RIPARIAN FOREST BUFFER SYSTEM RESEARCH AT THE COASTAL PLAIN EXPERIMENT STATION, TIFTON, GA

R. K. HUBBARD AND R. R. LOWRANCE

USDA-ARS, Southeast Watershed Research Laboratory

P. O. Box 946, Tifton, GA 31793

Abstract. Recent attention has focused on riparian forest buffer systems for filtering sediment, nutrients, and pesticides entering from upslope agricultural fields. Studies in a variety of physiographic areas have shown that concentrations of sediment and agrichemicals are reduced after passage through a riparian forest. The mechanisms involved are both physical and biological, including deposition, uptake by vegetation, and loss by microbiological processes such as denitrification. Current research by USDA-ARS and University of Georgia scientists at Tifton, GA is focusing on managing riparian forest buffer systems to alleviate agricultural impacts on the environment. The underlying concept for this research is that agricultural impact on streams is best protected by a riparian forest buffer system consisting of three zones. In consecutive upslope order from the stream these zones are (1) a narrow band of permanent trees (5-10 m wide) immediately adjacent to the stream channel which provides streambank stabilization, organic debris input to streams, and shading of streams, (2) a forest management zone where maximum biomass production is stressed and trees can be harvested, and (3) a grass buffer strip up to 10 m wide to provide control of coarse sediment and to spread overland flow. Several ongoing projects at Tifton, GA are focusing on using riparian forest buffer systems as filters. A forest management project is testing the effects of different management practices on surface and ground water quality. This project includes three different forest management practices: mature forest, selectively thinned forest, and clearcut. In a different study a natural wetland is being restored by planting trees. The effectiveness of this wetland on filtering nutrients from dairy wastes which are being applied upslope is being evaluated. At this same site, a pesticide study is being conducted on the side opposite to where dairy wastes are applied. An overland flow-riparian buffer system using swine lagoon waste is evaluating the effectiveness of different vegetative treatments and lengths of buffer zones on filtering of nutrients. In this study three vegetative treatments are compared: (1) 10 m grass buffer and 20 m riparian forest, (2) 20 m grass buffer and 10 m riparian forest, (3) 10 m grass buffer and 20 m of the recommended wetland species maidencane. Waste is applied at the upper end of each plot at either a high or low rate, and then allowed to flow downslope. The three zone riparian forest buffer system is being used for the Riparian Ecosystem Management Model (REMM). This model, which is currently under development at Tifton, GA, is a computer simulation model designed to reduce soil and water degradation by aiding farmers and land use managers in decision making regarding how best to utilize their riparian buffer system. Both information currently being collected in field studies and development of the REMM are innovative farm-level and forestry technologies to protect soil and water resources.

1. Introduction

Management of land resources in the United States historically has been focused primarily on the uplands. Riparian zones and wetlands largely were viewed as wasted land to be drained, while stream and river systems were channelized to control flooding. Ecosystem concepts including sustainable environment and management of riparian

Water, Air and Soil Pollution **77**: 409–432, 1994.

zones and wetlands are both relatively new. The concept that what happens in one part of the landscape affects other landscape segments, and that overall these events affect the environment globally is the foundation for much of our environmental research today. The concept of managing wetlands is still under some debate, with opinions ranging from those who believe that wetlands should exist in pristine condition with no interference from agricultural or other activities, to those who believe that wetlands are natural sinks that can be used to effectively filter materials entering from upslope, and that emphasis should be placed on restoration of natural wetlands so that they can resume their filtering function in the landscape.

Research conducted in the coastal plain of Georgia during the 1970's provided early evidence that riparian zones are effective nutrient filters. The research at this time primarily focused on nitrogen (N). Extensive studies (Asmussen *et al.*, 1979; Yates and Sheridan, 1983) of nutrient budgets in riparian areas of the Tifton Upland in the coastal plain of Georgia examined nitrate (NO_3-N) losses from cropped areas and riparian wetland zones, and NO_3-N loads in streamflow. It was estimated that 96 percent of the NO_3-N was retained, utilized, or transformed in the heavily vegetated riparian forests of the Coastal Plain (Yates and Sheridan, 1983). Stream outflow loads of NO_3-N on a mixed-use agricultural watershed were found to be lower than NO_3-N loads input by rainfall (Asmussen *et al.*, 1979). Filtering of N by riparian systems was attributed to both denitrification and vegetative uptake (Lowrance *et al.*, 1984a,b).

Denitrification occurs under anaerobic conditions. Denitrifiers are facultative anaerobes which carry out anaerobic respiration by substituting NO_3-N or a related nitrogenous compound for oxygen as the terminal electron acceptor (Rowe and Stinnett, 1975). The pathway generally proceeds by reduction from NO_3-N to NO_2-N to N_2O-N to N_2 gas although some intermediates have been postulated (Rowe and Stinnett, 1975).

A number of factors influence denitrification rate. Denitrification rates are slower in acid soils than in alkaline soils. The relative amounts of N_2O-N and N_2 produced are affected by temperature, with N_2O being predominantly formed at lower temperatures, and N_2 at higher ones (Rowe and Stinnett, 1975). Conditions conducive to denitrification are commonly found in fine-textured, water logged soils with high organic content. Water apparently has a direct effect on denitrification: the closer the soil is to saturation, the more denitrification occurs. Little denitrification occurs in soils less than about 60 percent saturated (Broadbent and Clark, 1965). High organic content is conducive to denitrification, because heterotrophic denitrifiers need oxidizable organic material as a source of carbon for synthesis of protoplasm and as a source of electrons for the reduction of nitrogenous compounds (Rowe and Stinnett, 1975). Groffman *et al.* (1992) found that hydric surface (0-15 cm) soils (poorly and very poorly drained) consistently had higher denitrification enzyme activity than upland-wetland transition zone (moderately well and somewhat poorly drained) surface soils. Peterjohn and Correll (1984) estimated N dissimulation by denitrification to be 45 kg N ha^{-1} yr^{-1} for riparian forested areas.

The second mechanism by which riparian zones can reduce NO_3-N concentrations in water arriving from uplands is through vegetative uptake, particularly by the trees in forested riparian zones. Several investigators (Vitousek and Reiners, 1975; Lowrance *et al.*, 1983, 1984b) have suggested that select harvest of "mature trees in riparian forests is a method of perpetuating vigorous vegetative uptake of soil nutrients. Odum (1969) hypothesized that constant, pulsed, and annually increasing impacts of nutrients may keep the riparian forest in a "bloom" state, and the forest may respond by high and vigorous growth and nutrient uptake rates for a considerable period of time; much longer, perhaps, than the age generally considered as forest maturity. Work of Peterjohn and Correll (1984) using a nutrient mass balance approach indicated a net retention by a forested wetland of 75 kg total N ha^{-1} yr^{-1}. Nutrient assimilation and long-term storage in wood biomass ranged from 12 to 20 kg N ha^{-1} yr^{-1}.

The combined effects of denitrification and NO_3-N uptake in the riparian zone on N concentrations entering from the uplands have been documented by a number of investigators. Concentrations of N in many watersheds have remained nearly constant as loading of N from agricultural nonpoint sources has increased (Tomlinson, 1970; Thomas and Crutchfield, 1974; Hill and Wylie, 1977). Reddy and Graetz (1981) found that shallow reservoirs and flooded organic soils could be used for ammonium (NH_4-N) and NO_3-N removal from wastewater. Van Kessel (1977) measured NO_3-N removal rates in ditches, and found them to be as high as commercial treatment of sewage. Robinson *et al.* (1978), Hoare (1979), and Hill (1983) measured significant stream loss of NO_3-N by denitrification which greatly affected stream and watershed budgets. Brinson et al. (1981) showed that 75% of NH_4-N and 94% of NO_3-N was removed as floodwater moved through two riverside swamps. Other studies which have shown the role of forested wetlands as partial nutrient sinks include those of Kitchens *et al.* (1975), Boyt *et al.* (1976), Ewel and Odum (1978), Nessel (1978), Mitsch *et al.* (1979), Tuschall *et al.* (1981), Day *et al.* (1981), and Qualls (1984).

Research in the North Carolina coastal plain on soils having significant shallow subsurface flow showed than from 10 to 56 kg ha^{-1} yr^{-1} of NO_3-N moved from cropped fields in subsurface drainage water (Jacobs and Gilliam, 1985). Natural riparian vegetation downslope from the cropped fields resulted in a substantial portion of the NO_3-N in the drainage water being removed. Nitrate losses were believed to be due primarily to denitrification. Buffer strips less than 15 m wide caused significant losses of NO_3-N before runoff water or subsurface flow reached the stream. It was also noted in this study that while soybean production had increased 760 percent since 1945, with commensurately more N fixation, and while fertilizer use had increased 400 percent since 1945, no proportional increase in the N content of most coastal plain streams has been observed. Jacobs and Gilliam (1985) concluded that from an environmental standpoint, the most effective system for removing N is a natural drainageway bordered by poorly drained soil and dense riparian vegetation. Gilliam and Terry (1973) also found no increase in NO_3-N in streams in North Carolina over the last 50 years despite increases in fertilizer application.

A series of studies (Lowrance *et al.*, 1983; Lowrance *et al.*, 1984a; Lowrance *et al.*, 1984b; Lowrance *et al.*, 1984c; Lowrance *et al.*, 1985) in the Georgia coastal plain in the 1980's measured streamflow and shallow groundwater quality and found reduction in NO_3-N levels in waters leaving the riparian zone as compared to the agricultural upland. Total annual N inputs to the riparian zone averaged 12.2 kg ha^{-1} yr^{-1} in precipitation, 29 kg ha^{-1} yr^{-1} in subsurface flow, 10 kg ha^{-1} yr^{-1} in surface runoff, and 10.6 kg ha^{-1} yr^{-1} as N fixation for a total of 61 kg ha^{-1} yr^{-1}. Losses of N in streamflow averaged 13 kg ha^{-1} yr^{-1}. It was projected that in this physiographic region, total replacement of riparian forest with a mixture of crops similar to those grown on the upland would increase present mean annual NO_3-N concentrations in streamflow from 0.20 mg L^{-1} to an estimated 4 mg L^{-1}.

Both direct and indirect approaches have been taken in studying the role of riparian forests in agricultural settings. One direct method is use of transects running from the edge of the agricultural fields through the riparian forest (Doyle *et al.*, 1975; Lowrance *et al.*, 1984a; Peterjohn and Correll, 1984; Lowrance, 1992; Hubbard and Lowrance, 1993; Simmons *et al.*, 1993). Lowrance (1992), using a transect of wells from a row-crop field to a stream in the Georgia coastal plain, determined that NO_3-N in groundwater decreased by a factor of 7 to 9 in the first 10 m of forest. Within the next 40 m of forest, the mean NO_3-N concentration decreased from 1.80 to 0.81 mg NO_3-N L^{-1}. Simmons *et al.* (1992) assessed the removal of groundwater NO_3-N on a soil drainage sequence ranging from moderately well to poorly drained. To assess NO_3-N removal, the change in groundwater concentrations of NO_3-N relative to the concentration of the conservative tracer Br was observed in monitoring wells located in each soil drainage class. Removal of groundwater NO_3-N was consistently high in the wetland locations, generally in excess of 80% in both growing and dormant seasons. In the transition zones, attenuation was less than 36% during the growing season, and ranged from 50 to 78% in the dormant season. Attenuation in the transition zones was positively correlated with water table elevations. A second direct method is to utilize chemical budgets (Lowrance *et al.*, 1983; Todd *et al.*, 1983; Lowrance *et al.*, 1984b; Peterjohn and Correll, 1984).

More indirect methods have compared the nutrient concentrations in stream water from agricultural watersheds with varying amounts of riparian forest or have analyzed the predictive capability of models which include or exclude the presence or proximity of riparian forest (McColl, 1978; Schlosser and Karr, 1981a: Schlosser and Karr, 1981b; Omernik *et al.*, 1981, Yates and Sheridan, 1983). With the exception of the Omernik *et al.* (1981) study, all studies have reached the general conclusion that riparian forests effectively reduce the loss of N from agricultural lands to receiving waters.

Lowrance *et al.* (1983), working in the Georgia coastal plain, used a nutrient budget approach to determine the effects of riparian zones on water quality. In preparing the schematic shown as Figure 1, they assumed water and nutrient movements from different land uses to be proportional to the length of interface between each

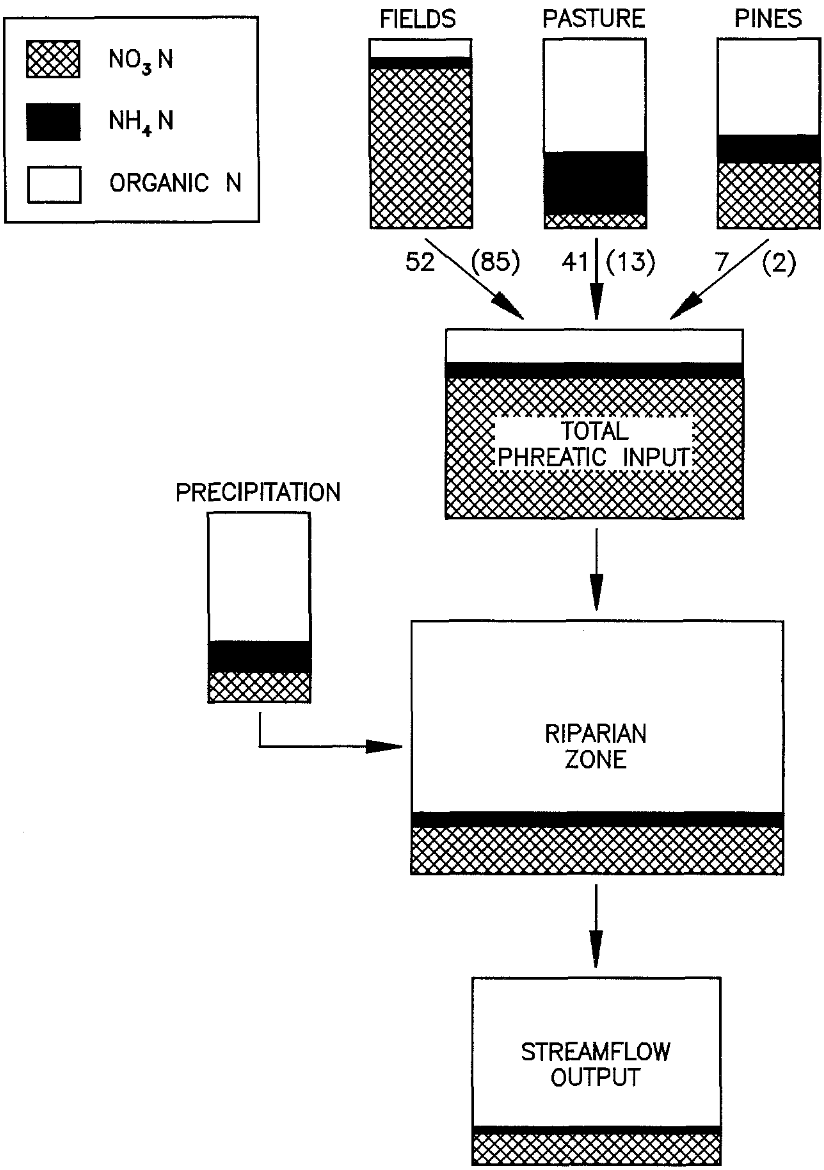

Figure 1. Change in N forms from subsurface and precipitation inputs to streamflow outputs. Bars represent relative amounts of nitrate, ammonium, and organic N making up inputs or outputs. Numbers on arrows represent percentages of water discharge and N (in parentheses) coming from fields, pastures, and pine forests. (From Lowrance et al., 1983)

land use and the riparian zone. Nitrogen movement from fields (row crops), pastures, and upland pine forest differed in both kind and amount. Of the total water volume moved from the upland mixed cover ecosystem to the riparian ecosystems, 52% came from fields, 41% from pasture lands, and 7% from pine forests. In contrast, 85% of the N moved from fields, 13% from pastures, and 2% from pines. Discharges from upland fields had 85% of the N as NO_3-N, 4% as NH_4-N and 11% as organic N. From pastures, only 9% of the total N moved as NO_3-N, while 31% was NH_4-N and 60% was organic N. Nitrogen losses in streamflow from the riparian zone were considerably smaller, and the forms had changed. While overall N inputs from the uplands were 74% NO_3-N, 8% NH_4-N, and 18% organic N, streamflow outputs were 18% NO_3-N, 2% NH_4-N, and 80% organic N. Lowrance *et al.* (1983) projected that partial conversion of the riparian forests of the coastal plain to cropland could increase NO_3-N and NH_4-N loads to streamflow by up to 800%.

The use of riparian management zones is relatively well established as a Best Management Practice (BMP) for water quality improvement in forestry practices (Comerford *et al.*, 1992), but has been much less widely applied as a BMP in agricultural areas or in urban or suburban settings. It is believed that riparian forest buffer systems are especially important on small streams where intense interaction of the terrestrial and aquatic ecosystems occurs. First and second order streams are estimated to comprise nearly three-quarters of the total stream length in the United States (Leopold, 1964). Fluvial activities influence the composition of riparian plant communities along these small streams (Gregory *et al.*, 1991). Likewise, terrestrial disturbances can have an immediate impact on aquatic populations (Sweeney, 1993; Webster *et al.*, 1992). Small streams can be completely covered by the canopies of streamside vegetation (Sweeney, 1992). Riparian vegetation is widely acknowledged to have beneficial effects on stream bank stability, stream biological diversity, and stream water temperatures (Karr and Schlosser, 1978).

In the late 1980's the need for more information on the filtering role of riparian zones relative to pollutants entering from agriculture was recognized. In response to this recognition USDA-ARS, beginning in 1989, committed monies and resources to the Southeast Watershed Research Laboratory at Tifton, GA, to expand existing research and initiate new research on the role of riparian zones in filtering not only N, but also sediment, phosphorus (P), and pesticides. The overall scientific objectives of the research were to gain information to assist in designing management strategies for riparian forest buffer systems so that permanent improvements in water quality can be achieved. Riparian forest buffer systems must be managed with an understanding of : 1) the processes which remove or sequester nonpoint source pollutants after they enter the system; 2) the effects of riparian management practices on the retention of nonpoint source pollutants; 3) the effects of riparian forest buffer systems on aquatic ecosystems; 4) the time till recovery after harvest of trees or re-establishment of riparian forest buffer systems; and 5) the effects of the underlying soil and geologic materials on chemical and biological processes.

A comprehensive program including both the United States Department of Agriculture - Agricultural Research Service (USDA-ARS) and cooperating scientists from the University of Georgia (UGA) was put together at Tifton, GA to intensively study riparian zone filtering processes and management. The program includes both research funded through USDA-ARS and UGA, and research funded through competitive grants. The projects include filtering of nutrients, sediment, and pesticides from row crop agriculture, restoration of a wetland to filter nutrients entering from an animal waste site, and comparison of different management techniques for filtering animal waste applied to riparian forest buffer systems by overland flow. The ultimate goal of the entire program of research is to determine management techniques for riparian forest buffer systems that contribute to a sustainable environment. This paper documents the projects in the riparian forest buffer systems research program.

2. Current Studies

Effect of Management of Riparian Forest Buffer Systems on Water Quality

In fall 1991 a project was started at a site near Tifton, GA to determine the effects of different riparian forest management practices on water quality (Figure 2). The work was started through funding by a CSRS National Research Initiative Competitive Grant (91-37102-6785) and with additional work at other sites will continue through 1996 with funding support by a new CSRS-NRI grant (93-37102-8955). The specific objectives of this research are to:

1) Determine rates of N, P, sediment, and bromide (Br) movement in surface and/or subsurface flow through managed and unmanaged areas of a riparian buffer system.

2) Determine the relative importance of denitrification, microbial immobilization, and root N uptake in NO_3-N removal in managed and unmanaged areas of a riparian forest buffer system.

3) Determine effects of the pesticide aldicarb (Temik) on soil microcosm processes that regulate N transformations in the riparian buffer system.

The investigations are being carried out at an existing riparian forest site located at the University of Georgia Coastal Plain Experiment Station near Tifton, GA (Figure 2). The soil of the riparian forest area is an Alapaha loamy sand (fine-loamy, siliceous, acid, thermic Typic Fluvaquents). The soil of the adjacent upland area is a Tifton loamy sand (fine-loamy, siliceous, thermic, Plinthic Kandiudults). The riparian forest trees are primarily slash pine (<u>Pinus elliottii</u> Engelm.) and long leaf pine (<u>Pinus palustris</u> Mill.). The 5 m nearest the stream channel supports different vegetation with more hardwoods including yellow poplar (<u>Liriodendron tulipifera</u> L.) and black gum (<u>Nyssa sylvatica</u> Marxh.). The forest provides a buffer which averages 55 m in width along an intermittent second-order stream channel.

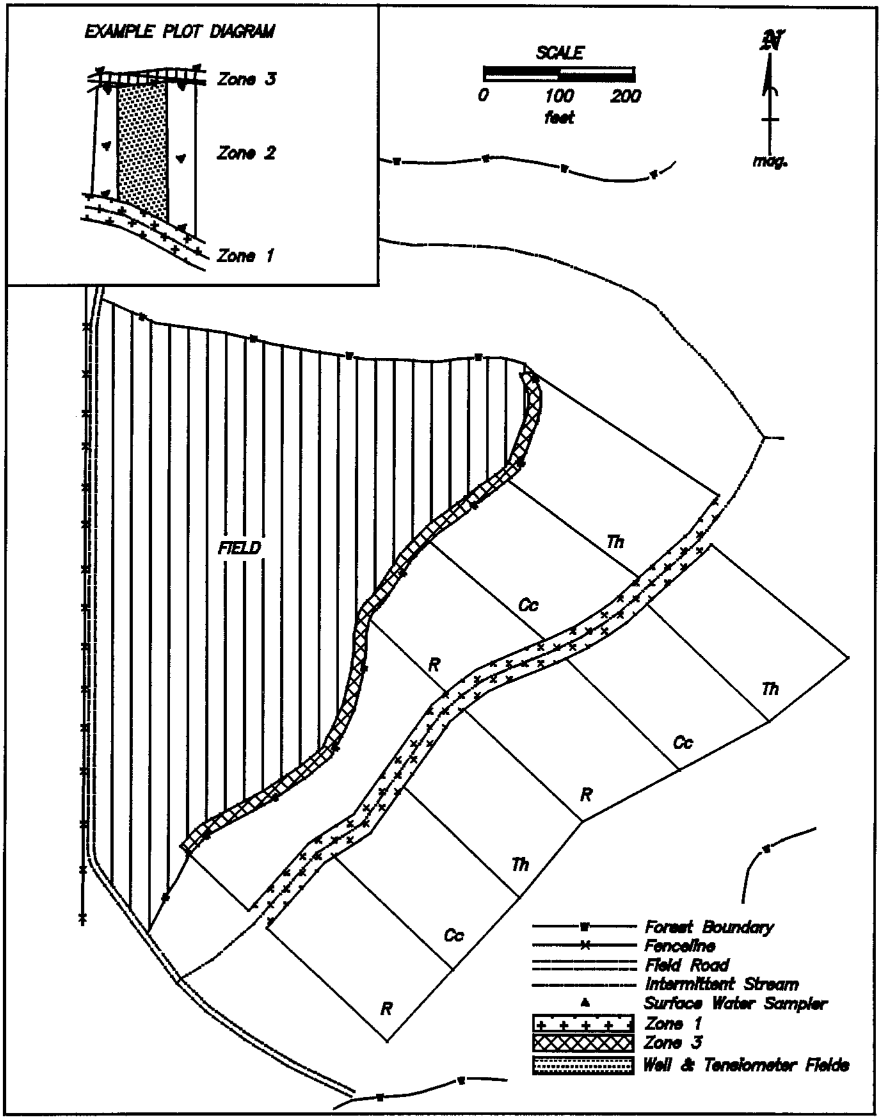

Figure 2. The three zone buffer system, the layout of Zone 2 treatment blocks, and the location of well and tensiometer fields and surface samplers within a representative block. Th = thinning cut; Cc = clear cut; R = reference-mature forest.

The riparian forest buffer system used for the study has three zones. The buffer system begins at the base of the field with Zone 3, a 5 m wide strip of Tifton 44 Coastal Bermudagrass (Cynodon dactylon L. Pers.). The Bermudagrass strip (Zone 3) is interplanted with abruzzi rye (Secale cereale L.) during winter to provide both biomass production and nutrient uptake. Zone 3 was established during fall 1991. The forest portion of the buffer consists of pines (Zone 2) and hardwoods (Zone 1). Zone 1 is a 10 m wide strip, adjacent to the stream channel, where trees will not be removed. Zone 2 is the remaining 50 m of forest between Zones 1 and 3. Zone 2 is being used for two forest management treatments and a reference. Treatment 1 is a clear-cut with all the merchantable tree biomass (either pulp wood or saw wood) removed. Removal of this material was accomplished during fall 1992. Limbs less than 6 cm dia. were left in the clear cut and thinned areas and were spread uniformly around the site. All other aboveground biomass was removed. Treatment 1 was reforested by planting of improved slash pine at a rate of 1,560 trees ha^{-1} during winter 1993. This rate was based on Georgia Forestry Commission (GFC) recommendations. Treatment 2, based on GFC recommendations, is a thinning cut with the standing biomass removed from all size classes to a target basal area of about 25 m^2 ha^{-1}. The thinning cut was done in fall 1992 at the same time as the clearcut. Woody and non-woody debris generated from the harvest treatments was allowed to remain in the respective treatments and was distributed within the sites at random by the log skidding operation. The control treatment for the study is the uncut forest. Each treatment is about 40 m wide and 50 m deep running downslope from the grass strip to the stream, on both sides of the stream channel.

The field above the buffer system on the west side of the stream was planted to corn (Zea mays L.) both in 1992 and 1993. The corn received 200 kg N ha^{-1} in fertilizer inputs. Atrazine and alachlor are being applied to the corn. The field above the buffer system on the west side of the stream will be in a three year rotation of corn-peanut-corn for 1994-1996. Conventional input corn (Zea mays L.) will be grown adjacent to the buffer area. The corn will receive 200 kg N ha^{-1} and 100 kg P ha^{-1} in fertilizer inputs in 1994 and 1996. No N will be applied to the peanuts, although fixation by high yielding peanuts can equal about 200 kg N ha^{-1} yr^{-1} (Hoyt, 1981). Fertilizer P additions will follow standard recommendations for peanuts of 50 kg P ha^{-1} yr^{-1}. Aldicarb will be applied to the peanuts to control thrips and nematodes.

Surface runoff measurements from the study to date show that sediment concentrations and loads were reduced by nearly 90% from the field output to the streamflow input. Mean sediment concentrations before timber harvest were 1281 mg L^{-1} entering the buffer system and 151 mg L^{-1} leaving the buffer systems.

Soil samplings from 1991 showed that in general, NO_3-N concentrations were high in the saturated layers at the edge of the upland field, but were significantly reduced within the first 5 m of the forest. Higher NH_4-N concentrations in the surface soils near the stream were consistent with the greater biomass N contents in this position.

2.1. WETLAND RESTORATION AND FILTERING OF ANIMAL WASTE

The project entitled "Development of an environmentally safe and economically sustainable year-round minimum tillage forage production system using farm animal manure as the only fertilizer" was started in 1991. This project, which was initially funded by the LISA (Low Input Sustainable Agriculture) program for a three year period, is being conducted by a multidisciplinary scientific team at a site where screened liquid dairy manure from a storage lagoon is applied on 5.6 ha by center pivot irrigation (Figure 3). The waste is applied to the east, west, south and north pivot quadrants at N application rates of 200, 400, 600, and 800 kg ha^{-1} yr^{-1}, respectively. These rates were selected so that the lowest rate is restrictive to plant growth and the highest rate is excessive for maximum plant growth based on N uptake rates calculated from previous experiments (Johnson *et al.*, 1984). The cropping system consists of overseeding of abruzzi rye (Secale cereale L.) into Tifton 44 Bermudagrass (Cynondon dactylon L.) sod in the fall, followed by minimum tillage planting of silage corn (Zea mays L.) into the bermudagrass and rye stubble in the spring, followed by summer crops of hay or silage from the residual bermudagrass.

The north quadrant of the pivot, which receives an N rate of 600 kg ha^{-1} yr^{-1}, drains downslope into a wetland area (Figure 2). This area (0.92 ha), which was forested until 1985, was distinctly different from the upslope areas in vegetation at the start of the upland study. The vegetation before restoration was primarily wetland grasses (Paspalum sp.) and rushes (Juncus sp.).

The wetland is being restored to a forested condition which allows determination of the effects of the wetland on water quality during the restoration process. The specific objectives for the restoration were to: (a) measure nutrient (N, P) concentration changes in surface runoff and shallow groundwater as they move through the wetland; b) determine nutrient uptake and removal in the wetland by soil microbial processes and vegetation; and (c) evaluate the wetland as a potential bioremediation site.

The wetland was partially restored in February 1991 by reintroducing a combination of native trees over 0.47 ha (Figure 4). The trees will be grown for eventual harvest as pulpwood, timber wood, or both. Slash pine (Pinus elliottii Engelm.) and yellow poplar (Liriodendron tulipifera L.) were selected as a combination that would provide fast growth and year-round nutrient uptake. Slash pine is commonly used in the coastal plain in the landscape position analogous to Zone 2 of the riparian forest buffer system, while yellow poplar commonly grows in the wetter areas near the streams. The trees were planted with 1.5 m spacing within rows and 3 m spacing between rows to permit seasonal mowing of herbaceous vegetation.

Due to low survivorship of the poplars, swamp black gum (Nyssa sylvatica var. biflora Marsh.) and green ash (Fraxinus pennsylvanica (Borkh.) Sarg.) saplings were introduced to the hardwood area in April 1991. In April 1992, marsh cordgrass

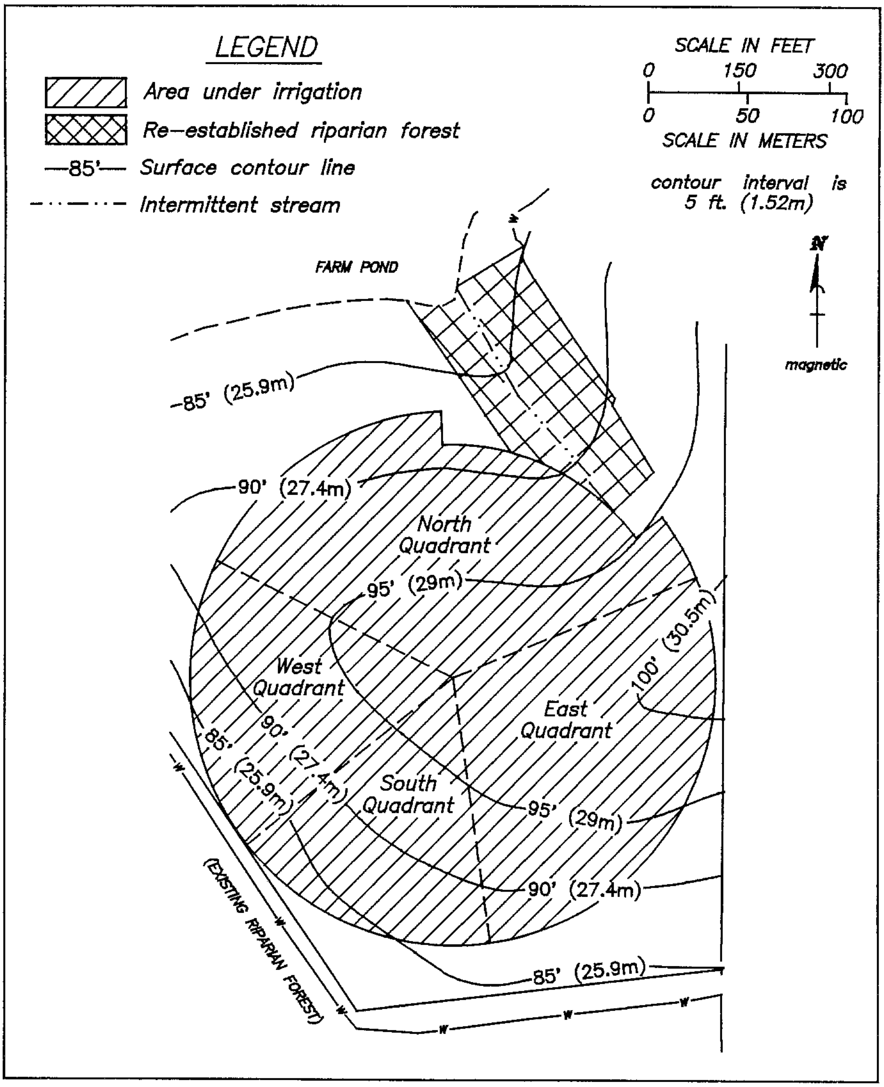

Figure 3. The dairy waste land application and dairy wetland restoration research facilities. The circle indicates the area irrigated by the center pivot waste application system. The wetland is indicated by the cross-hatched area.

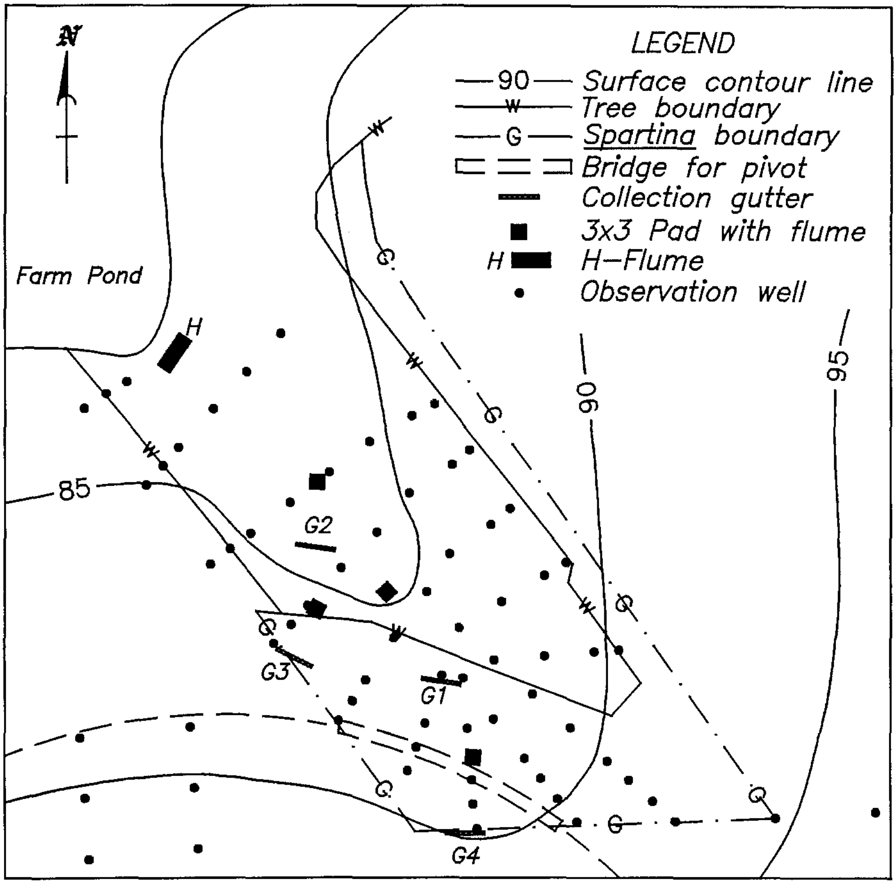

Figure 4. Map of the dairy wetland restoration site showing the network of monitoring wells and the location of the four collection gutters and flumes.

(Spartina patens (Aiton) Mulh.), a perennial grass, was established along the perimeter of the wetland (0.45 ha) to act as a transitional zone between the forage production system and the riparian forest.

Water quality measurements are made on water entering the wetland, moving through, and exiting. This is accomplished using a combination of monitoring wells, surface runoff collectors, and flumes. Nutrient movement and concentrations in the upland root zone and in shallow groundwater are being tracked in the north quadrant using both solution samplers and a network of 18 monitoring wells. The solution samplers are installed at 0.5 m, 1.0 m, 1.5 m, and 2.0 m depths. Nine of the 18 shallow groundwater wells in the north quadrant are at 3 m depth, while the other nine are at 6 m depth.

Groundwater in and around the perimeter of the wetland is monitored by 110 groundwater wells (Figure 4). On the side adjacent to the animal waste application site the wells are installed to a depth of 1 m and are fully slotted up to the soil surface. The opposite side from the animal waste site is being used for a pesticide study and the wells extend to a depth of 2 m. The upland wells were sampled and depth to the water table was measured biweekly from 1991 until June 1993 when a monthly sampling schedule was instituted. Water sampling of the suction lysimeters in the upland is on the same schedule as the sampling of the upland wells. A biweekly sampling schedule is used for measuring the depth to the water table and also collecting samples for nutrient and pesticide analyses in the wetland.

Surface runoff is sampled at two locations entering the wetland and at two locations near the stream flow (Vellidis *et al.*, 1992; Vellidis *et al.*, 1993). At each location, the runoff is collected in a gutter, passed through a 200 mm Modified Tucson Flume, and redistributed through a slotted gutter. Composite water samples are collected from the flumes with battery-powered peristaltic pumps.

Water samples from the wells in the upland are analyzed for NO_3-N, NH_4-N, total N, phosphate (PO_4), total P, calcium (Ca), potassium (K), magnesium (Mg), and sodium (Na) concentrations. Nitrate, NH_4-N, total N, PO_4, and total P analyses are performed by standard methods on the Lachat Flow Injection Analyzer (APHA, 1989). Analyses for Ca, K, Mg, and Na are done by atomic absorption. Nitrate concentrations in the wells on the north quadrant at 3 m have averaged about 15 mg L^{-1} since the start of the study (Figure 5). Water samples from the surface runoff collectors and shallow wells in the wetland are analyzed for NO_3-N, NH_4-N, total N, PO_4, and total P concentrations. The filtering effect of the wetland on NO_3-N is apparent from the contrast in NO_3-N concentrations in shallow wells at the upper edge of the wetland, and those found in wells in the stream area (Figures 6 and 7). Shallow lateral subsurface flow is the dominant loss pathway for water and solutes in the coastal plain of Georgia, as has been shown by numerous studies involving NO_3-N and conservative tracers such

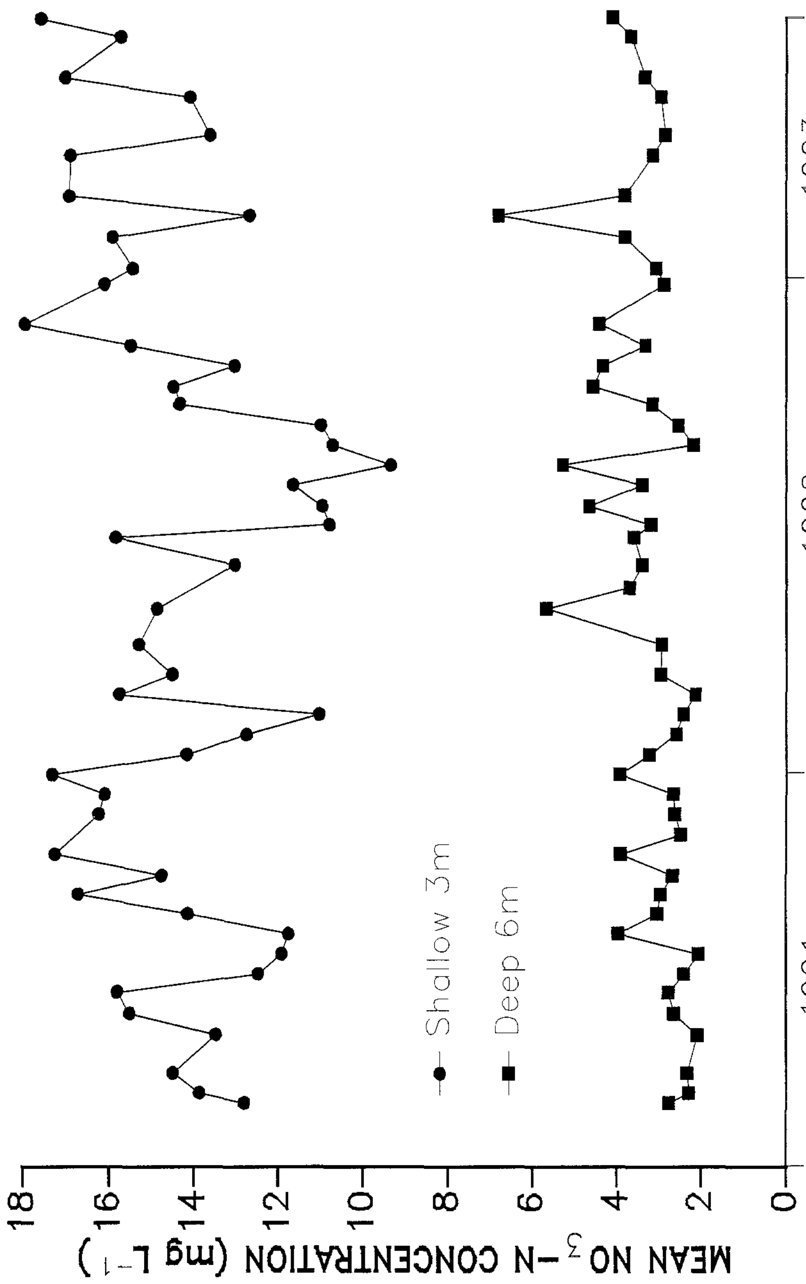

Figure 5. Mean NO_3-N concentrations in 3 and 6 m dairy upland wells in the quadrant draining into the wetland.

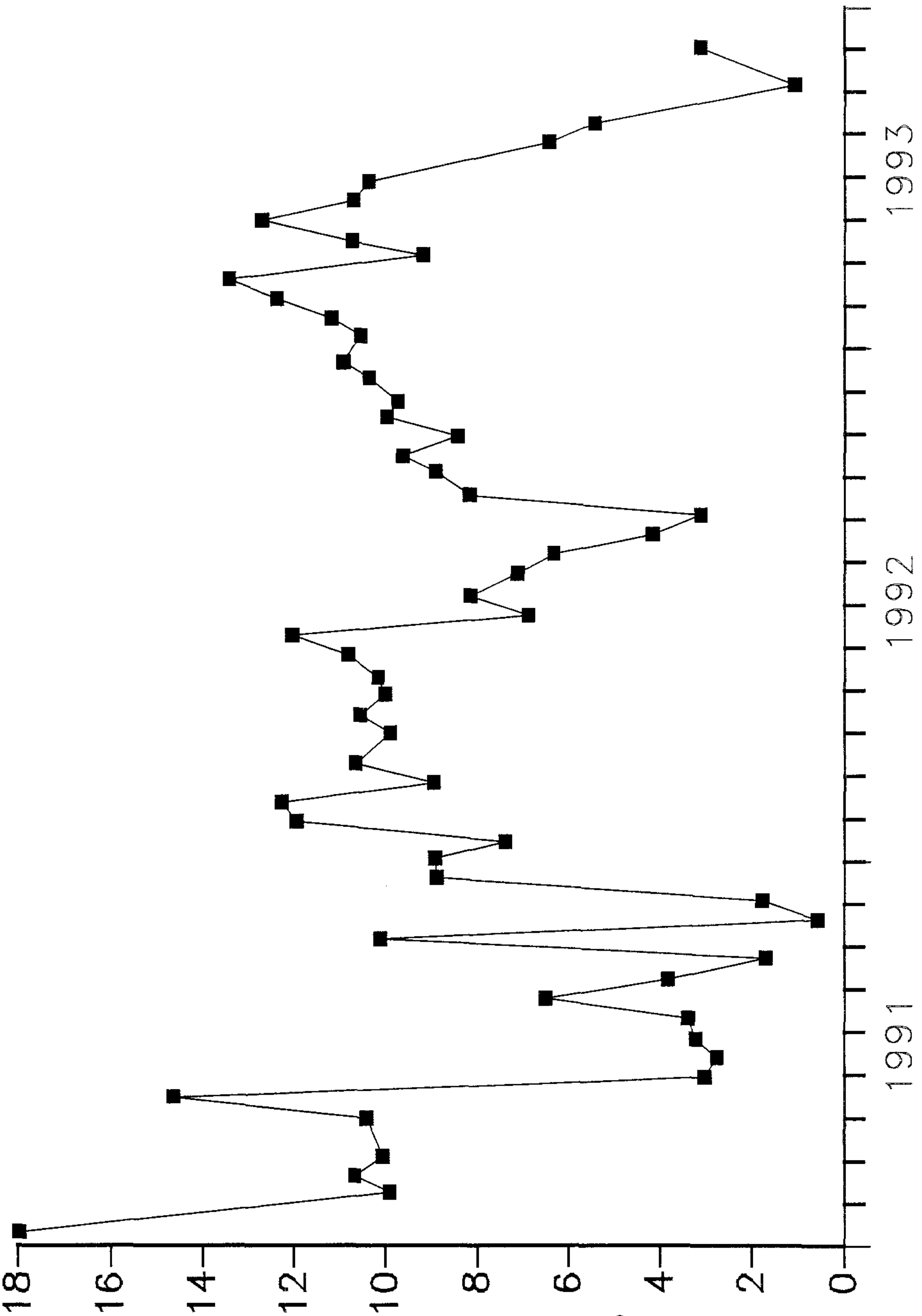

Figure 6. Mean NO_3-N concentrations in the wells in the uppermost landscape position at the dairy wetland.

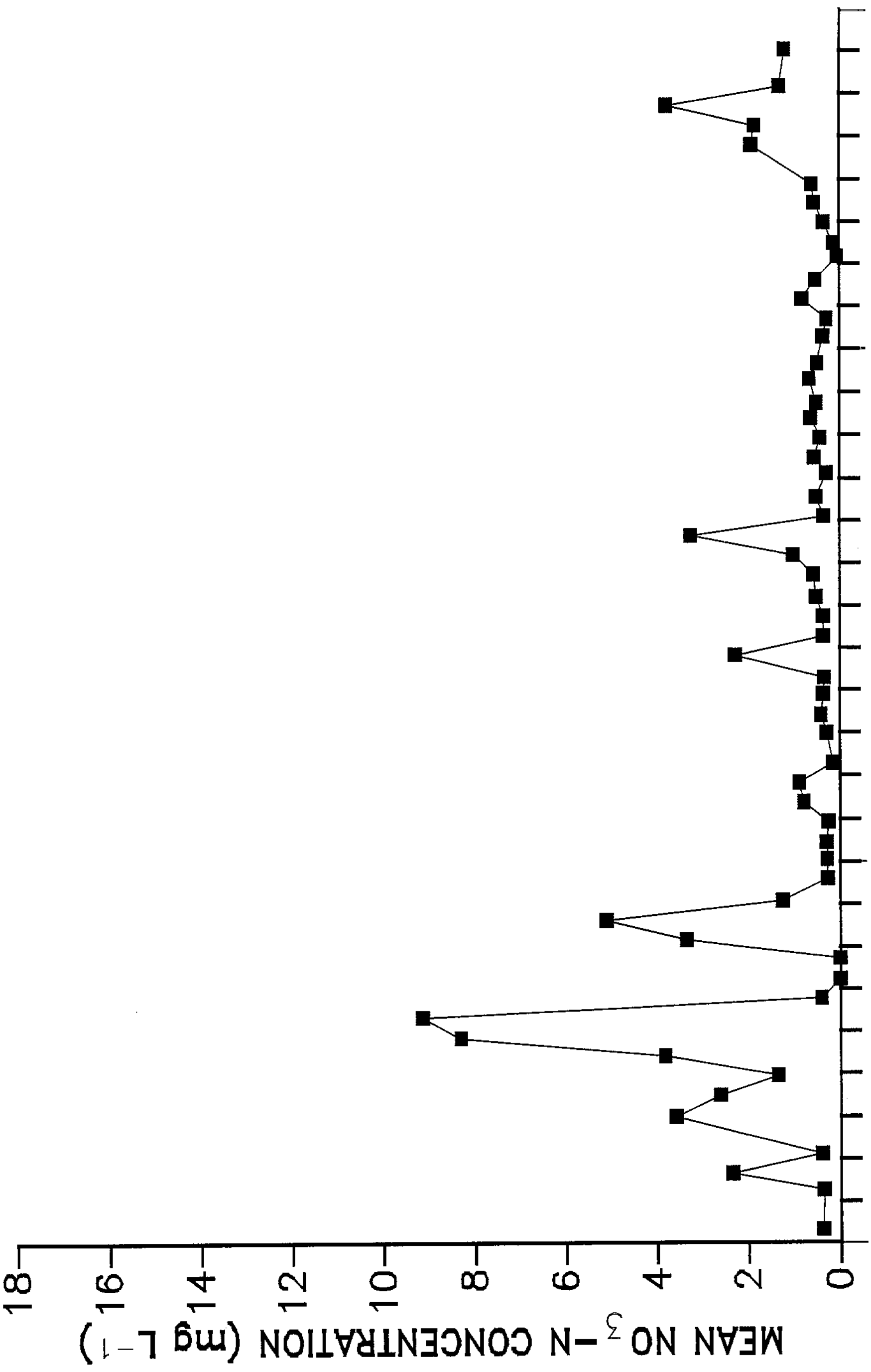

Figure 7. Mean NO_3-N concentrations in the wells in the lowest landscape position at the dairy wetland.

as Br (Hubbard and Sheridan, 1983; Hubbard and Sheridan, 1989; Hubbard and Lowrance, 1993).

Evaluation of the wetland as a bioremediation site will be accomplished by maintaining a nutrient budget for the riparian system over the life of the project (Hubbard *et al.*, 1992). This budget will include the observations of surface and shallow groundwater quality plus results from soil samples. Soil samples for denitrification and inorganic N measurements are being taken monthly at 5 depth increments to 0.3 m. Gaseous losses of N from the soil through denitrification are measured in intact core samples (Lowrance and Smittle, 1988). Nitrogen inputs by symbiotic N fixation will be estimated from the literature. It is anticipated that the effectiveness of the wetland ecosystem as a bioremediation system will increase as the trees mature.

2.2. OVERLAND FLOW - RIPARIAN ZONE TREATMENT OF SWINE WASTE

Work has been underway since January 1993 on the project entitled "Treatment of animal waste by overland flow through grass-riparian zone buffers". This work also is funded through a CSRS National Research Initiative Competitive grant (92-37102-7399). This project will (1) determine the ability of grass-riparian zone buffer strips to cleanse animal waste moving through the system via overland flow, and (2) compare the filtering effectiveness of naturally occurring riparian vegetation versus a recommended wetland species. Three different vegetative treatments are being used for the study: (1) 10 m grass buffer draining into 20 m of natural riparian vegetation forest vegetation, (2) 20 m grass buffer draining into 10 m natural riparian forest vegetation, and (3) 10 m grass buffer draining into 20 m of maidencane. Maidencane (Panicum hematomon) is a species recommended for constructed wetlands.

The animal waste used for the study is swine lagoon waste, which is applied to replicated plots of each vegetative treatment at either high or low wastewater application rates. Within the overall objectives the study will determine rates of sediment, N, P, copper (Cu), and zinc (Zn) removal and transformations. Movement of N (NO_3-N, NH_4-N, and total N), P (ortho, bioavailable, and total), sediment, Cu and Zn is measured in surface runoff-overland flow by collectors both within and at the bottom edge of the plots. Movement of N and ortho P is measured in the root zone and shallow groundwater within and below the plots using suction lysimeters and shallow wells. Soil samples were collected before the start of the study and will be collected again at the end of the study to determine nutrient and heavy metal accumulation over time.

Nitrogen retention in such systems is primarily dependent on denitrification and plant uptake. Rates of these processes will be measured simultaneously on a transect in each plot during the study. Denitrification is measured bimonthly using the acetylene inhibition technique on intact soil cores collected on transects from each plot. Nitrogen, P. Cu, and Zn uptake by the grass is measured periodically on cuttings.

Establishment and instrumentation of the 18 plots for this study were completed in September 1993 and wastewater application began in October 1993. It is anticipated that several years of data collection will be necessary to determine the vegetative treatment and swine lagoon waste application rate most effective in utilizing the waste without negatively impacting the environment.

2.3. MODELING

The information gained from these projects will help in understanding the processes occurring in riparian forest buffer systems. In addition, they will provide data for testing and validation of riparian forest buffer system models. In Tifton, a riparian forest buffer system model with the acronym REMM, Riparian Ecosystem Management Model, is currently under development (Altier, *et al.*, 1994).

The REMM uses a three zone concept. Zone 1 is a narrow band of permanent trees (5-10 m wide) immediately adjacent to the stream channel which provides streambank stabilization, organic debris input to streams, and shading of streams. Zone 2 is a forest management zone where maximum biomass production is stressed, within limits placed by economic goals. Zone 2 may be harvested on appropriate rotations (20-60 years). Zone 3 is a grass buffer strip up to 10 m wide to provide control of coarse sediment and spreading of overland flow.

The model comprises several interactive modules to keep track of water movement, nutrient cycling, and vegetative growth on a daily basis. Feedback between the different modules allows for considerable sensitivity to environmental changes. Algorithms are largely process-based so that the model can respond to diverse conditions. The soil is characterized in three layers through which vertical and horizontal movement of water and associated dissolved nutrients are simulated. The dynamics of carbon (C), N, and P are simulated by means of several organic matter pools characterized by different mineralization rates. Movement of N and P between pools is computed as a function of the mass of C and the C/N and C/P ratios in each pool. Inorganic P is in equilibrium between labile, active, and passive forms, each characterized by varying degrees of stability.

In the vegetation module, growth of upper and lower canopies are simulated concurrently. Carbon is allocated dynamically to the plant organs or held in reserve according to the phenological and nutritional status of the plants. Demand for N and P by the vegetation is determined as a function of biomass in leaf, stem, and root pools. The hydrology module has been run using upland surface and sub-surface input typical to the Southeastern Coastal Plain. At a riparian site in Tifton, GA, water depths in shallow wells have been recorded. Comparisons indicate a close correspondence between simulated and measured water levels.

The concepts of a three zone riparian forest buffer system have already been integrated into draft national specifications for riparian buffer systems by the USDA-Soil Conservation Service and Forest Service (USDA-SCS and USDA-FS). Completion of the REMM will result in a tool to assist agencies and land managers in developing best management designs for utilizing riparian forest buffer systems.

3. Summary

Ongoing studies by scientists of the Southeast Watershed Research Laboratory, USDA-ARS, and University of Georgia are examining the role of riparian forest buffer systems in filtering sediment, nutrients, and pesticides entering from upland agricultural fields. Previous studies have shown that N concentrations in shallow subsurface flow entering riparian forest buffer systems are substantially reduced by the forest. The current studies examine in detail the processes involved in the filtering of N, while also determining the fate of sediment, P, and pesticides. A study using swine lagoon waste also examines the fate of Cu and Zn.

A study with conventional upland agricultural practices (corn or peanuts) is examining the filtering of sediment and nutrients by three different forest management practices (mature trees, clearcut, or selective thinning). A study with liquid dairy manure is evaluating the filtering effectiveness of a reestablishing riparian wetland on nutrients entering from the waste application area via surface runoff or shallow subsurface flow. A pesticide study at this same site is in progress with a source applied to the wetland side not receiving animal waste. The feasibility of using grass-riparian forest buffer systems to filter nutrients from swine lagoon waste applied by overland flow will be investigated by a study examining both type of riparian vegetation and waste application rate.

The results of these studies will be evaluated by the Riparian Ecosystem Management Model (REMM). The model, currently under development at Tifton, uses a three zone concept (Zone 3, grass buffer; Zone 2, upland pine forest; Zone 1 streamside hardwood forest). The model has subcomponents for hydrology, sedimentation, and nutrients.

Trade names are used solely for the purpose of providing specific information. Mention of a trade name, proprietary product or specific equipment does not constitute a guarantee or warranty by the U.S. Department of Agriculture or the University of Georgia and does not imply approval of the named product to the exclusion of other products that may be suitable.

References

Altier, L. S., R. R. Lowrance, R. G. Williams, J. M. Sheridan, D. D. Bosch, R. K. Hubbard, W. C. Mills, and D. L. Thomas. 1994. An ecosystem model for the management of riparian areas. *Proceedings, Riparian Ecosystems in the Humid U. S. Conference.* (In press).

APHA. 1989. Standard methods for the examination of water and wastewater. 17th edition. *American Public Health Association*, Washington, D.C.

Asmussen, L. E., J. M. Sheridan, and C. V. Booram, Jr. 1979. Nutrient movement in streamflow from agricultural watersheds in the Georgia Coastal Plain. *Trans. ASAE* **22**:809-815, 821.

Boyt, F. L., S. E. Bayley, and J. Zoltec. 1976. Removal of nutrients from treated municipal wastewater by wetland vegetation. *J. Wat. Pollut. Control Fed.* **49**:789-799.

Brinson, M. M., H. D. Bradshaw, and E. S. Kane. 1981. Nitrogen cycling and assimilative capacity of nitrogen and phosphorus by riverain wetland forests. *Rep. No. 167, Wat. Resour. Res. Inst.* Univ. North Carolina. Raleigh, NC. 90 p.

Broadbent, F. E. and F. Clark. 1965. Denitrification. Bartholomew, W. V. (ed.). In: *Soil Nitrogen, Agronomy Monograph 10,* Madison, Amer. Soc. of Agron.: p. 347-362.

Comerford, N. B., D. G. Neary, and R. S. Mansell. 1992. The effectiveness of buffer strips for ameliorating offsite transport of sediment, nutrients, and pesticides from silvicultural operations. *Nat. Counc. Paper Ind. Air & Stream Improvement Tech. Bull. 631.* New York, NY.

Day, J. W., Jr., F. H. Schlar, C. S. Hopkinson, G. P. Kemp, and W. H. Conner. 1981. Modeling approaches to understanding and management of freshwater swamp forests in Louisiana (USA). *Coastal Ecology Laboratory. Center for Wetland Resources.* Louisiana State University, Baton Rouge.

Doyle, R. C., D. C. Wolf, and D. F. Bezdicek. 1975. Effectiveness of forest buffer strips in improving the water quality of manure polluted runoff. In: *Managing Livestock Wastes: 299-302. Proc. of the 1975 Int. Symp. on Livestock Wastes,* Am. Soc. of Agric. Eng., St. Joseph, MI.

Ewel, K. C. and H. T. Odum. 1978. Cypress swamps for nutrient removal and wastewater recycling. In: H. T. Odum, K. C. Ewel (prin. invest.), *Cypress Wetlands for Water Management, Recycling, and Conservation. Fourth Ann. Rept.*

to NSF and Rockefeller Found. Center for Wetlands, Univ. of Florida, Gainesville. pp. 16-34.

Gilliam, J. W. and D. L. Terry. 1973. Potential for water pollution from fertilizer use in North Carolina. *Ext. Circ. No. 550.* NC State Univ., Raleigh.

Gregory, S. V., F. J. Swanson, W. A. McKee, and K. W. Cummins. 1991. An ecosystem perspective of riparian zones. *BioScience* **41**:540-551.

Groffman, P. M., A. J. Gold, and R. C. Simmons. 1992. Nitrate dynamics in riparian forests: microbial studies. *J. Environ. Qual.* **21**:666-671.

Hill, A. R. and N. Wylie. 1977. The influence of nitrogen fertilizer on stream nitrate concentrations near Alliston, Ontario, Canada. *Prog. Water Technol.* **8**:91-100.

Hill, A. R. 1983. Denitrification: Its importance in a river draining an intensively cropped watershed. *Agric. Ecosyst. Environ.* **10**:47-62.

Hoare, R. A. 1979. Nitrate removal from streams draining experimental catchments. *Prog. Wat. Technol.* **11**,4-6:303-313.

Hoyt, G. D. 1981. Nitrogen cycling in a southeastern Coastal Plain agricultural ecosystem. *Ph.D. dissertation,* Univ. of Georgia, Athens, GA. 167.

Hubbard, R. K. and J. M. Sheridan. 1983. Water and nitrate-nitrogen losses from a small, upland coastal plain watershed. *J. Environ. Qual.* **12**:291-295.

Hubbard, R. K. and J. M. Sheridan. 1989. Nitrate movement to groundwater in the southeastern coastal plain. *J. Soil & Water Conserv.* **44**(1):20-27.

Hubbard, R. K., G. Vellidis, and R. Lowrance. 1992. Wetland restoration for filtering nutrients from an animal waste application site. *ASAE Symposium, Land Reclamation: Advances in Research and Technology.* 144-150.

Hubbard, R. K. and R. R. Lowrance. 1993. Spatial and temporal patterns of solute transport through a riparian forest. *Proceedings of the Riparian Ecosystems in the U. S. Conference.* (In press).

Jacobs, R. C. and J. W. Gilliam. 1985. Riparian losses of nitrate from agricultural drainage waters. *J. Environ. Qual.* **14**:472-478.

Johnson, J. C., R. E. Hellwig, G. L. Newton, J. L. Butler, and E. D. Threadgill. 1984. Use of liquid dairy cattle waste to produce Tifton 44 bermudagrass forage. *4th Annual Solar and Biomass Energy Workshop,* Atlanta, GA, April 17-19, 1984.

Karr, J. R. and I. J. Schlosser. 1978. Water resources and the land-water interface. *Science* **01**:229-234.

Kitchens, W. H., J. M. Dean, L. H. Stevenson, and J. H. Cooper. 1975. The Santee Swamp as a nutrient sink. In: F. G. Howell, J. B. Gentry, M. H. Smith (eds.), *Mineral Cycling in Southeastern Ecosystems. ERDA Symposium Series.* p. 349-366.

Leopold, L. B., M. G. Wolman, and J. P. Miller. 1964. Fluvial processes in geomorphology. W. H. Freeman and Company, San Francisco.

Lowrance, R. R., R. L. Todd, and L. E. Asmussen. 1983. Waterborne nutrient budgets for the riparian zone of an agricultural watershed. *Agr. Ecosystems Environ.* **10**: 371-384.

Lowrance, R. R., R. L. Todd, and L. E. Asmussen. 1984a. Nutrient cycling in an agricultural watershed: I. Phreatic movement. *J. Environ. Qual.* **13**:22-27.

Lowrance, R. R., R. L. Todd, and L. E. Asmussen. 1984b. Nutrient cycling in an agricultural watershed: II. Streamflow and artificial drainage. *J. Environ. Qual.* **13**:27-32.

Lowrance, R. R., R. Todd, J. Fail, Jr., O. Hendrickson, Jr., R. Leonard, and L. Asmussen. 1984c. Riparian forests as a nutrient filter in agricultural watersheds. *BioScience* **34**(6):374-377.

Lowrance, R., R. Leonard, and J. Sheridan. 1985. Managing riparian ecosystems to control nonpoint pollution. *J. Soil and Water Cons.* **40**:87-91.

Lowrance, R. and D. Smittle. 1988. Nitrogen cycling in a multiple-crop vegetable production system. *J. Environ. Qual.* **17**:158-162.

Lowrance, R. 1992. Groundwater nitrate and denitrification in a Coastal Plain riparian forest. *J. Environ. Qual.* **21**:401-405.

McColl, R. H. S. 1978. Chemical runoff from pasture: the influence of fertilizer and riparian zones. *N. Z. Journal of Marine and Freshwater Res.*, **12**:371-380.

Mitsch, W. J., C. L. Dorge, and J. R. Wiemhoff. 1979. Ecosystem dynamics and a phosphorus budget of an alluvial cypress swamp in southern Illinois. *Ecology.* **60**:1116-1124.

Nessel, J. K. 1978. Distribution and dynamics of organic matter and phosphorus in a sewage enriched cypress swamp. *Master's thesis.* Dept. Envir. Engrg. Sci., Univ. of FL, Gainesville.

Odum, E.P. 1969. The strategy of ecosystem development. *Science* 164:262-270.

Omernick, J. M., A. R. Abernathy, and L. M. Male. 1981. Stream nutrient levels and proximity of agricultural and forest land to streams: some relationships. *J. Soil Water Conserv.* **36**:227-231.

Peterjohn, W. T. and D. L. Correll. 1984. Nutrient dynamics in an agricultural watershed: observations on the role of a riparian forest. *Ecology* **65**:1466-1475.

Qualls, R. G. 1984. The role of leaf litter nitrogen immobilization in the nitrogen budget of a swamp stream. *J. Environ. Qual.* **13**:640-644.

Reddy, K. R. and D. A. Graetz. 1981. Use of shallow reservoir and flooded organic soil systems for waste water treatment: Nitrogen and phosphorus transformations. *J. Environ. Qual.* **10**:113-119.

Robinson, J. B., N. K. Kaushik, and L. Chatarpaul. 1978. Nitrogen transport and transformations in Canagigue Creek. *Internatl. Joint Commission,* Windsor, ON.

Rowe, M. L. and S. Stinnett. 1975. Nitrogen in the subsurface environment. EPA Report 660/3-75-030 Grant No. R801381. Corvallis, OR: Natl. Environmental Research Center, Office of Research and Development. *U. S. Govt. Printing Ofc.,* Washington, DC 20402.

Schlosser, I. J. and J. R. Karr. 1981a. Water quality in agricultural watersheds: Impact of riparian vegetation during base flow. Water Res. Bull. **17**:233-240.

Schlosser, I. J. and J. R. Karr. 1981b. Riparian vegetation and channel morphology impact on spatial patterns of water quality in agricultural watersheds. *Environ. Manag.* **5**:233-243.

Simmons, R. C., A. J. Gold, and P. M. Groffman. 1992. Nitrate dynamics in riparian forests: Groundwater studies. *J. Environ. Qual.* **21**:659-665.

Sweeney, B. W. 1993. Effects of streamside vegetation on macroinvertebrate communities of White Clay Creek in eastern North America. *Proc. Acad. Natur. Sci. Phila.* **144**:291-340.

Thomas, G. W. and J. D. Crutchfield. 1974. Nitrate-nitrogen and phosphorus contents of streams draining small agricultural watersheds in Kentucky. *J. Environ. Qual.* **3**:46-49.

Todd, R., R. Lowrance, O. Hendrickson, L. Asmussen, R. Leonard, J. Fail, and B. Herrick. 1983. Riparian vegetation as filters of nutrients exported from a coastal plain agricultural watershed. In: *Nutrient Cycling in Agricultural Ecosystems* (R. Lowrance, R. L. Todd, L. E. Asmussen and R. A. Leonard, eds.). p. 485-493. Special Publ. No. 23, Univ. of Georgia, College of Agriculture Experiment Stations, Athens, GA.

Tomlinson, T. E. 1970. Trend in nitrate concentrations in English rivers and fertilizer use. *Water Treat. Exam.* **19**:277-289.

Tuschall, J. R., P. L. Brezonik, and K. C. Ewel. 1981. Tertiary treatment of wastewater using flow-through wetland systems. In: *National Conference of Am. Soc. of Civil Engineers.* July 8-10, Atlanta, GA.

Van Kessel, J. F. 1977. Removal of nitrate from effluent following discharge on surface water. *Water Res.* **11**:533-537.

Vellidis, G., R. Lowrance, M. C. Smith, and R. K. Hubbard. 1993. Methods to assess the water quality impact of a restored riparian wetland. *J. Soil and Water Conserv.* **48**(3):223-230.

Vellidis, G., M. C. Smith, R. K. Hubbard, and R. Lowrance. 1992. Surface runoff samplers for nutrient assimilation measurement in a restored riparian wetland. *ASAE Symposium, Land Reclamation: Advances in Research and Technology.* 135-143.

Vitousek, P.M. and W.A. Reiners. 1975. Ecosystem succession and nutrient retention: A hypothesis. *BioScience* 25:262-270.

Webster, J. R., S. W. Golladay, E. F. Benfield, J. L. Meyer, W. T. Swank, and J. B. Wallace. 1992. Catchment disturbance and stream response: an overview of stream research at Coweeta Hydrologic Laboratory. p. 231-253. In P. J. Boon, P. Calow, and G. E. Petts (ed.) *River conservation and management.* John Wiley & Sons, New York.

Yates, P. and J. M. Sheridan. 1983. Estimating the effectiveness of vegetated flood plains/wetlands as nitrate-nitrite and orthophosphorus filters. *Agr. Ecosystems and Environ.* **9**:303-314.