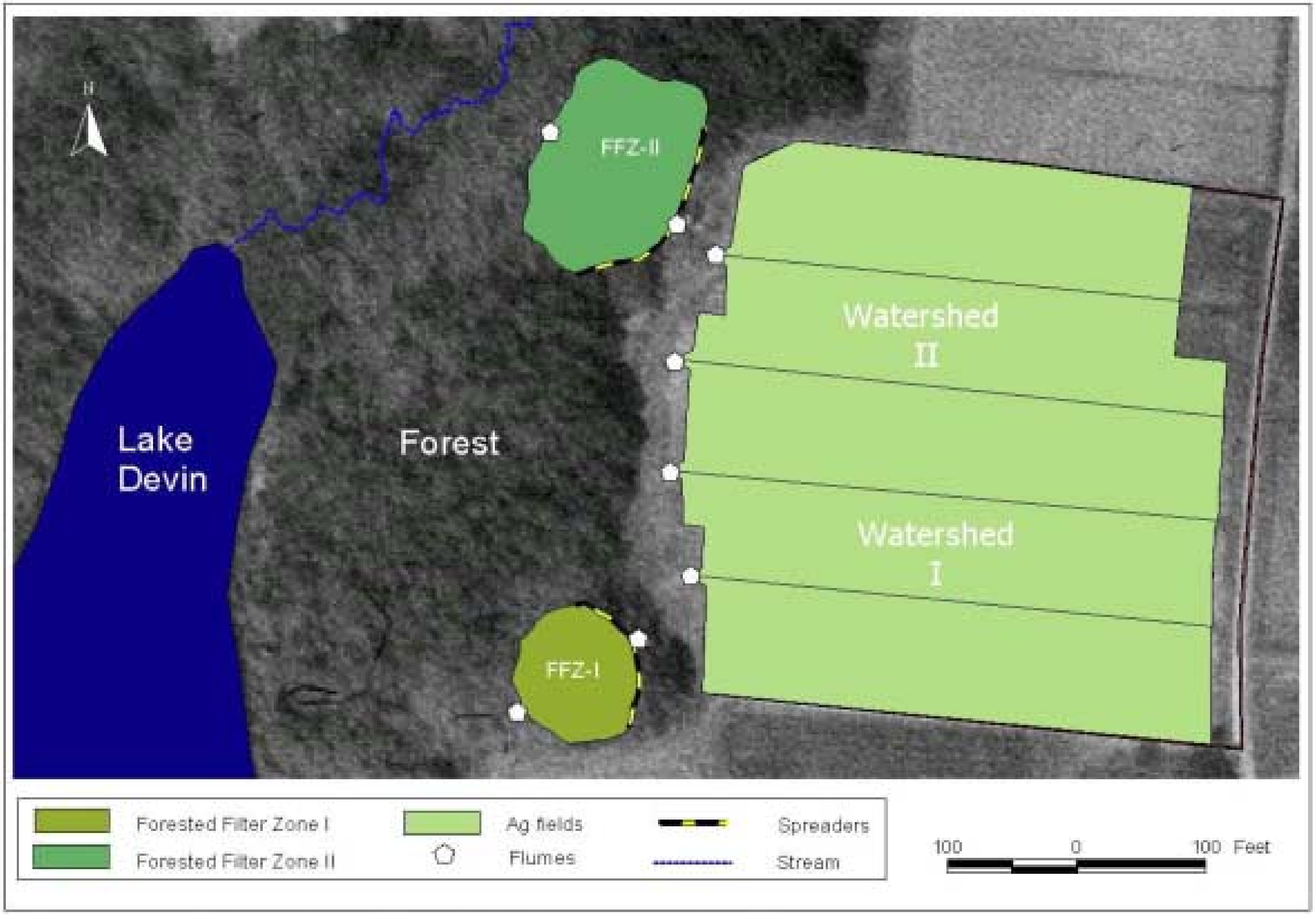

Figure 1. Watersheds I and II at the Oxford Tobacco Research Station

Table 2. Up-slope source watershed area, potential filter zone area, effective filter zone area, and effective filter zone to source area ratio

Site Name	Source Watershed Area (ha)	Potential Filter Zone Area (ha)	Effective Filter Zone Area (ha)	Effective Filter Zone Area to Source Area Ratio (%)
OTRS Watershed I (dispersed)	1.380	0.120	0.064	4.6
OTRS Watershed II (dispersed)	1.260	0.210	0.730	5.8
OTRS Watershed I (concentrated)	1.380	0.120	0.027	2.0
OTRS Watershed II (concentrated)	1.260	0.210	0.021	1.7
LWFL Pasture (dispersed)	2.560	1.381	1.380	22.0
LWFL Dry-lot (dispersed)	2.677	0.445	0.090	3.4
LWFL Detention Basin (dispersed)	0.128	0.172	0.172	134.4
CEFS Boundary Ditch (dispersed)	11.009	0.192	0.076	0.7
CEFS Access Road (dispersed)	5.434	0.262	0.048	0.9
CEFS River Floodplain (dispersed)	1.360	0.036	0.036	2.7

Structures on each watershed consisted of: (1) a 61-cm H-flume with wingwalls to collect and measure storm-flow at the inlet to the FFZ, (2) a distribution box and level spreaders to disperse storm-flow across the slope on contour of the receiving forested area, and (3) a second 61-cm H-flume with wingwalls to intercept and measure interflow and overland flow at the outlet from the FFZ.

On each Oxford watershed, level spreaders consisted of a distribution box and two treated wooden troughs consisting of 2.44 m sections, each with a cross-sectional area of 194 cm^2. The distribution box was centered on the natural ephemeral channel. Spreaders extended on contour nearly to the water divide. The ability to disperse flow (“dispersed”event) or allow flow to remain in the original ephemeral channel (“channelized” event) was unique to the two Oxford sites. On both Oxford sites, the spreader extended on contour on both sides of the ephemeral channel. Total length of the two segments on Watershed I was 43.9 m and on Watershed II 61.0 m.

On Watershed I the potential FZ was 0.120 ha and 0.210 ha on Watershed II. However, it was observed that some rechannelization occurred below the spreaders due to topography (Rajbhandari 1995) so that effective FZ was 0.064 ha on Watershed I and 0.730 ha on Watershed II resulting in an effective FZ to source area ratio area on Watershed I of 0.046 and on Watershed II of 0.059 (Table 2).

Data were collected from October 2, 1989 to March 8, 1995 on Watershed I and from April 7, 1990 to March 8, 1995 on Watershed II (Table 3). Runoff data and samples were successfully collected for 123 dispersed runoff events on Watershed I and 80 dispersed for Watershed II. Data and samples were collected for 39 channelized events for Watershed I and 37 for Watershed II (Table 2).

Table 3. Data collection period and number of runoff events where data were successfully collected during the period

Site Name	Data Collection Period	Number of Runoff Events Successfully Collected
OTRS Watershed I (dispersed)	Oct. 1989 - Mar. 1995	123
OTRS Watershed II (dispersed)	Apr. 1990 - Mar. 1995	80
OTRS Watershed I (channelized)	Feb. 1992 - Feb. 1994	39
OTRS Watershed II (channelized)	Feb. 1992 - Feb. 1994	37
LWFL Pasture (dispersed)	May. 1997 - Sep. 1998	47
LWFL Dry-lot (dispersed)	Oct. 1997 - Jul. 1998	12
LWFL Detention Basin (dispersed)	Dec. 1997 - Sep. 1998	31
CEFS Boundary Ditch (dispersed)	Jul. 1997 - Mar. 1998	11
CEFS Access Road (dispersed)	Jul. 1997 - Feb. 1998	9
CEFS River Floodplain (dispersed)	Mar 1997 - Mar. 1998	17

LWFL Pasture Watershed: The Lake Wheeler Field Laboratory pasture watershed was selected to evaluate level spreaders and VFZs in treating nutrient-enriched runoff from pastures under active cattle grazing. A 2.56-ha bowl-shaped pasture with a well-established fescue sod drained through an ephemeral channel into a 1.38 ha wetland from which a perennial stream flowed (Table 2, Figure 2). An earthen collection berm was constructed across the ephemeral channel to temporarily channel runoff into a 91.4 cm H-flume. An second 91.4 cm H-flume was installed in the perennial stream at the outlet of the wetland. A 152.5 m level spreader was installed below the upper H-flume along a contour just 20 m up-slope from the wetland. The spreader consisted of commercial galvanized half-round gutters with a cross-sectional area of 81 cm^2 mounted on wooden stakes just above the ground surface.

The ratio of effective FZ to the source-contributing pasture was 0.220. However, an additional 3.09 ha of watershed, much of it pasture, drained across the forested slope above the spreader and then under the spreader but did not flow through the upper flume (Figure 2). Data were collected from May 26, 1997 until September 3, 1998 (Table 3). Forty-seven runoff events occurred during the period for which all instruments worked properly.

After flume and spreader sites were selected but before installation, Hurricane Fran uprooted many of the large trees in the FFZ on September 6, 1996.

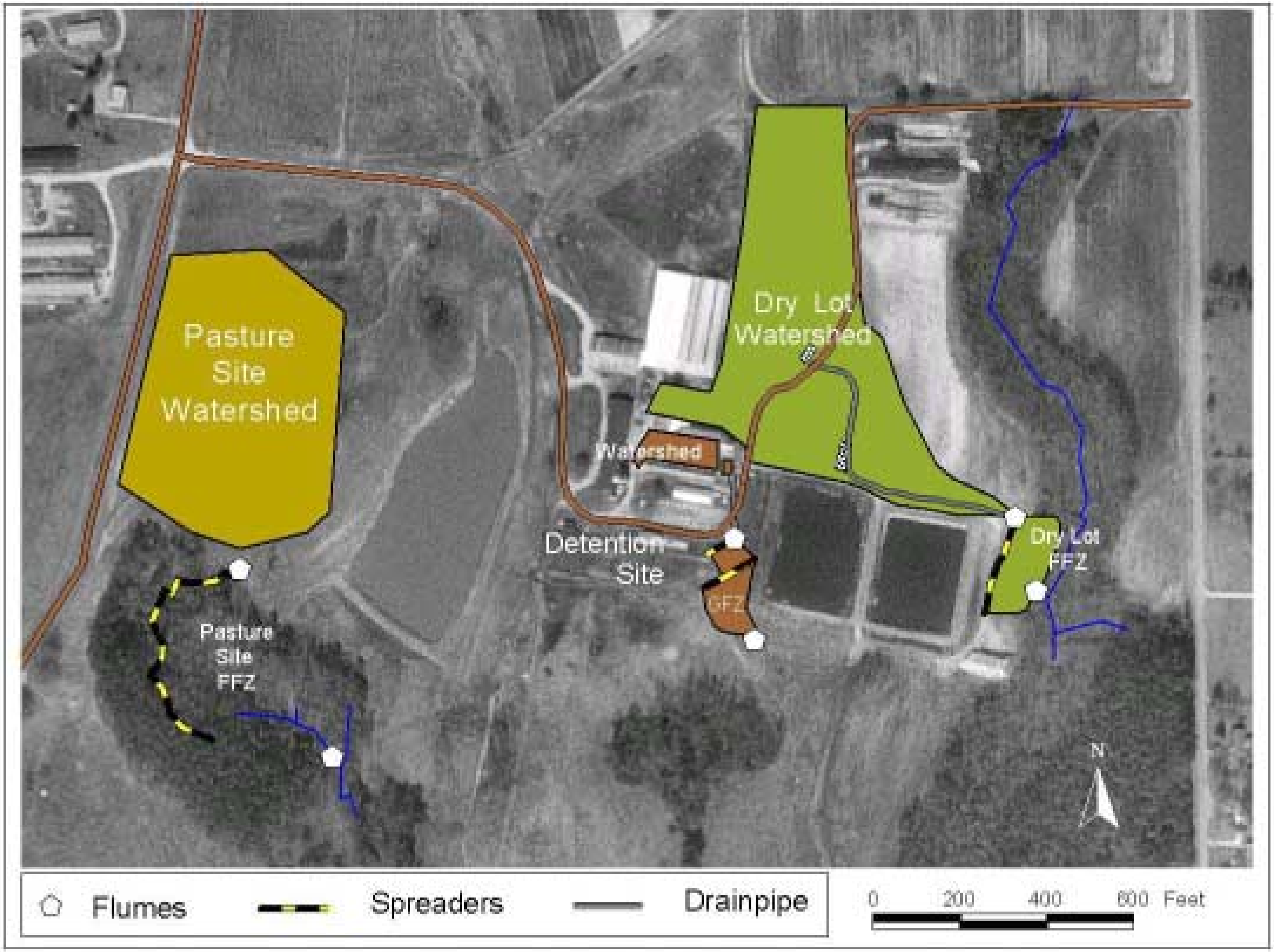

Figure 2. The Pasture Site, Dry-lot Site, and the Detention Site at the North Carolina State University Lake Wheeler Road Field Laboratory

LWFL Dry-lot Watershed: The 2.68-ha dry-lot watershed consisted of a combination of dry-lot and paved areas associated with the dairy at the NCSU Lake Wheeler Field Laboratory (Figure 2). An average of two hundred cows used the dry-lot for lounging resulting in high soil compaction and essentially no vegetative cover. Runoff from the dry-lot and paved areas flowed 100 meters through an open ditch to an eroding ephemeral channel then down a gully to a stream (Table 2). A series of rock check dams were installed in the ditch to reduce ditch velocities and dampen peak runoff rates. The effective portion of the FZ was 0.090 ha resulting in an effective FZ area to source area ratio of 3.36 (Table 2). A 91.4 cm H-flume was installed in the ditch just up-slope from the edge of the riparian forest. Flow was diverted from the flume into a 61-meter long level spreader consisting of 20.32-cm diameter half-round galvanized gutter material with a cross-sectional diameter of 81 cm^2 mounted on wooden stakes just above the soil surface. A second 91.4 cm H-flume and plywood runoff-collection wingwall were installed at the lower end of the FFZ. After flume and spreader sites were selected but before installation, Hurricane Fran uprooted many of the large trees in the FFZ on September 6, 1996, creating a thinned mature FFZ.

Data were collected from October 18, 1997 until July 25, 1998. Twelve runoff events occurred during the period for which all instruments worked properly (Table 3).

LWFL Detention Basin Watershed: The detention basin watershed was developed to accept stormflow from a 22 cubic-meter concrete detention basin below a paved heifer lot

(Figure 2). Manure and bedding material were regularly pushed into the basin with front-end loaders or other equipment. Accumulated solid material was periodically removed from the basin. The basin also received storm runoff. During runoff events, materials and entrained solids were in the runoff and delivered to the filter zone after passing over a retention dam 0.9 m in height. Runoff from the basin was piped 37 meters into the approach section of a 61-cm H-flume. Runoff was then received by a 18 m level spreader constructed at the upper slope of a 0.172 ha grassed filter zone which had been used as pasture just prior to construction of the spreader. The grassed FZ was narrow along contour but long down-slope such that most dispersed runoff from the spreader rechannelized by mid-slope. A second 41 m long spreader was constructed at mid-slope to receive and redistribute the rechannelized runoff in the FZ. The use of two spreaders in tandem made the best use of the long but narrow FZ. A 61-cm H-flume and plywood wingwall were constructed at the toe of the FZ slope to recollect and sample dispersed runoff. Data were collected from December 22, 1997 until September 3, 1998. Thirty-one events occurred during the period for which all instruments worked properly (Table 3).

CEFS Boundary Ditch Watershed: The CEFS Boundary Ditch Watershed consisted of a 10.5 ha portion of the No-Till Systems unit from which surface and subsurface runoff drains into a ditch along the western boundary of the No-Till Systems Unit (Figure 3, Table 2). A 61-cm H-flume was installed in the ditch in a portion where the soil surface slopes towards the natural drainage near the river. Water was diverted below the flume

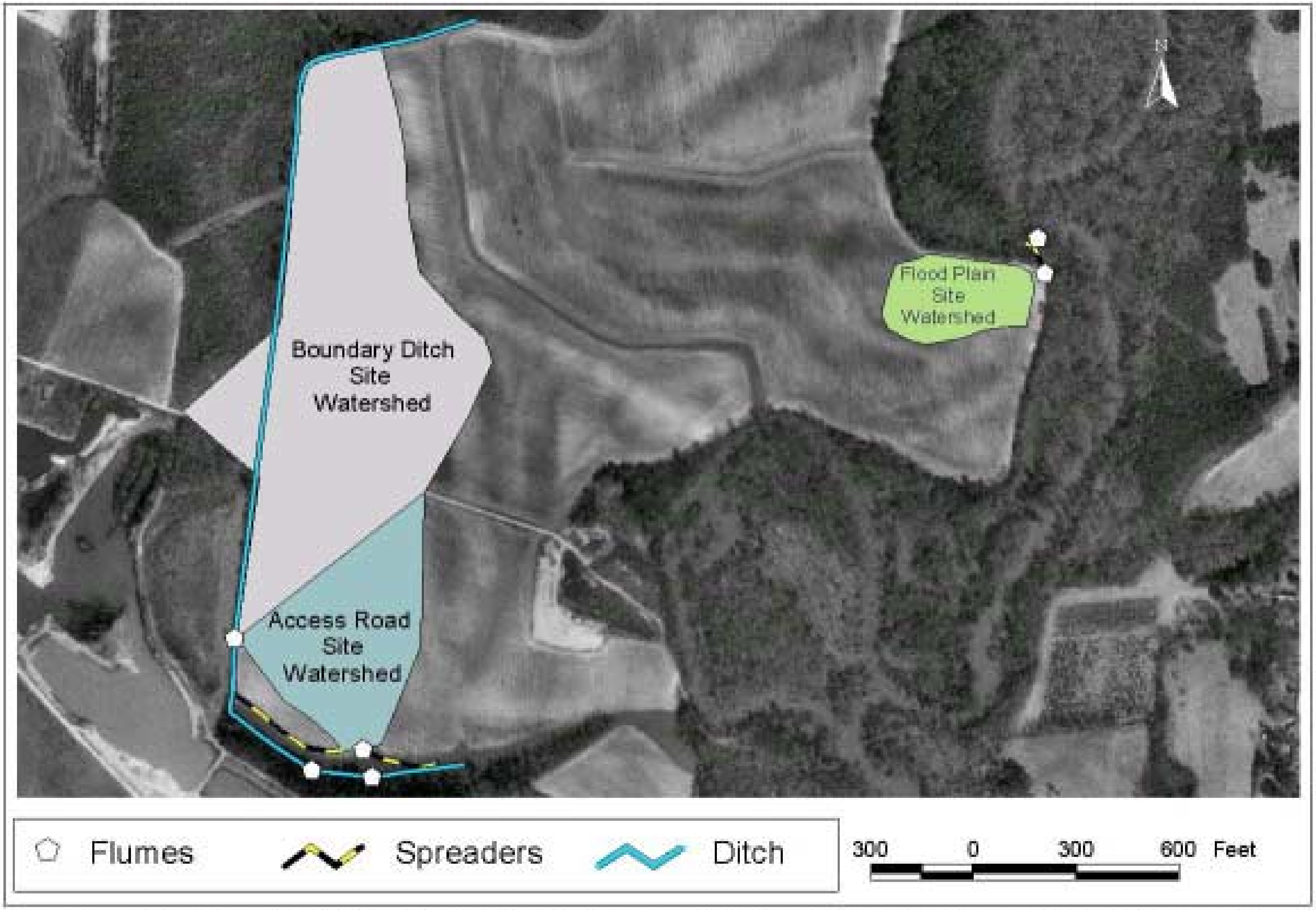

Figure 3. The Boundary Ditch Site, Access Road Site, and Little River Flood Plain Site at the Cherry Hospital Farm Center for Environmental Farming Systems

laterally into a 147.9 m gutter-type spreader mounted on wooden cradles and stakes just above the soil surface. An approximately 15-meter wide zone between the spreader and the ditch was abandoned from crops research and planted with hardwoods. However, during the study, FZ cover was mostly grass and low herbaceous plants. A berm was created along the ditch below the FZ to collect dispersed runoff and channel it into a 91.4-cm H-flume for measurement and sampling. The potential FZ was 0.192 ha, however, due to poor performance of the gutter-type spreader and due to reconcentration within the FZ, the effective FZ area was 0.076 ha. This resulted in a ratio of effective FZ area to source area of 0.69 (Table 2).

Data were collected from July 10, 1997 until March 17, 1998 (Table 3). Eleven events occurred during the period for which all instruments worked properly and where the FZ was not flooded.

CEFS Access Road Watershed: The CEFS Access Road Watershed consisted of a 5.4-ha portion of the No-Till Systems unit which drained onto a farm road which provided access to tillage research plots. Runoff on the road had created an eroding ephemeral channel below the end of the road through the lower field portion above a portion of the boundary ditch (Figure 3). As with the boundary-ditch site, an approximately 15-m wide zone between the spreader and the ditch was abandoned for crops research and planted with hardwoods, although as with the boundary ditch site, the FZ cannot be considered as "forested" FZ during the duration of the study because of the small seedling size. An earthen berm was constructed on the upper portion of the FZ and a 45.7-cm H-flume was installed in the ephemeral channel. A 86.9 m trenched level spreader dispersed runoff onto a 0.262 ha FZ of grass and low plants following crop abandonment. A berm was created along the ditch below the FZ to collect dispersed runoff and channel it into a 61-cm H-flume for measurement and sampling. Due to spreader performance and rechannelization, only a 0.048 ha portion of the FZ was effective which provided a ratio of effective FZ to source area of 0.88 (Table 2).

Data were collected from July 30, 1997 until February 25, 1998 (Table 3). Nine events occurred during the period for which all instruments worked properly and where the FZ was not flooded.

CEFS Little River Forested Flood Plain Watershed: Prior to installation of a level spreader, runoff from a 1.36-ha portion of the CEFS No-Till Systems unit flowed through a culvert under a perimeter farm road into an ephemeral channel into the flood plain of the Little River. A 30.5-cm H-flume was installed at the culvert outlet. Flow was then diverted into a 30-m level spreader which consisted of a shallow trench excavated with hand tools and lined with erosion fabric. Approximately 2-cm diameter rock was placed over the fabric down-slope from the trench to dissipate outfall from the spreader. Most of the 0.036 ha forested FZ was considered "effective" which resulted in a ratio of effective

FZ to source area of 2.65 (Table 2).

Data were collected from March 27, 1997 until March 7, 1998 (Table 3). Seventeen events occurred during the period for which all instruments worked properly and where the FZ was not flooded.

On all sites at LWFL and CEFS, spreaders extended to one side only because available FZ to receive dispersed runoff lay mostly or entirely to one side only of the natural channel or ditch.

Instrumentation

From October 1989 through October 1991 on OTRS Watersheds I and II, flume stage was measured with Stevens Type A-71 stage recorders. Stage-activated water samplers (ISCO Model 1392) collected samples from the flow in each flume. A discrete sample was taken at flow initiation and at each 6.1 cm change in stage. Thereafter, on all flumes, stage was measured using potentiometers geared to float pulleys to register position of the floats and a Campbell CR-10 data logger for data recording. Data loggers were programmed to interrogate potentiometers every 2.5 minutes. If stage at any flume changed at least 2 mm during the interval, stage and time were recorded for all sites flumes. Samplers were activated when an absolute change of 8.2 percent of the range of potential stage values occurred within a two-hour period. As an example, for a 610-mm flume (24 in), a sample was taken for 50 mm absolute change in stage occurred. Stage was recorded at 15-minute intervals regardless of change in stage. Rainfall was measured with a tipping bucket rain gauge located at each farm (OTRS I, pasture site, boundary ditch site). The data logger of the site at which the rain gage was located was pulsed for every 0.254 mm of rain. Five-minute totals were recorded by the logger.

Runoff Sample Collection and Analysis

Discrete 350 ml samples from the automatic samplers were normally collected within 24 hours, placed on ice in coolers in the field, and then refrigerated in the lab until analyzed. For most events, average concentrations and total loadings for the event at each flume were computed by mixing a single 500 ml flow-proportional composite sample for each flume. This was done by compositing the samples in the lab from hydrographs at each flume. For a subset of events, each discrete sample was analyzed to examine concentrations in relation to flow rate.

In preparation for analyses, samples were shaken and split into two portions: one for total suspended solids (TSS) analysis, and the second for nutrient analysis.

Standardized analytical procedures were used as follows:

Total Suspended Solids (TSS): Method 2540 D, Dried at 103-105°C (American Public Health Association, 1992). Limit of quantification - 0.1 mg l^{-1}.

Nitrate Nitrogen (NO_3-N): Method 4500-NO_3 F, Automated Cadmium Reduction Method (American Public Health Association 1992). NO_3-N was determined after filtration though a 0.45 μm-pore-diameter membrane filter. The limit of quantification was 0.1 mg l^{-1}.

Ammoniacal Nitrogen (NH_4-N): Method 4500-NH_3 H. Automated Phenate Method (American Public Health Association 1992). NH_4-N was determined after filtration though a 0.45 μm-pore-diameter membrane filter. The limit of quantification was 0.1 mg l^{-1}.

Total Kjeldahl Nitrogen (TKN): Method 4500-N_{org} C, Semi-Micro-Kjeldahl Method (American Public Health Association 1992). Limit of quantification - 0.1 mg l^{-1}. Analytically, NH_4-N and organic N are determined together as TKN, thus the difference between TKN and NH_4-N is an estimate of organic N. TKN was determined on unfiltered samples.

Ortho-phosphate (OP) and Total Phosphate (TP): Method 4500-P F, Automated Ascorbic Acid Reduction Method (American Public Health Association 1992). Limit of quantification - 0.01 mg l^{-1}. OP was determined after filtration though a 0.45 μm-pore-diameter membrane filter. TP was determined by measuring OP on unfiltered samples, thus the difference between TP and OP is an estimate of suspended P.

Data Analysis

Data files from the field notebook computer were uploaded to an office computer where logger event files were processed using programs developed by project staff in QBASIC. Potentiometer values of stage in millivolts were converted to millimeters of stage. Laboratory results for TSS, NH_4-N, NO_3-N, TKN, OP and TP were entered or input directly from laboratory spreadsheets. For each flume, the following variables were computed: total runoff volume (both in cubic meters and cubic meters per contributing area), peak flow rate, total rainfall, average five-minute rainfall, maximum five-minute rainfall, mean event concentration for each analyte, and gravimetric total or "mass" for each analyte in kilograms (computed by multiplying total volume by mean concentration).

No direct measurements of antecedent soil moisture were made. However, a soil moisture surrogate was calculated for each event by dividing the total of the last rainfall in millimeters divided by the days since that rainfall. When multiple runoff events occurred on the same day (midnight to midnight), the days since last rain was set as one rather than dividing by zero. During 1992 and 1993, a series of artificial events were created on the Oxfords watersheds using irrigation pumps (Rajbhandari 1995). The events simulated a one-year return-period rainfall event of 51 mm. For six of the events at Oxford in the combined data set, an artificial event represented the "last" event. In each case 51 mm was used for the last rainfall total.

To evaluate any differences in FZ behavior among seasons, a variable "season," was created by recording the quarter of the year in which the event occurred based on Julienne date: January - March, April - June, July - September, and October - December. After excluding events where special problems had been noted with the site or instruments, the combined data set comprised 233 runoff events.

Gravimetric loading or “mass flow” was determined by multiplying mean event concentration for each analyte times the total runoff into or out of the FZ. Long-term analyte detention was estimated for each site by totaling total mass into the FZ and then subtracting the total mass which left the FZ in runoff. To estimate annual detention, the long-term detention estimate was multiplied by the ratio of 12 months divided by the total number of months in the sampling period. Although, this method of estimation provides an approximation of annual loading and detention, it fails to account for seasonal influences of under or over-represented seasons in the sampling period for any site. Statistical computations were made using the Statistical Analysis System (SAS 1982) on a desk-top PC. Pearson correlations, chi-square analysis, and analysis of variance (ANOVA) procedures were used to evaluate performance of filter zones with, and in the case of OTRS,I and II without level spreaders.

Results and Discussion

In most cases, effective FZ area was less than potential area (Table 4). In many cases, cross-sectional area of the spreader was too limited for large flow events resulting in only a portion of the total length being functional. Although the remaining length of spreader

Table 4. Event averages for total rainfall, upper-flume peak flow, upper-flume total flow, lower-flume total flow, and area-based upper-flume total flow

Site Name	Average Total Rainfall (mm)	Average Peak Flow Upper Flume (m^{3}hr^{-1})	Average Total Flow Upper Flume (m^3)	Average Total Flow Lower Flume (m^3)	Average Total Flow per ha of Source Area of Uper Flume (m^{3}ha^3)
OTRS Watershed I (dispersed)	19.71	196.12	112.48	108.47	83.94
OTRS Watershed II (dispersed)	30.56	99.17	64.73	37.26	53.05
OTRS Watershed I (channelized)	18.82	123.03	116.28	132.30	86.77
OTRS Watershed II (channelized)	19.84	58.94	75.31	57.54	61.73
LWFL Pasture (dispersed)	20.00	7.60	58.75	171.02	23.00
LWFL Drylot (dispersed)	25.45	373.12	580.87	272.40	190.34
LWFL Detention Basin (dispersed)	25.29	6.65	11.82	58.95	92.36
CEFS Boundary Ditch (dispersed)	39.84	88.37	677.83	561.45	64.40
CEFS Access Road (dispersed)	26.15	100.28	495.32	567.81	103.67
CEFS River Floodplain (dispersed)	31.42	9.24	13.68	14.32	10.06

filled with runoff, only a minor but undetermined portion of the total runoff overflowed the spreader in those sections. Because a portion of the spreader length was essentially not functional, a major portion of the potential FZ remained out of the flow path. Examples include the wooden spreaders at OTRS I and II, the galvanized gutters at the dry-lot and boundary ditch sites, and the access road site.

Variation in total rainfall for events contributed to an approximately two-fold difference between the lowest event average (OTRS I - channelized) and the highest (boundary ditch) (Table 4). However, slope, source area size, and surface condition of the source area were more important in determining peak flow rates and total flow into the level spreaders as measured at the upper flume. The highly compacted dry-lot, although having only the third largest source area, had 1.9 times the average peak flow rate of the next highest watershed. The compacted dry-lot also had the highest average total flow per unit of source area suggesting low infiltration in the source area. The pasture site, with its well established thick fescue cover, had nearly the same source area as the dry-lot site, yet average peak flow rates were only approximately two percent of the average for the dry-lot site. The boundary ditch site, with the largest source area of all watersheds, had the highest average total flow, but only the sixth highest peak flow rate at the upper flume due to the large storage capacity of the up-slope ditch which greatly dampened peak rates. Overall slope for the fields was less than two percent which also contributed to reduced peak flow rates. The detention site had the lowest peak flow rates at the upper flume not only due to the small source area, but also due to the dampening effect of the 22 m^3 capacity detention basin which filled during larger runoff events and then slowly released flow to the upper flume and upper level spreader immediately below the flume through "weep" holes in the flashboard riser at the basin outlet.

Average TSS concentration was highest on the detention site with an average of 355 mg l^{-1} of TSS (Table 5). However, the highest single events occurred on the Oxford sites following tillage of tobacco fields. Most solids from the calf and heifer pens were trapped by the basin for later removal by tractor. During runoff events the basin was essentially filled with a slurry of manure, bedding material, and water so that even though many solids remained in the basin, runoff which flowed into the upper flume and spreader contained high TSS concentrations. The dry-lot site with the heavy dairy cow concentration had high levels of TSS as well (214 mg l^{-1}). Both the access road site

Table 5. Average and maximum concentrations in storm runoff for total suspended solids (TSS) and ammoniacal nitrogen (NH_4-N)

Site Name	Avg. TSS (mgl^{-1})	Max. TSS (mgl^{-1})	Avg. NH_4-N (mgl^{-1})	Max. NH_4-N (mgl^{-1})
OTRS Watershed I (dispersed)	135.6	2943.4	0.06	1.22
OTRS Watershed II(dispersed)	84.5	9128.2	0.02	4.50
OTRS Watershed I (channelized)	102.1	2852.6	0.01	1.95
OTRS Watershed II (channelized)	36.0	9527.1	0.01	3.66
LWFL Pasture (dispersed)	21.7	171.0	0.07	0.10
LWFL Drylot (dispersed)	213.6	1384.0	5.46	21.00
LWFL Detention Basin (dispersed)	355.5	394.0	25.01	156.00
CEFS Boundary Ditch (dispersed)	91.8	421.6	0.30	4.78
CEFS Access Road (dispersed)	185.0	928.0	0.08	0.26
CEFS River Floodplain (dispersed)	3.6	891.0	0.01	4.77

with the heavy road erosion and OTRS 1-dispersed had relatively high TSS concentrations with 185 and 136 mg l^{-1} of TSS respectively. The high levels of TSS for events on OTRS I-dispersed were due to the large number of events monitored during the tobacco-tillage season.

Average N and P concentrations at the upper flume were relatively low for all sites except the detention and dry-lot sites (Tables 5-7). Despite low average concentrations, both conventional tillage and conservation-tillage row-crop sites (OTRS I and II, boundary ditch, access road, and flood plain) experienced spikes in N levels with NO_3-N concentrations reaching 3 to 4 mg l^{-1}, especially during the first two to four events following fertilizer application (Table 6). Roberts (1987) found that a large portion of N loss in surface flow and near-surface interflow occurred following fertilizer application. On the pasture site, N levels were somewhat elevated when heifers were grazing on the

Table 6. Average and maximum concentrations in storm runoff for nitrate nitrogen (NO3-N) and total Kjeldahl nitrogen (TKN)

Site Name	Avg. NO_3-N ($mg1^{-1}$)	Max. NO_3-N ($mg1^{-1}$)	Avg. TKN ($mg1^{-1}$)	Max. TKN ($mg1^{-1}$)
OTRS Watershed I (dispersed)	0.06	1.22	0.50	1.85
OTRS Watershed II (dispersed)	0.02	4.50	0.57	5.84
OTRS Watershed I (channelized)	0.01	1.95	0.01	3.19
OTRS Watershed II (channelized)	0.01	3.66	0.37	20.53
LWFL Pasture (dispersed)	0.07	8.10	0.83	8.40
LWFL Drylot (dispersed)	5.46	21.00	2.83	25.00
LWFL Detention Basin (dispersed)	25.01	156.00	1.85	8.30
CEFS Boundary Ditch (dispersed)	0.30	4.78	1.42	14.00
CEFS Access Road (dispersed)	0.08	0.26	0.30	1.50
CEFS River Floodplain (dispersed)	0.01	4.77	0.01	2.66

Table 7. Average and maximum concentration in storm runoff for ortho-phosphorus (OP) and total phosphorus (TP)

Site Name	Avg. OP ($mg1^{-1}$)	Max. OP ($mg1^{-1}$)	Avg. TP ($mg1^{-1}$)	Max. TP ($mg1^{-1}$)
OTRS Watershed I (dispersed)	0.05	0.88	0.21	7.49
OTRS Watershed II (dispersed)	0.02	3.40	0.11	16.48
OTRS Watershed I (channelized)	0.01	1.32	0.17	7.06
OTRS Watershed II (channelized)	0.01	2.45	0.09	14.32
LWFL Pasture (dispersed)	0.28	0.62	0.36	2.30
LWFL Drylot (dispersed)	8.33	25.00	9.77	26.80
LWFL Detention Basin (dispersed)	25.01	156.00	1.85	8.30
CEFS Boundary Ditch (dispersed)	0.54	2.25	0.64	4.49
CEFS Access Road (dispersed)	0.37	1.40	0.48	1.50
CEFS River Floodplain (dispersed)	0.01	2.30	0.01	2.80

pasture. At those times, NO_3-N levels occasionally exceeded 8 mg l^{-1}. For watersheds where mineral fertilizers were the primary source of N fertilization (OTRS I and II, boundary ditch, access road, flood-plain), NO_3-N in runoff was roughly twice the N in NH_4-N. With similar N sources, Lowrance (1992) found that in surface runoff, nitrogen loss was composed of 20% NO_3-N, 11% NH_4-N, and 60% organic N. On both the detention and dry-lot sites, with manure being the primary N source, NH_4-N was approximately double the mass of NO_3-N in runoff.

Detention of TSS

Estimates of annual detention demonstrate the capacity of VFZs with dispersed flow to detain suspended solids (Table 8). Sites with dispersed flow detained 30 to 89 percent of TSS. The relatively small FZ on the access road watershed detained TSS at a rate 114,000 kg ha^{-1} of TSS. Although only 37 % of TSS was detained, a much higher percentage of TSS could have been detained if a greater portion of the potential FZ had been utilized. This could have been possible through use of a larger cross-section level and thus more functional level spreader. Even though the total length of several of the

Table 8. Estimated annual detention by vegetated filter zones of total suspended solids

Site Name	Effective Filter Zone Area (ha)	Entering Filter Zone from Source Area	Detained in Filter Zone (kg)	Detained per Unit Area of Filter Zone (kg/ha)	Percent Entering the Filter Zone Detained (%)	Export From Filter Zone (kg)
OTRS Watershed I (dispersed)	1.380	8151	2434	1764	29.9	5717.0
OTRS Watershed II (dispersed)	0.090	4718	2529	28099	53.6	2188.6
OTRS Watershed I (channelized)	0.172	8141	1214	7055	14.9	6927.3
OTRS Watershed II (channelized)	0.076	2669	916	12052	34.3	1752.9
LWFL Dry-lot (dispersed)	0.036	9824	5419	150000	55.2	4405.3
LWFL Detention Basin (dispersed)	0.064	177	157	2453	88.9	19.5
CEFS Boundary Ditch (dispersed)	0.073	2937	1616	22136	55.0	1321.3
CEFS Access Road (dispersed)	0.027	8327	3090	114458	37.1	5236.5
CEFS River Floodplain (dispersed)	0.021	133	53	2545.4	40.2	79.5

spreaders was not fully utilized, any detention of TSS can be attributed to use of level spreaders on the Lake Wheeler and CEFS sites. On OTRS Watershed I where the ephemeral channel was broader and multi-pathed, level spreaders doubled TSS detention. Estimated TSS detention in the dry-lot FFZ exceeded 9,820 kg yr^{-1} demonstrating the high potential of VFZs to capture solids once channelized flow is converted to sheet flow resulting in lowered flow velocities. On all sites, detained TSS also resulted in detention of an unmeasured and unknown amount of particulate-adsorbed nutrients such as NH_4-N and P.

Detention of Nitrogen

Estimates of annual gravimetric loading of NH_4-N was less than 10 kg yr^{-1} for all FZ sites except the dry-lot where detention was estimated to be 69 % of the 251 kg yr^{-1} entering the FFZ (Table 9). Detention ranged from 20 to 100 percent for the sites with dispersed flow except the access road site where export from the VFZ exceeded inputs for an undetermined reason. Results for NO_3-N were more variable with net export in the detention FZ and essentially no detention in the access road and OTRS I FZs, whereas detention of NO_3-N in other FZs with dispersed flow ranged from 23 to 58 % (Table 10). Nitrate nitrogen entering both OTRS zones was less than 2 kg yr^{-1}. Highest gravimetric loading of NO_3-N was 130 kg yr^{-1} where 48 % was detained by the dry-lot FFZ. Gravimetric loading of TKN was also highest on the dry-lot site where 67 % of the 516 kg yr^{-1} was detained (Table 11).

Table 9. Estimated annual detention by or export from vegetated filter zones of ammoniacal nitrogen (minus sign indicates net export)

Site Name	Effective Filter Zone Area (ha)	Entering Filter Zone from Source Area (kg)	Detained in Filter Zone (kg)	Detained per Unit Area of Filter Zone (kg/ha)	Percent Entering the Filter Zone Detained (%)	Export From Filter Zone (kg)
OTRS Watershed I (dispersed)	1.380	2.1	0.4	0.3	19.9	1.7
OTRS Watershed II (dispersed)	0.090	1.2	0.7	7.2	52.4	0.6
OTRS Watershed I (channelized)	0.172	1.1	0.3	1.5	23.8	0.8
OTRS Watershed II (channelized)	0.076	0.5	0.1	1.0	15.8	0.4
LWFL Dry-lot (dispersed)	0.036	251.3	173.7	4823.6	69.1	77.7
LWFL Detention Basin (dispersed)	0.064	0.3	0.3	5.4	100.0	0.0
CEFS Boundary Ditch (dispersed)	0.073	9.7	5.6	77.3	58.1	4.1
CEFS Access Road (dispersed)	0.027	3.5	-4.2	-156.5	-119.8	7.8
CEFS River Floodplain (dispersed)	0.021	0.3	0.2	10.4	66.7	0.1

Table 10 . Estimated annual detention by or export from vegetated filter zones of nitrate nitrogen (minus sign indicates net export)

Site Name	Effective Filter Zone Area (ha)	Entering Filter Zone from Source Area (kg)	Detained in Filter Zone (kg)	Detained per Unit Area of Filter Zone (kg/ha)	Percent Entering the Filter Zone Detained (%)	Export From Filter Zone (kg)
OTRS Watershed I (dispersed)	1.380	2.0	0.0	0.0	2.0	2.0
OTRS Watershed II (dispersed)	0.090	1.8	1.1	11.7	58.0	0.8
OTRS Watershed I (channelized)	0.172	0.9	-0.9	-5.0	-90.9	1.8
OTRS Watershed II (channelized)	0.076	0.7	0.3	3.5	39.0	0.4
LWFL Dry-lot (dispersed)	0.036	130.3	62.9	1746.1	48.2	67.4
LWFL Detention Basin (dispersed)	0.064	7.7	-1.1	-17.4	-14.5	8.8
CEFS Boundary Ditch (dispersed)	0.073	27.2	6.4	87.2	23.4	20.9
CEFS Access Road (dispersed)	0.027	13.6	0.2	6.7	1.3	13.5
CEFS River Floodplain (dispersed)	0.021	0.4	0.2	10.8	53.1	0.2

Table 11. Estimated annual detention by or export from vegetated filter zones of total Kjeldahl nitrogen

Site Name	Effective Filter Zone Area (ha)	Entering Filter Zone from Source Area (kg)	Detained in Filter Zone (kg)	Detained per Unit Area of Filter Zone (kg/ha)	Percent Entering the Filter Zone Detained (%)	Export From Filter Zone (kg)
OTRS Watershed I (dispersed)	1.380	22.1	2.2	1.6	10.1	19.9
OTRS Watershed II (dispersed)	0.090	12.6	4.4	48.6	34.8	8.2
OTRS Watershed I (channelized)	0.172	29.0	-4.0	-23.5	-14.0	33.0
OTRS Watershed II (channelized)	0.076	17.3	6.2	81.2	35.7	11.1
LWFL Dry-lot (dispersed)	0.036	516.1	347.4	9650.2	67.3	168.7
LWFL Detention Basin (dispersed)	0.064	8.4	6.3	97.7	74.1	2.2
CEFS Boundary Ditch (dispersed)	0.073	45.6	18.5	253.8	40.7	27.0
CEFS Access Road (dispersed)	0.027	25.7	9.8	364.1	38.3	15.9
CEFS River Floodplain (dispersed)	0.021	1.0	0.4	17.5	38.3	0.6

Detention of Phosphorus

Estimated gravimetric loading of OP was less than 2 kg yr^{-1} for both OTRS FFZs. More OP left the access road FZ than entered for reasons not apparent (Table 12). Gravimetric loading of OP was highest in the dry-lot FZ where 71 % of the 383 kg yr^{-1} entering the FZ was detained. Detention of TP ranged from 16 % to 71 % for sites with dispersed flow (Table 13).

Three watersheds, the pasture site (not shown on Tables 8-13), access road site, and detention site showed negative reductions (more analytes leaving the FZ than entering) for all or most analytes. In each of these cases, due to topographic features, a large amount of runoff could not be captured and measured with the upper flume. In each of these watersheds, substantially more runoff flowed through the lower flume than through the upper. Considerably more runoff flowed through the lower flume than would have occurred due to the additional precipitation in the FZ alone (Table 4).

Table 12. Estimated annual detention by or export from vegetated filter zones of orthophosphorus (minus sign indicates net export)

Site Name	Effective Filter Zone Area (ha)	Entering Filter Zone from Source Area (kg)	Detained in Filter Zone (kg)	Detained per Unit Area of Filter Zone (kg/ha)	Percent Entering the Filter Zone Detained (%)	Export From Filter Zone (kg)
OTRS Watershed I (dispersed)	1.380	1.7	0.1	0.1	6.9	1.6
OTRS Watershed II (dispersed)	0.090	0.8	0.3	3.7	41.3	0.5
OTRS Watershed I (channelized)	0.172	1.7	0.1	0.5	5.0	1.6
OTRS Watershed II (channelized)	0.076	1.1	0.3	3.8	25.9	0.8
LWFL Dry-lot (dispersed)	0.036	383.2	272.7	7574.9	71.2	110.5
LWFL Detention Basin (dispersed)	0.064	4.6	1.0	15.7	21.9	3.6
CEFS Boundary Ditch (dispersed)	0.073	17.4	6.2	85.3	35.8	11.1
CEFS Access Road (dispersed)	0.027	16.8	-0.6	-21.4	-3.4	17.4
CEFS River Floodplain (dispersed)	0.021	0.3	0.2	10.2	63.6	0.1

Table 13. Estimated annual detention by vegetated filter zones of total phosphorus

Site Name	Effective Filter Zone Area (ha)	Entering Filter Zone from Source Area (kg)	Detained in Filter Zone (kg)	Detained per Unit Area of Filter Zone (kg/ha)	Percent Entering the Filter Zone Detained (%)	Export From Filter Zone (kg)
OTRS Watershed I (dispersed)	1.380	12.0	2.0	1.5	16.8	10.0
OTRS Watershed II (dispersed)	0.090	7.2	3.5	38.8	48.5	3.7
OTRS Watershed I (channelized)	0.172	16.3	0.8	4.6	4.9	15.5
OTRS Watershed II (channelized)	0.076	9.1	4.0	52.4	43.9	5.1
LWFL Dry-lot (dispersed)	0.036	449.3	320.3	8896.5	71.3	129.0
LWFL Detention Basin (dispersed)	0.064	5.4	1.4	21.3	25.3	4.0
CEFS Boundary Ditch (dispersed)	0.073	20.4	7.6	104.4	37.3	12.8
CEFS Access Road (dispersed)	0.027	21.5	3.5	130.0	16.3	18.0
CEFS River Floodplain (dispersed)	0.021	0.4	0.3	12.6	60.1	0.2

Thus, complete accounting for TSS and nutrient loading was not possible. However, examination of data for the detention-basin site indicates a steady improvement in performance. For the last six events, average reductions were positive for all but NO_3-N, even though accounting for other contributions to the FZ was not possible (Table 6). Immediately prior to construction of the level spreaders and associated instrumentation, the detention FZ was heavily grazed. One possibility for the apparent continued improvement in detention site FZ performance is flushing of nutrients from the FZ after abandonment from grazing and partial recovery of desired hydrologic characteristics of the FZ.

Sites with larger effective FZ area relative to source area were able to reduce TSS by at least 40 percent or more. Filter zones, (especially forested) more efficiently detain or retain courser sands and silts while fine materials of high specific surface area reach streams (Correll 1994) or at least are carried deeper into the FZ (Cooper and Gilliam 1986) where they can be more easily transported later to surface water or where nutrients and pesticides can be desorbed and transported. A goal in dispersing runoff is to convert channelized flow to sheet flow and thereby reduce transport capacity causing sediments and organic particulates to "drop out" sooner and at higher rates. However, no estimate was made on the effectiveness to detain specific soils fractions, especially clay and fine silts. Characteristics of fractions varies by soil series. Adsorbed nutrients and pesticides associated with these fractions will vary with series and with specific agricultural practices. Yet, ultimately, the effectiveness of a FZ to reduce sediment-associated nutrients and pesticides will be a function of the ability of a FZ to detain clays and other fines. Reducing transport capacity by reducing flow rates can be seen on hydrographs where lower flume peak flow rates are lower than upper (Figure 4).

Net Detention versus Net Export Events

The high loading of N, P and other nutrients associated with field drainage during precipitation events is well documented in many north temperate regions, particularly during planting and fertilizing activities (Burkholder and Bachmann 1979, Henderson-Sellers and Markland 1987, Coffey *et al*. 1989). Many lakes and impoundments in the southeast are phosphate-limited, and even a small amount of phosphate (ppb range) can stimulate algal growth in receiving Piedmont and Coastal Plain waters (Weiss and Kuenzler 1976). However, over time in the growing season, the algae in these systems can sufficiently deplete inorganic nitrogen so that the primary nutrient which stimulates algal growth may switch from P to N (Smith 1987). Algae are capable of sequestering some of sediment-adsorbed nutrients from the suspended sediments delivered by high precipitation events (Sonzogni *et al*. 1982, Grobbelaar 1983). Thus, nuisance blooms can result from simultaneous nutrient/sediment entry into surface waters during the growing season (Cuker *et al*. 1990, Burkholder and Cuker 1991). However, if nutrients can be detained by FZs during the growing season when field outputs are often higher and released during the cooler portions of the year, nuisance blooms may be reduced even if annual total through-puts from the FZs are not reduced.

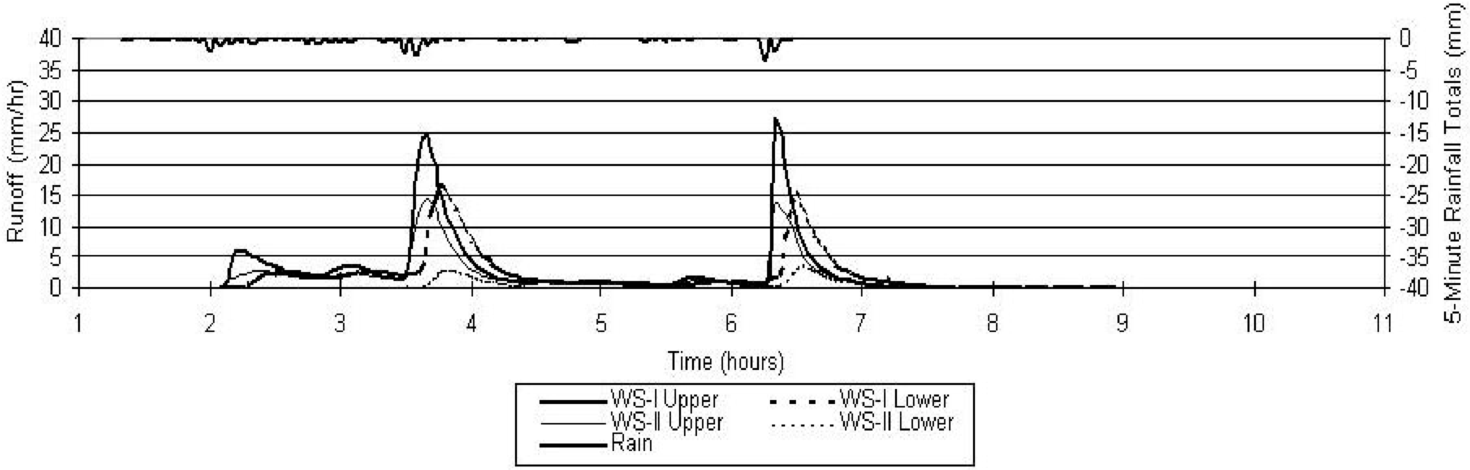

Figure 4. Stormflow for two events which occurred 1/5/93 with dispersed flow in the forested filter zones. Antecedent soil moisture was low prior to the first event.

On all sites, events occurred where FZ output exceeded input for all analytes (net export events). Chi-square comparisons of frequencies of net export events versus net retention events by season indicate a predominance of net export events in the first quarter - January through March (Table 14; Appendix Tables 1-6). Chi-square tests were significant for all analytes except OP. Factors which may contribute to this phenomenon include greater soil moisture levels due to lower evapotransporation rates, release of nutrients from fall leaf-drop, and loss of structural resistence to flow due to loss of annual herbaceous plants and dormancy of low perennials. An examination of means by quarters shows that the net export events are characteristically long steady often high total runoff volume events in which both input and output concentrations are low compared with net retention events. A disproportionately high number of both net retention and net export events occurred during the first quarter.

Analysis of Factors Affecting Filter Zone Performance

ter computing single variable models, analysis of variance was computed for mass retained using the following independent variables: filter zone, total input volume, peak flow rate, peak flow rate times total input volume, peak flow rate squared, total input volume squared, and mean concentration (appendix tables 19-30). Without inclusion of mean concentration, R-squares ranged from 0.25 to 0.87 (Table 15). With inclusion of mean concentration R-squares ranged from 0.77 to 0.93 except for TSS which only improved to 0.32 from 0.30.

Table 14. Percent occurrence of events by season and probability results from Chi-square comparisons for frequencies by season of net detention events versus net export events for total suspended solids (TSS), ammoniacal nitrogen (NH_4-N) , nitrate nitrogen (NO_3-N), total Kjeldahl nitrogen, orthophosphorus, and total phosphorus

Variable	% Events Occurring Jan-Mar	% Events Occurring Apr-Jun	% Events Occurring Jul-Sept	% Events Occurring Oct-Dec	Chi-Square Probability
TSS					0.0003
Net Retention	46	10	24	21	
Net Export	80	8	4	8	
NH_4-N					0.0106
Net Retention	51	11	20	19	
Net Export	81	9	3	6	
NO_3-N					<0.0001
Net Retention	44	7	26	23	
Net Export	83	9	7	2	
TKN					0.0007
Net Retention	46	11	23	20	
Net Export	80	4	4	11	
OP					0.1080
Net Retention	49	12	21	19	
Net Export	74	4	11	11	
TP					0.0038
Net Retention	50	10	21	19	
Net Export	86	7	7	0	

Table 15. R-squares and probability of a greater F value for analyses of variance for net detention (difference in input mass at the upper flume minus the output mass at the lower flume) for analytes in agricultural runoff flowing through vegetated filter zones as a function of storm runoff characteristics

Dependent Variable	With mean input concentration included as an independent variable R-square	Without mean input concentration included as an independent variable R-square
% reduction in TSS	0.301106	0.321687
% reduction in NH_4-N	0.254614	0.797909
% reduction in NO_3-N	0.867801	0.934834
% reduction in TKN	0.334543	0.766654
% reduction in OP	0.643126	0.875214
% reduction in TP	0.545877	0.781730

The ANOVAs for net retention of analytes suggested development of predictive regression models for net retention using these same variables. Most of these variables (total storm runoff, peak runoff rates, output concentrations from the fields or pastures) can be predicted from published models used to evaluate the impacts of crop and field management on storm runoff behavior. It was hoped that these variables could be used with FZ area to evaluate specific filter zones based on effective FZ area with and without level spreaders to predict the value of spreaders on a specific site. However, when these same independent variables were included in regression models, the regression coefficient for area became negative and non-significant for most analytes if input concentration was included as an independent variable. An examination of Pearson correlations of input concentrations and FZ area showed high significant positive correlations. An examination of ranking sites based on mean concentrations closely matched ranking sites by effective FZ size (Table 16). This chance occurrence of the site-selection process made evaluation of net retention based on FZ size impossible because net retention is highly correlated with input concentrations.

Table 16. Rank of sites (1 being the highest value and 8 being the lowest) for effective filter zone area and mean concentration of total suspended solids and nutrients in agricultural runoff

Site Name	Rank of Effective Filter Zone Area	Rank of Mean Concentrations					
		TSS	NH_4-N	NO_3-N	TKN	OP	TP
OTRS Watershed I (dispersed)	5	4	5	5	6	5	5
OTRS Watershed II (dispersed)	4	7	6	4	7	6	7
OTRS Watershed I (channelized)	8	5	7	7	4	7	6
OTRS Watershed II (channelized)	7	8	8	8	8	8	8
LWFL Dry-lot (dispersed)	2	2	2	1	2	2	2
LWFL Detention Basin (dispersed)	1	1	1	2	1	1	1
CEFS Boundary Ditch (dispersed)	3	6	3	3	3	3	3
CEFS Access Road (dispersed)	6	3	4	6	5	4	4

CHAPTER III

PERFORMANCE OF SPECIFIC TYPES OF LEVEL SPREADERS AND INSTALLATION AND MAINTENANCE COSTS

History

In 1989 and 1990, level spreaders were constructed in the receiving portion of forested filter zones of two agricultural watersheds on the Oxford Tobacco Research Station in Granville County North Carolina (Franklin *et al.* 1992). On each watershed, spreaders were constructed of treated wood on contour on both sides of the ephemeral channel. These experimental spreaders had a rectangular cross section to permit installation of flash-boards on any portion thus allowing evaluation of performance of the FFZs with varying spreader length.

The study demonstrated the feasibility of using level spreaders to disperse flow and improve FFZ performance. Although the experimental spreaders were very functional and have remained functional for more than ten continuous years, widespread adoption of level spreaders as a BMP will require designs and configurations that can be used on a variety of site conditions. Estimates on construction and maintenance costs are also required.

In 1997, Drs. Carlyle Franklin and James D. Gregory received US EPA Section 319 funding through the North Carolina Division of Water Quality (NC DWQ) to evaluate the cost and effectiveness of several level spreader designs and configurations. The following evaluation of spreader designs and configuration and costs of installation and maintenance were based on this study plus data from the original 1989 WRRI-funded Oxford study and from a recently funded study at the Oxford Tobacco Research Station.[1]

Objectives

The objectives of this research were:

1. Evaluate several designs and configurations for level spreaders for dispersing agricultural runoff.
2. Estimate construction and maintenance costs for several level spreader designs.
3. Estimate the cost per kilogram for retaining solids and nutrients within the filter zones utilized in this study by installing level spreaders.

Methods

Site conditions where level spreaders are needed to disperse channelized agricultural

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[1] "Evaluation of Three Best Management Practice for Reducing Non-Point Source Pollution from Piedmont Tobacco Fields." Proposal funded by University of North Carolina Water Resources Research Institute. E. Carlyle Franklin, Principal Investigator. Funded April 2000.

runoff may vary considerably from grass sod along field edges or waterways to forests with closely spaced trees and large tree roots. Available equipment for construction and installation of level spreaders may vary in size and function. Several potential spreader designs were selected to evaluate spreader performance and to determine costs of installation and maintenance. For each watershed, records of materials, labor, and equipment were kept to determine installation costs. During data collection and other site visits, problems were noted and maintenance records kept.

Topography of each site determined the number of spreaders to be constructed. Where the ephemeral channel or ditch was near the center of the potential FZ, two spreaders were constructed to disperse flow on contour to both sides of the channel. Where potential FZ was completely or mostly on one side of the channel, only one spreader was constructed. In the case of the detention site, the potential FZ was narrow along the contour but long down-slope. One spreader was constructed in the upper portion of the FZ and a second spreader was constructed down-slope to redisperse runoff after rechannelization below the first spreader.

To estimate installation and maintenance costs $8 per hour labor rates were used. Where specialized equipment such as ditch excavators were used, actual rental charges were used. Where farm tractors were used, a rate of $50 per hour was used as an average per hour cost for acquiring, operating, and maintaining a 75 horsepower farm tractor.

Types of Level Spreaders Evaluated

Four types of spreaders were tested: treated wood on a gravel bed, galvanized gutters on treated wood stakes, fabric-lined trench with level gravel “lip,” and a berm and trench shaped from soil (Table 17).

Table 17. Type of spreader constructed, number of spreaders per channel, and total spreader length for instrumented and non-instrumented sites tested

Site Name	Type Spreader Constructed	Number of Spreaders	Total (m)
OTRS Watershed I forested filter zone	Treated wood on gravel bed	2	43.9
OTRS Watershed II forested filter zone	Treated wood on gravel bed	2	61.0
OTRS Watershed I grass filter zone	Berm and trench	2	42.1
OTRS Watershed II grass filter zone	Berm and trench	2	31.4
LWFL Pasture	Galvanized gutters on treated wood stakes	1	146.3
LWFL Drylot	Galvanized gutters on treated wood stakes	1	96.6
LWFL Detention Basin	Fabric-lined trench with gravel "lip"	2	100.2
LWFL Non-instrumented Site	Berm and trench	1	41.8
CEFES Boundary Ditch	Galvanized gutters on treated wood stakes	1	147.9
CEFES Access Road	Fabric-lined trench with gravel "lip"	1	86.9
CEFES River Floodplain	Fabric-lined trench with gravel "lip"	1	90.0

Treated Wood on Gravel Bed: Level spreaders were constructed and installed on both watersheds at OTRS in late 1989 and have been continually in use to date. Level spreaders were constructed as 2.44 m (8 ft) sections made from treated lumber (Figure 5). Each section had a lower down-slope edge so that runoff only overflowed on the down-slope side. Cross-sectional area was 194 cm^2. A elevation contour was selected and flagged on which to install the spreaders. Surface obstructions were removed and a shallow depression was excavated along the length and filled with gravel to provide a

Figure 5. Level spreader made from treated wood installed at the Oxford Tobacco Research Station

stable bed for the spreader and to allow runoff from up-slope to flow under the spreader. Each section was mounted using u-bolts on vertical 5.08 cm diameter pipes driven into the ground. Initial leveling was done with a masonry level and final leveling was done using a construction level. Aluminum flashing was used to join and seal sections.

Galvanized Gutters Mounted on Treated Wood Stakes: Semicircular galvanized roof gutters were tested as a "prefab"-type level spreader on the pasture, dry-lot, and boundary ditch sites. On each site, the first sections (sections closest to the ephemeral channel) were 20.32 cm in diameter and a 3.05 m in length. Cross-sectional area of these first sections was 81 cm^2. Gutter sections were attached onto cradles cut from treated plywood with wood screws (Figure 6). The cradles were then attached with screws onto vertical treated-wood stakes after leveling with a masonry level. The spreaders were mounted 2 to 10 cm above ground depending on microtopographic variation. On the pasture site and boundary ditch sites, 20.32-cm diameter gutters were used for the entire spreader length. On the dry-lot site, 20.32-cm diameter gutters were used for the first 46.3 m and 15.24-cm diameter gutters were used for the last 50.3 m.

Fabric-lined trench with gravel lip: Two methods were tested to construct level spreaders by excavating a trench and then lining the trench with erosion fabric for stability. On the detention site, a triangular cross sectional trench was made by using first breaking the cattle-compacted ground with a walk-behind trench excavator. Then a three-point hitch-mounted blade mounted at a 45-degree angle relative to ground plane was

Figure 6. Level spreader made from galvanized gutters installed at the Pasture Site at the North Carolina State University Field Laboratory

used on repeated trips along the length of the spreader to create an average top width of 60 cm on the upper spreader and 35 cm on the lower spreader. Loose soil was removed by hand shovels and the trench was lined with fabric. A portion of the loose soil was deposited on the down-slope surface, leveled with a masonry level, and tamped to create a level lip. Gravel was placed over the fabric on both the up- and down-slope edges (Figure 7).

At the access road site, a 15.24 cm wide rectangular trench 30 cm in depth was excavated with a walk-behind ditch excavator. Loose soil was removed by shovel. The trench was lined with fabric and rock was placed over the fabric on both up- and down-slope sides of the trench. Average cross-sectional area was 450 cm^2.

Trench and Berm: None of the spreaders described above could be crossed with farm or other equipment. In an attempt to develop a design that can be employed where farm or other vehicle traffic is necessary, a “berm and trench” design was tested in the grass filter zones at OTRS and at an uninstrumented site at the NCSU Lake Wheeler Field Laboratory. At the Lake Wheeler Laboratory, relatively uncompacted soil was shaped into a combination berm and trench with a three-point hitch-mounted blade (Figure 8). The structure was essentially a low berm with a shallow trench on the up-slope side. Final leveling was done with hand tools. All exposed soil was covered with erosion fabric, seeded with grass, and then covered with straw. Average cross-sectional area of the combination shallow trench with down-slope berm was approximately 900 cm^2. On

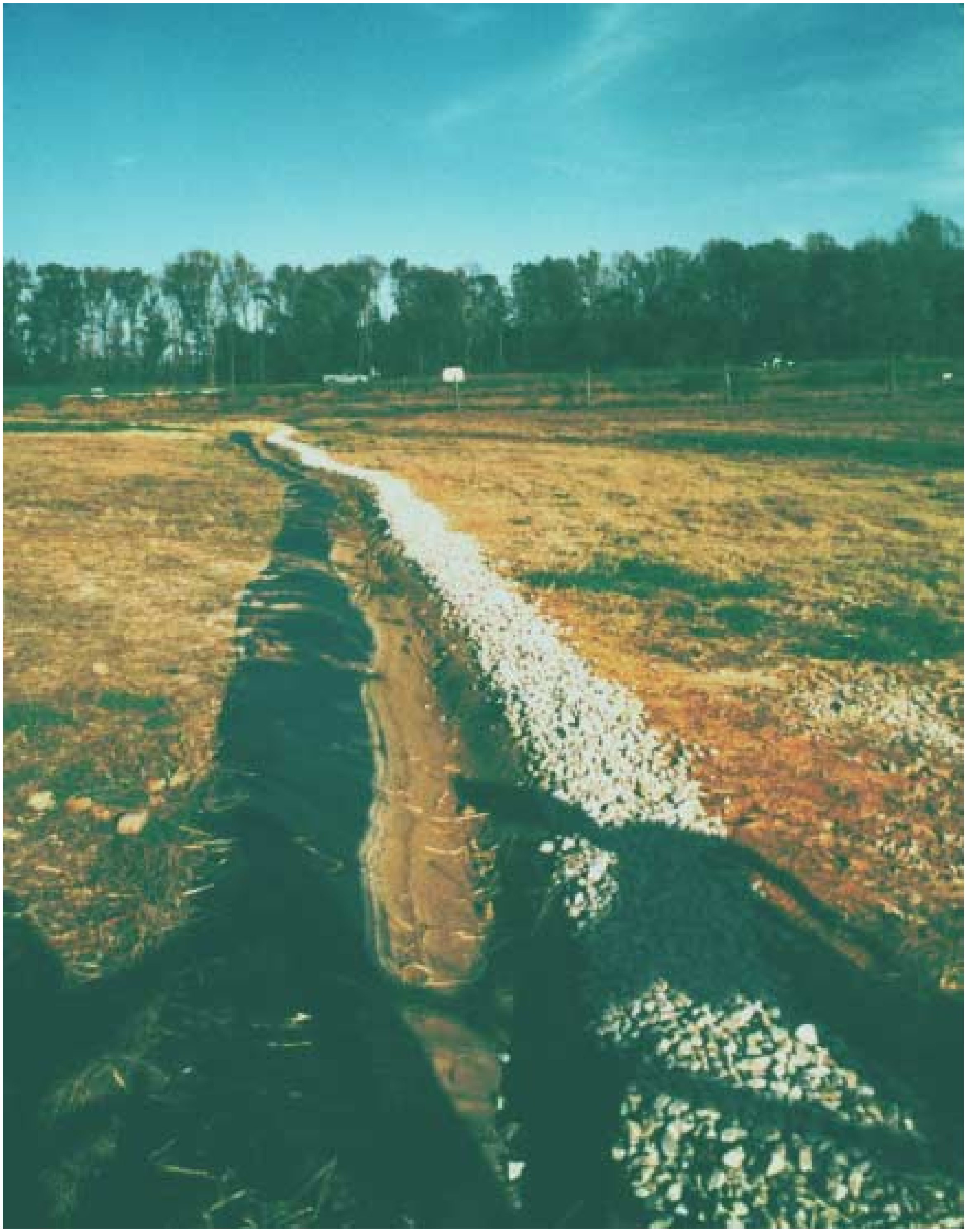

Figure 7. Trenched level spreader at the Detention Site at the North Carolina State University Lake Wheeler Road Field Laboratory.

Figure 8. Trench and berm level spreader installed at the North Carolina State University Lake Wheeler Road Field Laboratory.

the OTRS I and II sites, a disk harrow was first used to break up compacted spoil and grass sod before shaping with the three-point hitch blade.

Results and Discussion

Spreaders were observed on each during runoff events of varying flow rates. Each type tested dispersed channelized runoff. However, several of the sites with smaller cross-sectional spreaders appeared to disperse most runoff (but an unknown portion) in the first 15 to 20 meters. These sites included: the dry-lot site, the boundary ditch site, and the access road site. Although the pasture site had the same spreader cross section as the dry-lot and boundary ditch sites, peak rates were sufficiently low that the spreaders flowed over most of the length. Flows in excess of about 75 m^3 hr^{-1} appeared to mostly overflow gutter-type spreaders within the first 15 m and flows in excess of about 150 m^3 hr^{-1} appeared to mostly overflow the treated wood spreaders within the first 10 m. The net result of having a major portion of the spreader being minimally functional is a reduction in the effective FZ area, as discussed in Chapter II.

Construction and installation costs were comparable for all but the fabric-lined trench spreader type which was about half the cost of the other three types (Table 18). All types were labor intensive because of the requirement that level spreaders indeed be “level” and structurally stable. Although no type is inexpensive, it should be noted that each type tested is intended with maintenance to be a permanent BMP. In the case of OTRS, the spreaders were continuously functional for over 10 years.

Table 18. Material, labor, and equipment costs to construct level spreaders of different designs

Spreader Design	Material ($ per m)	Labor ($ per m)	Equipment ($ per m)	Total ($ per m)
Treated wood on gravel bed	8.76	4.94	0.00	13.70
Galvanized gutters on treated wood stakes	6.07	5.45	0.00	11.52
Fabric-lined trench with gravel "lip"	2.01	3.41	1.23	6.65
Berm and trench	4.08	2.04 - 6.35	1.82 - 2.04	5.94 - 10.47

Table 19. Principal maintenance needs and estimated annual maintenance costs for level spreaders of different designs

Spreader Design	Maintenance Activity	Total Annual ($per m)
Treated wood on gravel bed	grass trimming, leaf cleaning, sediment removal	0.38
Galvanized gutters on treated wood stakes	grass trimming, leaf cleaning, sediment removal	0.19
Fabric-lined trench with gravel lip	grass trimming, sediment removal	0.12
Berm and trench	mowing	NA*

* At time of writing, no maintenance had been performed on any of this type.

Maintenance costs ranged from \$.12 to \$.38 per m per year (Table 19). Most maintenance costs were associated with cleaning debris or trimming with a string trimmer (where spreaders are in open sunlight). The more flow-constricted gutter and treated-wood types were the most likely to clog from dead leaves, growing grass, or in open sunlight - algae. These types also may require annual removal of sediment if they receive sediment-laden runoff. Trench-type spreaders needed an annual mowing and biennial sediment removal. Maintenance costs are were associated with location factors. As an example, OTRS I spreaders were located under sweetgum (*Lireodendron styraciflua* L.) trees and required frequent removal of "gum balls." The gutters were especially subject to damage from falling limbs or trees or traffic from tractors or all-terrain vehicles.

Total annual costs for level spreaders for seven sites were estimated using a 20-year life expectancy, a 5 % discount rate, and functional spreader length. No inflation factor for maintenance costs was used (Table 20). Costs ranged from \$9.75 per year where only 15 m of spreader length was functional to \$90.28 per year at OTRS II where the full 61 m length was functional. Costs for detaining each kilogram of analyte was computed for the same seven sites by dividing estimated annual costs (Table 20) by the annual estimated detention experienced (Table 21). Costs per kilogram of TSS were \$.41 or less for all sites. Costs for the dry-lot site where annual loading is high were \$.28 per kg or less for all analytes. Costs for all N and P analytes at Oxford exceeded \$20 due to long spreaders, but low N and P annual loading.

Table 20. Total estimated annual costs for level spreader installation and maintenance on seven sites assuming a 20-year service life and a five percent discount rate

Site Name	Effective Length of Spreader (m)	Amortized Annual Construction Costs ($/m)	Annual Maintenance Costs ($/m)	Total Annual Cost ($)
OTRS Watershed I	43.9	1.10	0.38	64.97
OTRS Watershed II	61.0	1.10	0.38	90.28
LWFL Dry-lot	16.0	0.92	0.19	17.76
LWFL Detention Basin	100.2	0.53	0.12	65.13
CEFS Boundary Ditch	16.0	0.92	0.19	17.76
CEFS Access Road	15.0	0.53	0.12	9.75
CEFS River Floodplain	27.0	0.53	0.12	17.55

Table 21. Costs per kilogram per year for detention of pollutants from agricultural runoff by installing and maintaining level spreaders

Site Name	TSS ($/kg)	NH_4-N ($/kg)	NO_3-N ($/kg)	TKN ($/kg)	OP ($/kg)	TP ($/kg)
OTRS Watershed I	0.03	158.47	1624.30	29.14	541.43	32.16
OTRS Watershed II	0.04	138.89	85.98	20.66	273.58	25.87
LWFL Dry-lot	0.01*	0.10	0.28	0.05	0.07	0.06
LWFL Detention Basin	0.41	187.23	**	10.41	65.01	47.76
CEFS Boundary Ditch	0.01	3.15	2.79	0.96	2.85	2.33
CEFS Access Road	0.01*	**	53.82	0.99	**	2.78
CEFS River Floodplain	0.33	80.64	77.53	47.71	82.28	66.09

* Costs are less than $0.01 per kg.

** No cost per kg was computed due to estimated annual net export.

CHAPTER IV

CONCLUSIONS AND RECOMMENDATIONS FOR USE OF VEGETATED FILTER ZONES AND FOR ENHANCING FILTER ZONE PERFORMANCE WITH LEVEL SPREADERS

Vegetated Filter Zone Performance

Performance of filter zones is a function of many factors including: FZ size relative to input volumes and concentrations; runoff rates relative to FZ size; vegetative cover type and condition; concentration of pollutants in runoff; and the effective size of the zone. The three factors which can be most manipulated to improve FZ performance are effectiveness of the level spreaders, vegetative cover and effective size of the zone. Vegetation type and condition can be managed in the long-term through planting of desirable species, thinning or removal of the overstory, and perhaps through mechanical means such as mowing. However, the most immediate improvement that can be made on many filter zones is increasing effective size through dispersing channelized flow within the zone by installing level spreaders.

Even though many of the spreaders tested were only partly functional, all filter zones without large unaccounted-for runoff contributions removed or detained solids and nutrients. Four of the zones which conclusively demonstrated removal or detention (dry-lot, detention, boundary ditch, flood-plain) were made functional only through installation of level spreaders which dispersed otherwise completely channelized (ditched) storm runoff. In the case of both watersheds at OTRS where runoff was not entirely channelized prior to installation of level spreaders, dispersing runoff with spreaders approximately doubled the ability of the zones to reduce TSS and nutrients passing through them.

A general positive relationship existed between retention capacity of a FZ and size of the FZ relative to the size of the source. Filter zones where FZ area was greater than two percent of source-area size generally removed a least a third of each analyte. An exception was OTRS I where the FZ area receiving runoff was 4.6 percent of the source area, yet the FZ was relatively ineffective in removing nutrients. One possibility for the lack of effectiveness is that the predominance of seasonally saturated soils along the ephemeral channel reduced infiltration (Franklin *et al*. 2000). Another exception was the boundary ditch site which performed relatively well in spite of a low FZ to source area ratio. In this case the large storage capacity of the ditch above the upper flume reduced flow rates to the relatively small FZ and created long, low-flow runoff events.

The North Carolina Environmental Management Commission adopted the Neuse River Sensitive Waters Management Strategy in December 1997 designed to achieve a 30 percent reduction in nitrogen. Of the six sites with dispersed flow which did not have large unaccounted contributions to the FZ, only OTRS I failed to reduce N by 30 percent.

The detention characteristic of FZs demonstrated by this study may be one of the most significant functions of FZs. The FZs studied largely detained sediment and nutrients during the high concentration events of the warm seasons and released them in low concentrations during the cool season when nuisance algal blooms in surface waters do not occur. This cool season release indicates that seasonal releases provided for seasonal renewal of detention capacity of the filter zone. Others have expressed concern regarding the need for renewal of retention capacity and have suggested periodic timber harvesting as a solution (Lowrance *et al*. 1984c). However, releases of nutrients in surface flow in winter events and N losses due to denitrification, indicate a continual renewal of the detention capacity of FZs. Dispersed flow may be expected to enhance this detention capacity.

Performance and Costs of Level Spreaders

The types of spreaders tested were capable of serving as permanent functional FZ enhancers. Commercial gutters and treated wood spreaders have special application where soil moving equipment use is not feasible. Spreader types can also be used in combination, such as where a grass zone is on one side of the ephemeral channel and closely-spaced trees are on the other. The different designs for the level spreaders can be combined to enhance efficiency. For example, a level spreader can start at the channel as a fabric-lined trench in a grassed zone, and then continue as a gutter-type at the distant end in a forested zone.

Spreaders are especially cost effective where high loading is expected such as on erodible soils being tilled or where concentrated animal wastes enter the FZ. Annual maintenance costs are considerably less than initial installation costs. Servicing and repair was neither especially time consuming nor expensive, monthly inspections were required to detect and correct deficiencies.

Recommended Configuration of Level Spreaders

Level spreaders must be constructed in configurations to take advantage of potential filter zone area. Where an ephemeral channel or ditch enters a potential FZ near the center of that zone, spreaders should be constructed on both sides of the channel or ditch (Figure 9). Examples from this study include OTRS I and II. Where the ephemeral channel or ditch is located on one side of the potential FZ, the spreader must be constructed as a single spreader only on one side (Figure 10) as was done on the pasture site, dry-lot site, boundary ditch site, access road site, and Little River flood plain site. This obviously doubles the peak loading of the spreader compared to a double spreader configuration. This must be considered in the selection of the spreader type and cross-sectional area.

Areas available for FZs have differing shapes. On long (downslope length) narrow filter zones, spreaders can be constructed in tandem (Figure 11) as was done on the detention-basin site. Tandem spreaders are appropriate where rechannelized runoff from an upslope spreader can be redispersed to take advantage of additional potential filter zone.

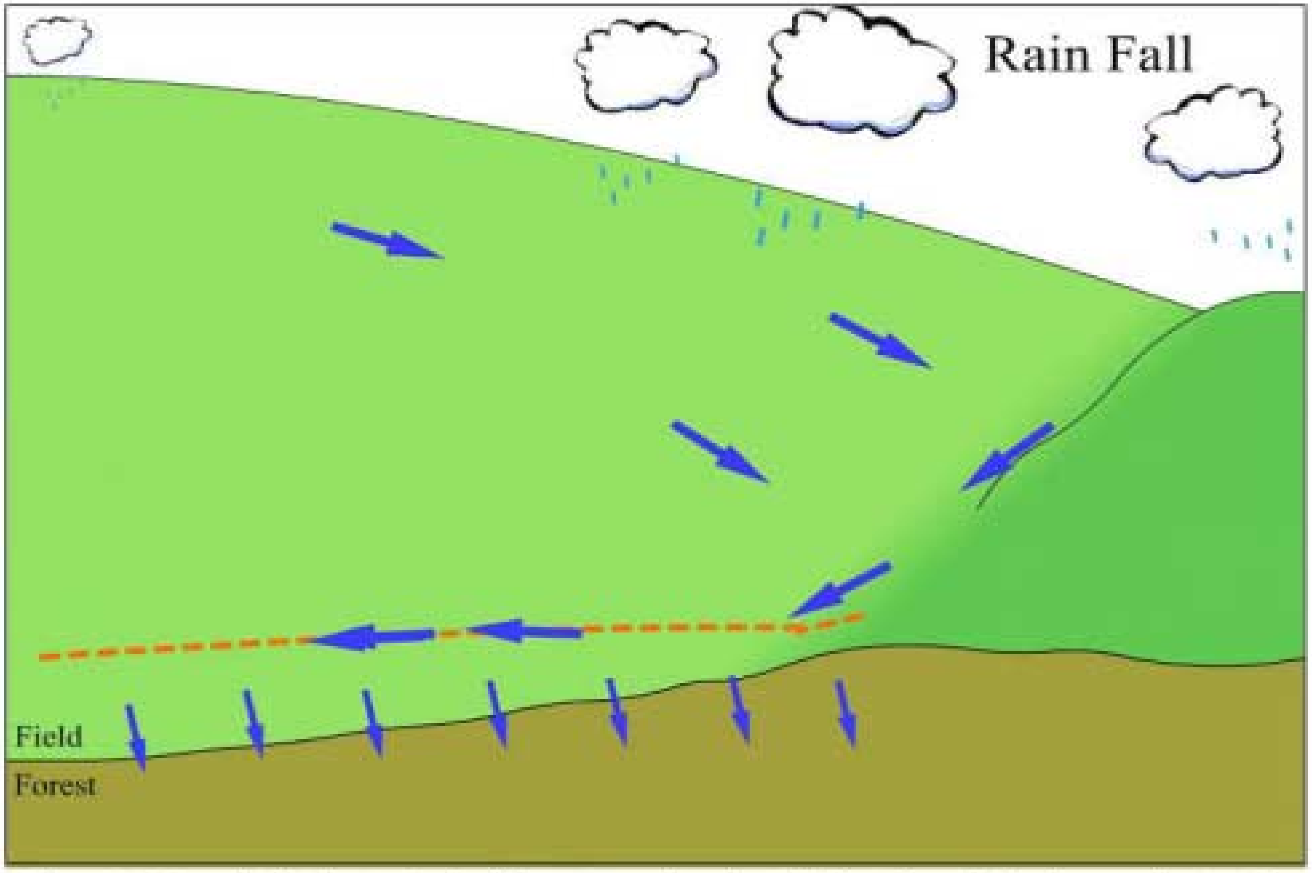

Figure 9. Hypothetical watershed with contours showing the location of a level spreader to only one side of the ephemeral channel

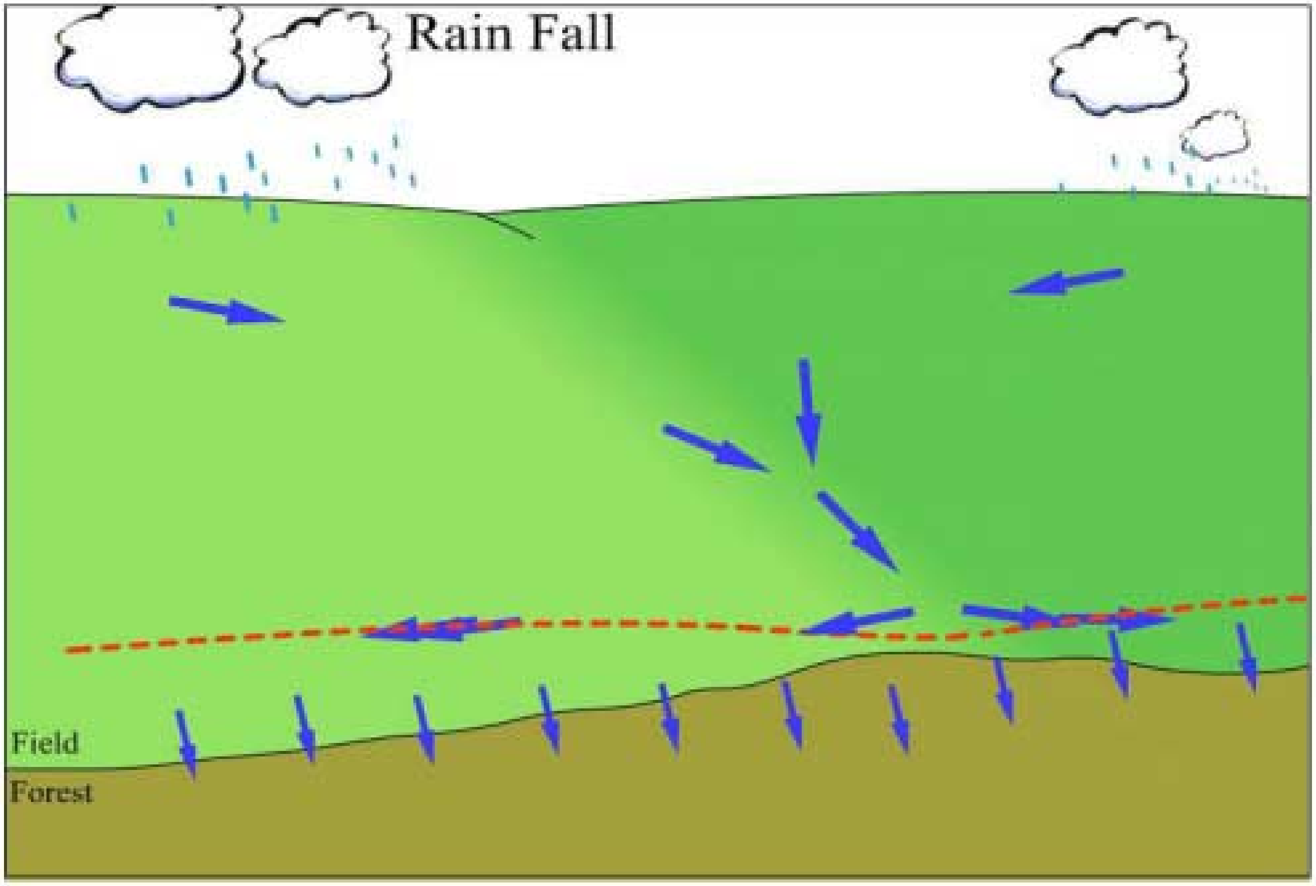

Figure 10. Hypothetical watershed with contours showing the location of level spreaders on both sides of the ephemeral channel

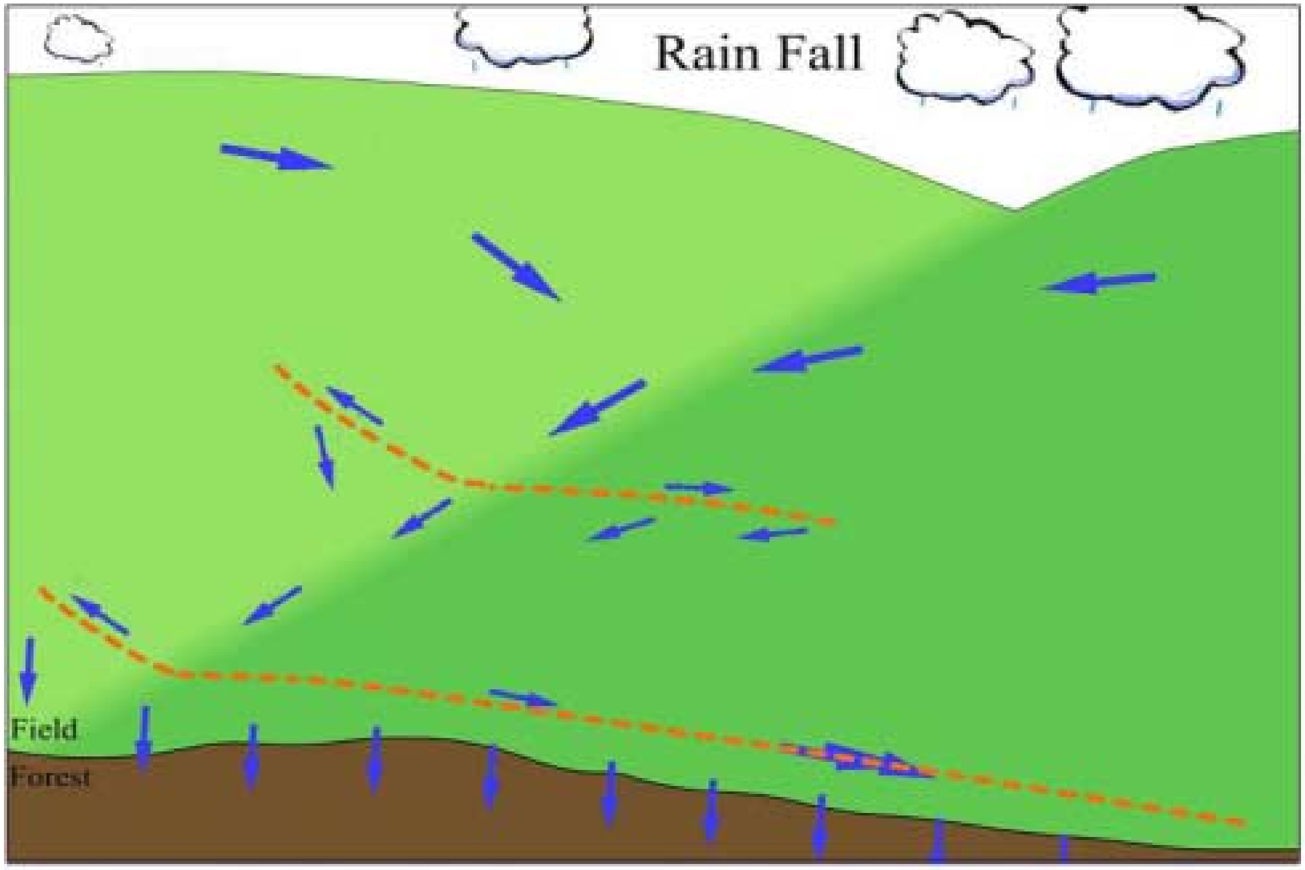

Figure 11. Hypothetical watershed with contours showing the location of level spreaders in tandem on one side of the ephemeral channel.

Recommendations for Determination of Cross-sectional Areas

The major limitation to the functioning of the spreaders used in this study was their limited cross-sectional area at the receiving portion of the spreader. Bernoulli's equation (Vennard and Street 1976) can be used to design spreaders for the large predicted storm runoff peak rates for a given watershed, such as a two-year return-period storm For spreaders recommended for this study, the spreader is functionally an open channel, thus both equations apply. Any of several field models can be used to estimate peak flow rates for a given set of field and storm parameters. Velocity can then be determined for an expected peak rate for an entrance cross section that can be reasonably used given topographic and other limitations using Q = VA, where:

where: Q = runoff rate (m^3 s^{-1})
V = Velocity (m s^{-1})
A = cross sectional area of entrance (m^2)

For example, it may be determined that no more than 0.2 m of depth in the spreader is desirable and that a spreader entrance width of no more than 1.0 m is desired. Thus, a maximum cross sectional area of 0.2 m^2 would be possible for a rectangular cross-section spreader. Velocity could then be determined for a predicted peak flow rate.

Several cross sections areas may be tested to result in a velocity that is not excessive (perhaps less than 2 meters per second). Then Bernoulli's equation can be used to determine cross sectional area for a spreader with uniform slope at a given length of the spreader.

Bernoulli's equation is: $p_1/\gamma + V_1^2/2g_n + z_1 = p_2/\gamma + V_2^2/2g_n + z_2$

where: p_n is pressure at point n on the spreader

V_n is velocity at point n

γ is the weight density of water

g_n is the force of acceleration due to gravity

z_n is the height above datum at point n

For a spreader of uniform depth, γ and p are constant and cancel, thus allowing the solution of V at the second point (some distance down the spreader from the entrance or other point where V has been calculated). The A can be determined from A = Q/V and the cross section determined.

Determining cross sections at several points for a level spreader with a slight slope (less than or equal to 1 %) will give the dimensions at which overflow will occur throughout the length for the velocity of the predicted determining event. Flows less than the V used to size the spreader will result in more flow overflowing at the section furthest from the entrance. Flows greater than that V will result in a disproportionate volume overflowing nearest the entrance. Where rechannelization due to topography below the spreader is expected, it should be noted that the end furthest from the entrance will usually provide the longest flow path, and hence greatest opportunity for treatment, back to the ephemeral channel.

As an example using Q = VA, the entrance cross-sectional area to the dry-lot spreader in this study was 0.061 m^2 which resulted in a peak velocity of 2.231 m s^{-1} for a larger storm with a peak rate of 0.138 m^3 s^{-1}. If a 0.279 m^2 cross section had been used, the same peak would have produces a velocity of only 0.496 m s^{-1}.

Using Bernoulli's equation with a 1 % slope, the cross sectional area at 10 m would have to be 0.047 m^2 for a spreader with an entrance cross section of 0.279 m^2.

Typical and Special Conditions for Use of VFZs and Level Spreaders

An ideal FZ system may well be a combination of a grassed, upland forested, and riparian-like forested filter zone. Where only grassed waterways or field-edge FZs are available, year-round deep rooted grasses are preferred. Tandem level spreaders may be required at several points to improve runoff-FZ contact, especially in waterways.

Course sediment fractions will be deposited in a well maintained up-slope field edge zone. Flow will then be introduced to the upland portion where infiltration in the relatively deep soils would be high. Old stump holes and root channels will further increase infiltration of surface runoff. Nitrate in subsurface flow will be denitrified in the lower upland and riparian zones where a combination of reducing conditions and the presence of dissolved organic carbon promote denitrification. Installation of level spreaders in any zone with mostly channelized flow is appropriate. However, less than ideal conditions usually exist and must be used. Treatment of NPSP with VFZs requires a strategy of using whatever types of zones are available when they are available and improving them when possible and reasonable.

Piedmont

Because of sloping topography near riparian zones, a forested zone with upland soils often exists up-slope from the riparian zone. Dispersing channelized flow in the upper receiving portion of the upland zone provides the best opportunity for infiltration and treatment. Where an available grass zone exists above the upland forested zone, level spreaders may be installed to take advantage of their treatment characteristics. Recent research has demonstrated that detention of TSS varies seasonally and differently in grass and forested FZs, suggesting that use of both is a good strategy (Franklin *et al*. 2000b). If dispersed flow in the grassed zone will rechannelize before the FFZ, then runoff may be redispersed above the FFZ.

Where no upland zone exists, a portion of the adjacent field or pasture can be planted with trees to establish an upland zone. Over time, this zone will present more structural resistance to flow than grass and will have higher infiltration as litter layers develop and as root channels from dying roots develop. Deeper incorporation of dissolved organic carbon will promote denitrification (Verchot 1995c). Where establishment of this enlarged up-slope zone presents shading or root competition problems for fields, woody shrub species can be planted closest to the field edge. As distance from the field edge increases, increasingly taller species can be planted. Such plantings will improve wildlife habitat, aesthetics, and recreation potential as well as improving water quality.

Upper Coastal Plain

Many fields in the upper Coastal Plain have upland areas near the field edge. Like on Piedmont watersheds, the best opportunity for treatment of runoff is by using the upland zone to the extent feasible, typically including installation of level spreaders. Grassed zones, with spreaders, likewise should be used when available. Many upper Coastal Plain fields will have no upland FFZ above the riparian zone. In these level fields, storm flow is frequently channelized in ditches. In these cases, the only opportunity to disperse flow with level spreaders may be at the field/riparian zone edge. It must be recognized that dispersing flow immediately above a riparian zone may accomplish little when soils are saturated allowing no infiltration.

Lower Coastal Plain

Tiled field drainage systems and ditched drainage systems in the lower Coastal Plain often present special problems. Frequently the outlet for such systems is deep into the riparian zone and cannot be changed. Compared with the upper Coastal Plain, relatively fewer opportunities to use level spreaders exist. Osborne and Kovacic (1993) and Schultz *et al*. 1995 have each proposed establishment of wetland filters within riparian FFZs for drainage outfalls. Both designs have merit and should reduce nutrient input into surface water except where such wetlands must be constructed in floodplains. During times of ponding in the floodplain, nutrients will be essentially emptied directly into surface water. However, when used in conjunction with subirrigation (Skaggs *et al*. 1978) where water in tiles or ditches is raised to promote denitrification in the fields during winter, this drawback will be partly eliminated.

Summary

Level spreaders should be constructed at any location where channelized runoff containing sediments or nutrients enters a potential FZ and where the effective filter zone area can be substantially increased by dispersing runoff. Spreaders may not be appropriate where runoff will reconcentrate a short distance downslope or where spreaders will distribute runoff into flood plains where soils will be frequently saturated.

Several general recommendations can be made based on these studies:

S Use existing or created filter zones to reduce NPSP in runoff from agricultural sources. Some crop area may have to be abandoned from agriculture to provide adequate filter zone area.

S Use level spreaders to disperse channelized runoff to increase effective area of the FZ.

S Use or create filter zones where effective area is at least three percent of source area. Factors such as low infiltration of FZ soils, steep slopes, and high pollutant concentrations may indicate a need for even larger filter zones, perhaps as much as ten percent of source area.

S Construct level spreaders with sufficiently large cross-sectional area so that flow will not be too constricted for large events and so the entire length will be effective.

S Use up-slope BMP’s such as well-maintained waterways and minimum tillage to reduce flow rates and concentrations of runoff entering the filter zones.

S Install berm and trench level spreaders in areas open enough to accommodate tractors for construction and where vehicle traffic over the spreaders is necessary. These spreaders must be installed where sufficient sunlight will permit an adequate sod cover to be established.

S Where relief is minimum, such as in Coastal Plain filter zones, install trench level spreaders to avoid ponding runoff that would occur with berm and trench spreaders on relatively flat filter zones.

S Where use of equipment is impractical, such as in forests, use gutter or treated wood spreaders that can be installed above ground.

S Inspect all level spreaders monthly to detect and correct problems.

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APPENDIX TABLES

Table 1. Chi-square analysis comparing events where more suspended solids entered the filter zone that were removed in runoff (net detention) with events where more were removed in runoff than entered (net export)

Frequency Percent Row Pct Col Pct	Jul-Sep	Sep-Dec	Apr-Jun	Jan-Mar	Total
Net Export Events	2	4	4	40	50
	1.08	2.16	2.16	21.62	27.03
	4.00	8.00	8.00	80.00	
	5.88	12.50	23.53	39.22	
Net Retention Events	32	28	13	62	135
	17.30	15.14	7.03	33.51	72.97
	23.7	20.74	9.63	45.93	
	94.12	87.50	76.47	60.78	
Total	34	32	17	102	185
	18.38	17.30	9.19	55.14	100.00

Statistic	DF	Value	Prob
Chi-Square	3	18.9205	0.0003
Liklihood Ratio Chi Square	3	21.4094	<.0001

Table 2. Chi-square analysis comparing events where more ammoniacal nitrogen entered the filter zone than was removed in runoff (net detention) with events where more was removed in runoff than entered (net export)

Frequency Percent Row Pct Col Pct	Jul-Sep	Sep-Dec	Apr-Jun	Jan-Mar	Total
Net Export Events	1	2	3	27	33
	0.70	1.40	2.10	18.88	23.08
	3.03	6.06	9.09	81.82	
	4.35	9.09	20.00	32.53	
Net Retention Events	22	20	12	56	110
	15.38	13.99	8.39	39.16	76.92
	20.00	18.18	10.91	50.91	
	95.65	90.91	80.00	67.47	
Total	23	22.00	15	83	143
	16.08	15.38	10.49	58.04	100.00

Statistic	DF	Value	Prob
Chi-Square	3	11.2275	0.0106
Liklihood Ratio Chi Square	3	13.1425	0.0043

Table 3. Chi-square analysis comparing events where more nitrate nitrogen entered the filter zone than was removed in runoff (net detention) with events where more was removed in runoff than entered (net export)

Frequency Percent Row Pct Col Pct	Jul-Sep	Sep-Dec	Apr-Jun	Jan-Mar	Total
Net Export Events	3	1	4	38	46
	1.95	0.65	2.60	24.68	29.87
	6.52	2.17	8.70	82.61	
	9.68	3.85	33.33	44.71	
Net Retention Events	28	25	8	47	108
	18.18	16.23	5.19	30.52	70.13
	25.93	23.15	7.41	43.52	
	90.32	96.15	66.67	55.29	
Total	31	26	12	85	154
	20.13	16.88	7.79	55.19	100.00

Statistic	DF	Value	Prob
Chi-Square	3	23.4396	<.0001
Liklihood Ratio Chi Square	3	27.4601	<.0001

Table 4. Chi-square analysis comparing events where more Kjeldahl nitrogen entered the filter zone than was removed in runoff (net detention) with events where more was removed in runoff than entered (net export)

Frequency Percent Row Pct Col Pct	Jul-Sep	Sep-Dec	Apr-Jun	Jan-Mar	Total
Net Export Events	2	5	2	36	45
	1.12	2.79	1.12	20.11	25.14
	4.44	11.11	4.44	80.00	
	6.06	15.63	11.76	37.11	
Net Retention Events	31	27	15	61	134
	17.32	15.08	8.38	34.08	74.86
	23.13	20.15	11.19	45.52	
	93.94	84.38	88.24	62.89	
Total	33	32	17	97	179
	18.44	17.88	9.50	54.19	100.00

Statistic	DF	Value	Prob
Chi-Square	3	16.9277	0.0007
Liklihood Ratio Chi Square	3	18.7671	0.0003

Table 5. Chi-square analysis comparing events where more orthophosphorus entered the filter zone than was removed in runoff (net detention) with events where more was removed in runoff than entered (net export)

Frequency Percent Row Pct Col Pct	Jul-Sep	Sep-Dec	Apr-Jun	Jan-Mar	Total
Net Export Events	3	3	1	20	27
	1.73	1.73	0.58	11.56	15.61
	11.11	11.11	3.70	74.07	
	9.09	9.68	5.56	21.98	
Net Retention Events	30	28	17	71	146
	17.34	16.18	9.83	41.04	84.39
	20.55	19.18	11.64	48.63	
	90.91	90.32	94.44	78.02	
Total	33	31	18	91	173
	19.08	17.92	10.40	52.60	100.00

Statistic	DF	Value	Prob
Chi-Square	3	6.0764	0.1080
Liklihood Ratio Chi Square	3	6.4618	0.0912

Table 6. Chi-square analysis comparing events where more total phosphorus entered the filter zone that was removed in runoff (net detention) with events where more was removed in runoff that entered (net export)

Frequency Percent Row Pct Col Pct	Jul-Sep	Sep-Dec	Apr-Jun	Jan-Mar	Total
Net Export Events	2	0	2	24	28
	1.10	0.00	1.10	13.19	15.38
	7.14	0.00	7.14	85.71	
	5.88	0.00	11.76	23.76	
Net Retention Events	32	30	15	77	154
	17.58	16.48	8.24	42.31	84.62
	20.78	19.48	9.74	50.00	
	94.12	100.00	88.24	76.24	
Total	34	30	17	101	182
	18.68	16.48	9.34	55.49	100.00

Statistic	DF	Value	Prob
Chi-Square	3	13.4295	0.0038
Liklihood Ratio Chi Square	3	17.9839	0.0004

Table 7. Analysis of variance for the dependent variable TSS-difference (difference between total suspended solids mass entering the filter zone in runoff and total suspended solids mass leaving the filter zone) for runoff events on eight agricultural watersheds in the North Carolina Piedmont and Coastal Plain. Mean input is not included as an independent variable

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	6746046.85	1124341.14	12.21	<.0001
Error	170	15658163.28	92106.84		
Corrected Total	176	22404210.13			

R- Square	Coeff Var	Root MSE	Mean
0.301106	1460.554	303.4911	20.77917

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Total Volume (upper flume)	1	386123.597	386123.597	4.19	0.0422
Filter Zone Area	1	13826.329	13826.329	0.15	0.6989
Peak Flow Rate (upper fume)	1	113217.279	113217.279	1.23	0.2691
Peak Flow * Total Flow (upper flume)	1	756165.123	756165.123	8.21	0.0047
Peak Flow Rate Squared (upper flume)	1	466797.273	466797.273	5.07	0.0257
Total Volume Squared (upper flume)	1	5009917.251	5009917.251	54.39	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Total Volume (upper flume)	1	22290.354	22290.354	0.24	0.6234
Filter Zone Area	1	11403.803	11403.803	0.12	0.7254
Peak Flow Rate (upper fume)	1	41.531	41.531	0.00	0.9831
Peak Flow * Total Flow (upper flume)	1	5394241.027	5394241.027	58.57	<.0001
Peak Flow Rate Squared (upper flume)	1	4339651.404	4339651.404	47.12	<.0001
Total Volume Squared (upper flume)	1	5009917.251	5009917.251	54.39	<.0001

Table 8. Analysis of variance for the dependent variable TSS-difference (difference between total suspended solids mass entering the filter zone in runoff and total suspended solids mass leaving the filter zone) for runoff events on eight agricultural watersheds in the North Carolina Piedmont and Coastal Plain. Mean input concentration is included as an independent variable

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	7207143.92	102991.99	11.45	<.0001
Error	169	15197066.21	89923.47		
Corrected Total	176	22404210.13			

R- Square	Coeff Var	Root MSE	Mean
0.321687	1443.140	299.8724	20.77917

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Total Volume (upper flume)	1	386123.597	386123.597	4.29	0.0398
Filter Zone Area	1	13826.329	13826.329	0.15	0.6955
Peak Flow Rate (upper fume)	1	113217.279	113217.279	1.26	0.2634
Peak Flow * Total Flow (upper flume)	1	756165.123	756165.123	8.41	0.0042
Peak Flow Rate Squared (upper flume)	1	466797.273	466797.273	5.19	0.0240
Total Volume Squared (upper flume)	1	5009917.251	5009917.251	55.71	<.0001
Mean TSS Concentration (upper flume)	1	461097.065	461097.065	5.13	0.0248

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Total Volume (upper flume)	1	54.333	54.333	0.00	0.9804
Filter Zone Area	1	23355.871	23355.871	0.26	0.6110
Peak Flow Rate (upper fume)	1	132857.216	132857.216	1.48	0.2259
Peak Flow * Total Flow (upper flume)	1	4970674.583	4970674.583	55.28	<.0001
Peak Flow Rate Squared (upper flume)	1	4412531.930	4412531.930	49.07	<.0001
Total Volume Squared (upper flume)	1	4348879.521	4348879.521	48.36	<.0001
Mean TSS Concentration (upper flume)	1	461097.065	461097.065	5.13	0.0248

Table 9. Analysis of variance for the dependent variable NH_4-N-difference (difference between ammoniacal nitrogen mass entering the filter zone in runoff and ammoniacal nitrogen mass leaving the filter zone) for runoff events on eight agricultural watersheds in the North Carolina Piedmont and Coastal Plain. Mean input concentration is not included as an independent variable

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	70.2277298	11.7046216	9.22	<.0001
Error	162	205.5928814	1.2690919		
Corrected Total	168	275.8206112			

R- Square	Coeff Var	Root MSE	Mean
0.254614	398.1195	1.126540	0.282965

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Total Volume (upper flume)	1	17.71369812	17.71369812	13.96	0.0003
Filter Zone Area	1	10.65515877	10.65515877	8.40	0.0043
Peak Flow Rate (upper fume)	1	2.03875546	2.03875546	1.61	0.2068
Peak Flow * Total Flow (upper flume)	1	5.58595669	5.58595669	4.40	0.0375
Peak Flow Rate Squared (upper flume)	1	1.56861840	1.56861840	1.24	0.2679
Total Volume Squared (upper flume)	1	32.66554234	32.66554234	25.74	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Total Volume (upper flume)	1	24.38893350	24.38893350	19.22	<.0001
Filter Zone Area	1	9.65440000	9.65440000	7.61	0.0065
Peak Flow Rate (upper fume)	1	0.33194853	0.33194853	0.26	0.6097
Peak Flow * Total Flow (upper flume)	1	9.25623390	9.25623390	7.29	0.0077
Peak Flow Rate Squared (upper flume)	1	10.44193993	10.44193993	8.23	0.0047
Total Volume Squared (upper flume)	1	32.66554234	32.66554234	25.74	<.0001

Table 10. Analysis of variance for the dependent variable NH_4-N-difference (difference between ammoniacal nitrogen mass entering the filter zone in runoff and ammoniacal nitrogen mass leaving the filter zone) for runoff events on eight agricultural watersheds in the North Carolina Piedmont and Coastal Plain. Mean input concentration is included as an independent variable

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	220.0798153	31.4399736	90.81	<.0001
Error	161	55.7407959	0.3462161		
Corrected Total	168	275.8206112			

R- Square	Coeff Var	Root MSE	Mean
0.797909	207.9412	0.588401	0.282965

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Total Volume (upper flume)	1	17.7136981	17.7136981	51.16	<.0001
Filter Zone Area	1	10.6551588	10.6551588	30.78	<.0001
Peak Flow Rate (upper fume)	1	2.0387555	2.0387555	5.89	0.0163
Peak Flow * Total Flow (upper flume)	1	5.5859567	5.5859567	16.13	<.0001
Peak Flow Rate Squared (upper flume)	1	1.5686184	1.5686184	4.53	0.0348
Total Volume Squared (upper flume)	1	32.6655423	32.6655423	94.35	<.0001
Mean NH_4-N Concentration (upper flume)	1	149.8520855	149.8520855	432.83	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Total Volume (upper flume)	1	2.5647906	2.5647906	7.41	0.0072
Filter Zone Area	1	0.1764912	0.1764912	0.51	0.4763
Peak Flow Rate (upper fume)	1	0.8905417	0.8905417	2.57	0.1107
Peak Flow * Total Flow (upper flume)	1	3.5832532	3.5832532	10.35	0.0016
Peak Flow Rate Squared (upper flume)	1	4.1018307	4.1018307	11.85	0.0007
Total Volume Squared (upper flume)	1	6.5321850	6.5321850	18.87	<.0001
Mean NH_4-N Concentration (upper flume)	1	149.8520855	149.8520855	432.83	<.0001

Table 11. Analysis of variance for the dependent variable NO_3-N-difference (difference between nitrate nitrogen mass entering the filter zone in runoff and nitrate nitrogen mass leaving the filter zone) for runoff events on eight agricultural watersheds in the North Carolina Piedmont and Coastal Plain. Mean input concentration is not included as an independent variable

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	118.7677218	19.7946203	168.20	<.0001
Error	155	18.2409344	0.1176834		
Corrected Total	161	137.0086562			

R- Square	Coeff Var	Root MSE	Mean
0.866863	275.0074	0.343050	0.124742

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Total Volume (upper flume)	1	17.96860186	17.96860186	152.69	<.0001
Filter Zone Area	1	1.04605109	1.04605109	8.89	0.0033
Peak Flow Rate (upper fume)	1	47.27299793	47.27299793	401.70	<.0001
Peak Flow * Total Flow (upper flume)	1	48.14278220	48.14278220	409.09	<.0001
Peak Flow Rate Squared (upper flume)	1	4.26596122	4.26596122	36.25	<.0001
Total Volume Squared (upper flume)	1	0.07132749	0.07132749	0.61	0.4374

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Total Volume (upper flume)	1	0.02530861	0.02530861	0.22	0.6435
Filter Zone Area	1	0.42711192	0.42711192	3.63	0.0586
Peak Flow Rate (upper fume)	1	6.57476027	6.57476027	55.87	<.0001
Peak Flow * Total Flow (upper flume)	1	0.36144706	0.36144706	3.07	0.0817
Peak Flow Rate Squared (upper flume)	1	1.59285328	1.59285328	13.54	0.0003
Total Volume Squared (upper flume)	1	0.07132749	0.07132749	0.61	0.4374

Table 12. Analysis of variance for the dependent variable NO_3-N-difference (difference between nitrate nitrogen mass entering the filter zone in runoff and nitrate nitrogen mass leaving the filter zone) for runoff events on eight agricultural watersheds in the North Carolina Piedmont and Coastal Plain. Mean input concentration is included as an independent variable

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	128.0803268	18.2971895	315.60	<.0001
Error	154	8.9283294	0.0579762		
Corrected Total	161	137.0086562			

R- Square	Coeff Var	Root MSE	Mean
0.934834	193.0240	0.240782	0.124742

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Total Volume (upper flume)	1	17.96860186	17.96860186	309.93	<.0001
Filter Zone Area	1	1.04605109	1.04605109	18.04	<.0001
Peak Flow Rate (upper fume)	1	47.27299793	47.27299793	815.39	<.0001
Peak Flow * Total Flow (upper flume)	1	48.14278220	48.14278220	830.39	<.0001
Peak Flow Rate Squared (upper flume)	1	4.26596122	4.26596122	73.58	<.0001
Total Volume Squared (upper flume)	1	0.07132749	0.07132749	1.23	0.2691
Mean NO_3 -N Concentration (upper flume)	1	9.31260503	9.31260503	160.63	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Total Volume (upper flume)	1	0.20378729	0.20378729	3.52	0.0627
Filter Zone Area	1	0.89461702	0.89461702	15.43	0.0001
Peak Flow Rate (upper fume)	1	4.33341596	4.33341596	74.74	<.0001
Peak Flow * Total Flow (upper flume)	1	0.22827159	0.22827159	3.94	0.0490
Peak Flow Rate Squared (upper flume)	1	1.25024286	1.25024286	21.56	<.0001
Total Volume Squared (upper flume)	1	0.11223875	0.11223875	1.94	0.1661
Mean NO_3 -N Concentration (upper flume)	1	9.31260503	9.31260503	160.63	<.0001

Table 13. Analysis of variance for the dependent variable TKN-difference (difference between total Kjeldahl nitrogen mass leaving the filter zone in runoff and total Kjeldahl nitrogen mass leaving the filter zone) for runoff events on eight agricultural watersheds in the North Carolina Piedmont and Coastal Plain. Mean input concentration is included as an independent variable

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	257.3821566	42.8970261	9.79	<.0001
Error	168	735.8298216	4.3799394		
Corrected Total	174	993.2119782			

R- Square	Coeff Var	Root MSE	Mean
0.259141	344.9704	2.092830	0.606670

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Total Volume (upper flume)	1	91.43345213	91.43345213	20.88	<.0001
Filter Zone Area	1	44.35340372	44.35340372	10.13	0.0017
Peak Flow Rate (upper fume)	1	4.50282746	4.50282746	1.03	0.3121
Peak Flow * Total Flow (upper flume)	1	1.01804360	1.01804360	0.23	0.6304
Peak Flow Rate Squared (upper flume)	1	22.61788002	22.61788002	5.16	0.0243
Total Volume Squared (upper flume)	1	93.45654969	93.45654969	21.34	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Total Volume (upper flume)	1	92.71501045	92.71501045	21.17	<.0001
Filter Zone Area	1	36.82908478	36.82908478	8.41	0.0042
Peak Flow Rate (upper fume)	1	0.34443585	0.34443585	0.08	0.7795
Peak Flow * Total Flow (upper flume)	1	18.16050735	18.16050735	4.15	0.0433
Peak Flow Rate Squared (upper flume)	1	13.12233701	13.12233701	3.00	0.0853
Total Volume Squared (upper flume)	1	93.45654969	93.45654969	21.34	<.0001

Table 14. Analysis of variance for the dependent variable TKN-difference (difference between total Kjeldahl nitrogen mass leaving the filter zone in runoff and total Kjeldahl nitrogen mass leaving the filter zone) for runoff events on eight agricultural watersheds in the North Carolina Piedmont and Coastal Plain. Mean input concentration is included as an independent variable

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	693.9151082	99.1307297	55.31	<.0001
Error	167	299.2968700	1.7921968		
Corrected Total	174	993.2119782			

R- Square	Coeff Var	Root MSE	Mean
0.698658	220.6687	1.338730	0.606670

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Total Volume (upper flume)	1	91.4334521	91.4334521	51.02	<.0001
Filter Zone Area	1	44.3534037	44.3534037	24.75	<.0001
Peak Flow Rate (upper fume)	1	4.5028275	4.5028275	2.51	0.1148
Peak Flow * Total Flow (upper flume)	1	1.0180436	1.0180436	0.57	0.4521
Peak Flow Rate Squared (upper flume)	1	22.6178800	22.6178800	12.62	0.0005
Total Volume Squared (upper flume)	1	93.4565497	93.4565497	52.15	<.0001
Mean TKN Concentration (upper flume)	1	436.5329516	436.5329516	243.57	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Total Volume (upper flume)	1	43.1251842	43.1251842	24.06	<.0001
Filter Zone Area	1	6.4854035	6.4854035	3.62	0.0589
Peak Flow Rate (upper fume)	1	1.6937174	1.6937174	0.95	0.3324
Peak Flow * Total Flow (upper flume)	1	8.1284088	8.1284088	4.54	0.0347
Peak Flow Rate Squared (upper flume)	1	4.0001305	4.0001305	2.23	0.1371
Total Volume Squared (upper flume)	1	36.4881263	36.4881263	20.36	<.0001
Mean TKN Concentration (upper flume)	1	436.5329516	436.5329516	243.57	<.0001

Table 15. Analysis of variance for the dependent variable OP-difference (difference between orthophosphorus mass entering the filter zone in runoff and orthophosphorus mass leaving the filter zone) for runoff events an eight agricultural watersheds in the North Carolina Piedmont and Coastal Plain. Mean input concentration is not included as an independent variable

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	433.8087809	72.3014635	50.76	<.0001
Error	169	240.7232368	1.4243979		
Corrected Total	175	674.5320177			

R- Square	Coeff Var	Root MSE	Mean
0.643126	280.8781	1.193481	0.424911

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Total Volume (upper flume)	1	116.3232703	116.3232703	81.66	<.0001
Filter Zone Area	1	21.5837618	21.5837618	15.15	0.0001
Peak Flow Rate (upper fume)	1	96.7569329	96.7569329	67.93	<.0001
Peak Flow * Total Flow (upper flume)	1	34.1482790	34.1482790	23.97	<.0001
Peak Flow Rate Squared (upper flume)	1	4.9243263	4.9243263	3.46	0.0647
Total Volume Squared (upper flume)	1	160.0722105	160.0722105	112.38	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Total Volume (upper flume)	1	19.1636420	19.1636420	13.45	0.0003
Filter Zone Area	1	15.0194183	15.0194183	10.54	0.0014
Peak Flow Rate (upper fume)	1	14.1778707	14.1778707	9.95	0.0019
Peak Flow * Total Flow (upper flume)	1	110.3690471	110.3690471	77.48	<.0001
Peak Flow Rate Squared (upper flume)	1	77.5758533	77.5758533	54.46	<.0001
Total Volume Squared (upper flume)	1	160.0722105	160.0722105	112.38	<.0001

Table 16. Analysis of variance for the dependent variable OP-difference (difference between orthophosphorus mass entering the filter zone in runoff and orthophosphorus mass leaving the filter zone) for runoff events on eight agricultural watersheds in the North Carolina Piedmont and Coastal Plain. Mean input concentration is included as an independent variable

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	590.3599160	84.3371309	168.33	<.0001
Error	168	84.1721017	0.5010244		
Corrected Total	175	674.5320177			

R- Square	Coeff Var	Root MSE	Mean
0.875214	166.5834	0.707831	0.424911

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Total Volume (upper flume)	1	116.3232703	116.3232703	232.17	<.0001
Filter Zone Area	1	21.5837618	21.5837618	43.08	<.0001
Peak Flow Rate (upper fume)	1	96.7569329	96.7569329	193.12	<.0001
Peak Flow * Total Flow (upper flume)	1	34.1482790	34.1482790	68.16	<.0001
Peak Flow Rate Squared (upper flume)	1	4.9243263	4.9243263	9.83	0.0020
Total Volume Squared (upper flume)	1	160.0722105	160.0722105	319.49	<.0001
Mean OP Concentration (upper flume)	1	156.5511350	156.5511350	312.46	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Total Volume (upper flume)	1	2.8782992	2.8782992	5.74	0.0176
Filter Zone Area	1	5.2422222	5.2422222	10.46	0.0015
Peak Flow Rate (upper fume)	1	10.3256595	10.3256595	20.61	<.0001
Peak Flow * Total Flow (upper flume)	1	53.4814664	53.4814664	106.74	<.0001
Peak Flow Rate Squared (upper flume)	1	36.8579187	36.8579187	73.57	<.0001
Total Volume Squared (upper flume)	1	59.8018257	59.8018257	119.36	<.0001
Mean OP Concentration (upper flume)	1	156.5511350	156.5511350	312.46	<.0001

Table 17. Analysis of variance for the dependent variable TP-difference (difference between total phosphorus mass entering the filter zone in runoff and total phosphorus mass leaving the filter zone) for runoff events on eight agricultural watersheds in the North Carolina Piedmont and Coastal Plain. Mean input concentration is not included as an independent variable

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	491.7295333	81.9549222	34.66	<.0001
Error	173	409.0775560	2.3646102		
Corrected Total	179	900.8070893			

R- Square	Coeff Var	Root MSE	Mean
0.545877	291.0858	1.537729	0.528273

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Total Volume (upper flume)	1	155.8425502	155.8425502	65.91	<.0001
Filter Zone Area	1	28.0505476	28.0505476	11.86	0.0007
Peak Flow Rate (upper fume)	1	121.0998666	121.0998666	51.21	<.0001
Peak Flow * Total Flow (upper flume)	1	68.7610712	68.7610712	29.08	<.0001
Peak Flow Rate Squared (upper flume)	1	32.7867136	32.7867136	13.87	0.0003
Total Volume Squared (upper flume)	1	85.1887839	85.1887839	36.03	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Total Volume (upper flume)	1	52.83733702	52.83733702	22.35	<.0001
Filter Zone Area	1	18.76449918	18.76449918	7.94	0.0054
Peak Flow Rate (upper fume)	1	8.71816627	8.71816627	3.69	0.0565
Peak Flow * Total Flow (upper flume)	1	30.80474271	30.80474271	13.03	0.0004
Peak Flow Rate Squared (upper flume)	1	7.06771659	7.06771659	2.99	0.0856
Total Volume Squared (upper flume)	1	85.18878394	85.18878394	36.03	<.0001

Table 18. Analysis of variance for the dependent variable TP-difference (difference between total phosphorus mass entering the filter zone in runoff and total phosphorus mass leaving the filter zone) for runoff events on eight agricultural watersheds in the North Carolina Piedmont and Coastal Plain. Mean input concentration is included as an independent variable

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	704.1876823	100.5982403	88.00	<.0001
Error	172	196.6194070	1.1431361		
Corrected Total	179	900.8070893			

R- Square	Coeff Var	Root MSE	Mean
0.781730	202.3905	1.069175	0.528273

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Total Volume (upper flume)	1	155.8425502	155.8425502	136.33	<.0001
Filter Zone Area	1	28.0505476	28.0505476	24.54	<.0001
Peak Flow Rate (upper fume)	1	121.0998666	121.0998666	105.94	<.0001
Peak Flow * Total Flow (upper flume)	1	68.7610712	68.7610712	60.15	<.0001
Peak Flow Rate Squared (upper flume)	1	32.7867136	32.7867136	28.68	<.0001
Total Volume Squared (upper flume)	1	85.1887839	85.1887839	74.52	<.0001
Mean TP Concentration (upper flume)	1	212.4581490	212.4581490	185.86	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Total Volume (upper flume)	1	24.3432495	24.3432495	21.3	<.0001
Filter Zone Area	1	5.0137183	5.0137183	4.39	0.0377
Peak Flow Rate (upper fume)	1	6.8293526	6.8293526	5.97	0.0155
Peak Flow * Total Flow (upper flume)	1	19.2123616	19.2123616	16.81	<.0001
Peak Flow Rate Squared (upper flume)	1	3.4881614	3.4881614	3.05	0.0825
Total Volume Squared (upper flume)	1	41.2027830	41.2027830	36.04	<.0001
Mean TP Concentration (upper flume)	1	212.4581490	212.4581490	185.86	<.0001