LITERATURE REVIEW PERTAINING TO BUFFER STRIPS

An extensive and comprehensive search, review and summary of the current literature on buffer strips (also known as vegetative or vegetated filter strips or zones, riparian plantings, grass strips)

A research Sub-Program of

THE NATIONAL SOIL CONSERVATION PROGRAM

Dr. W. Findlay, Scientific Authority

Prepared by

Helen Lammers-Helps

and Douglas M. Robinson

and the

Soil and Water Conservation Information Bureau

University of Guelph, Guelph, Ontario

Dr. M.H. Miller, Science Advisor

July, 1991

EXECUTIVE SUMMARY

of a Literature Review Pertaining to Buffer Strips

Buffer strips historically have been used for the improvement of surface water runoff from logging and surface mine operations. More recently they have been promoted in the U.S. and now Ontario for feedlot and cropland runoff.

Buffer strips are bands of planted or indigenous vegetation situated downslope from cropland or animal production facilities to provide localized erosion protection and filter nutrients, sediment and other pollutants from agricultural runoff before they reach receiving waters. Buffer strips are also known as vegetative filter strips, grass filters, grass strips, riparian plantings and combinations thereof.

The two major removal mechanisms at work in vegetative filter strips are deposition and infiltration. As runoff enters the filter strip, its flow is retarded by the increased surface roughness and resistance of the vegetation. The decrease in velocity results in a decrease in the sediment transport capacity of the flow. If the resultant transport capacity is less than the inflow sediment load, sediment is deposited at the interface between the filter and the upslope area. The deposition wedge is typically 30-50 cm wide and occurs immediately upslope of the filter. Once this deposition zone fills up, the deposition front moves downslope in 50 cm intervals until the buffer strip is completely full. Sediment-bound pollutants are also deposited.

Soluble nutrients and some fine particles enter the soil profile with runoff infiltrating into the buffer strip. After entering the soil profile they can be removed by a combination of chemical, physical and biological processes. Mobile water soluble nutrients such as nitrate may leach through the soil profile.

Other mechanisms presumed to be at work are filtration of suspended solids, adsorption to plant and soil surfaces and absorption of soluble pollutants by plants. However, these mechanisms are not well understood at this time.

Research in the U.S. has shown that both tree and grass buffer strips can effectively remove coarse sediments if the runoff flow is shallow and uniform. Buffer strips are less efficient at removal of the small particle sizes. Buffer strips do remove sediment-bound nutrients but with a slightly less efficiency than sediment.

Removal of soluble nutrients by buffer strips is highly variable. The concentration can actually increase due to the re-release of previously trapped nutrients as flow passes through the buffer strip.

There is very little information currently available with respect to the abilities of buffer strips to remove pesticides or pathogens from runoff water. Sediment-bound pesticides and pathogens are likely deposited to some extent but could be re-released at a later time. Some pathogens and pesticide would be removed with infiltrating water. More research is needed in this area.

Buffer strips have been credited with stabilizing streambanks and reducing in-channel erosion. Tillage implements are kept away from the watercourse edge, heavy equipment off the banks and vegetation roots stabilize the soil.

The buffer strip width required depends on many site, vegetation and climatic factors. In general terms, the width required increases as:

? slope of the land above the filter strip increases
? cross-slope of the buffer strip increases
? drainage area increases
? particle size of the soil upslope decreases
? infiltration of the soil upslope decreases

? velocity/volume of runoff increases

There are currently no simple design models available. According to James Krider, the National Environmental Engineer with the United States Department of Agriculture in Washington, D.C. a national handbook with design recommendations for site-specific conditions is in draft form and should be available later this year. The design criteria only consider sediment and surface flow.
This may offer some guidance to extension personnel in Ontario.

There has not been any research to date on recommended species for buffer strips for Ontario conditions. Species recommended for grassed waterways could serve as a guide for grass buffer strips. There has not been any research yet on the most appropriate species selection for riparian tree plantings.

Since runoff must cross the buffer strip as sheet flow in order to be most effective, in-field buffer strips or grassed waterways may be more appropriate in hilly areas where water tends to concentrate in natural drainageways prior to crossing the buffer strip.

No research to date has examined the effectiveness of buffer strips during the winter and early spring when vegetation is dormant. Runoff from snowmelt and winter/spring rains is very significant in Ontario.

Maintenance of a dense vegetation is essential to the long-term performance of the buffer strip. Mowing, fertilization and possibly herbicide application are necessary. Using the buffer strips as turn lanes or traffic lanes or for grazing livestock destroys the vegetation. Leaving a plough furrow parallel to the edge of the buffer strip results in water concentrating and flowing along the buffer strip edge and then crossing as concentrated flow at a low point. Furrows can be removed following ploughing with a light disking.

There is also a tendency for the strips to get narrower each year due to ploughing of the edge of the strip. This should be avoided.

More research is needed in several key areas in order to utilize buffer strips effectively in Ontario.

1. How can they be used effectively in the upland areas of the province where flow tends to concentrate in natural drainageways prior to entering watercourses?

2. How effective are buffer strips during the winter and early spring when vegetation is dormant?

3. What is the ability of limited-width buffer strips in removing fine particles? This is of particular importance in the lowland areas of the province with heavy clay soils such as Essex, Lambton and Haldimand counties.

4. Most experiments have been short-term. What is the long-term effectiveness of buffer strips? What is the fate of organic material trapped in the filter? Are nutrients re-released into runoff flows? What impact do buffer strips have on subsurface water quality due to increased infiltration of runoff water and associated pollutants?

5. Simple design criteria which consider particle size, nitrogen, phosphorus, pathogens and pesticides under various site-specific conditions such as topography and soil texture are needed in order to utilize buffer strips effectively.

6. What is the effectiveness of buffer strips with respect to the removal of pathogens (if they are a problem) and pesticides?

7. What tree and herbaceous species are most suitable for vegetative filter strips here in Ontario?.

BACKGROUND AND INTRODUCTION

The effects of non-point source (NPS) pollution (or pollution from cropland runoff) has received increasing attention in Ontario. The International Joint Commission, Pollution from Land Use Activities Reference Group (PLUARG), released a report in 1978 which indicated that a large proportion of the phosphorus entering the Great Lakes was from cropland runoff (Miller and Spires, 1978). As much as 80% of this phosphorus was associated with sediment which had eroded from intensively cultivated land (Logan, 1988).

More recently, there have been increasing concerns relating to pesticides, pathogens and nitrogen in waters draining from agricultural land. Buffer strips, also known as vegetated or vegetative filter strips, grass strips, buffer zones, grass buffer strips and riparian plantings, have been one form of Best Management Practice (BMP) promoted in the U.S. and more recently in Ontario to remove contaminants from runoff prior to entering watercourses.

This literature review has been funded by the National Soil Conservation Program under the Canada-Ontario Agreement on Soil Conservation. The purpose of the Program is to encourage the implementation of appropriate soil resource management practices to maximize societal benefits and sustain the long-term productivity of soil within the framework of environmentally sustainable agriculture.

The Scope

This report will review, interpret and summarize the information that is currently available on buffer strips for use by advisors carrying out farm planning at the farm level. In addition, this paper will identify additional research needed in order to evaluate buffer strips under Ontario conditions.

Specifically, this paper will examine the literature on buffer strip effectiveness in the removal of sediment, nutrients, pesticides and pathogens with respect to slope, soil type, buffer strip width, species of vegetative cover etc. In addition, information on the impact of buffer strips on the physical protection of stream banks will also be presented.

A comprehensive search was made of the available literature with a total of 14 databases accessed. The following databases were searched: the Soil and Water Conservation Information Bureau's ENVIRO.DOC (formerly called S&WCONS which includes AGRICOLA, USDA Library) and ASK_ELTON; CAB (Commonwealth Agricultural Bureau); CAN/OLE (Canadian On Line Enquiry for CISTI MONOGRAPH and CISTI SERIAL); NTIS (National Technical Information Service); UTLAS (University of Toronto Library Acquisition Service); ICAR (Inventory of Canadian Agri-food Research), University Microfilms International; MICROLOG Micromedia Ltd, CURRENT CONTENTS Institute for Scientific Information; Directory of Federally Supported Research; GROUND WATER ON-LINE (National Ground Water Information Center); AQUAREF (Environment Canada) and the U.S. Environmental Protection Agency (EPA) Non-Point Source Pollution Database. Several search word combinations were used.

Researchers at the University of Illinois, University of Guelph, Oregon State University, University of Maryland and University of Kentucky were contacted directly for their input and status of ongoing research (see Table 1).

TABLE 1: RESEARCHERS CONTACTED

Researcher	University
G. O'Neill	U. of Guelph, Dept. Env. Biology
N. Kaushik	U. of Guelph, Dept. Env. Biology
T. Dickinson	U. of Guelph, School of Engineering
B. Barfield	U. of Kentucky, Dept. of Ag. Engineering
D.A. Kovacic	U. of Illinois, Water Res. Ctr.
B. Emmingham	Oregon State U., Fish & Wildlife Dept.
W. Magette	U. of Maryland, Dept. of Ag. Engineering
T. Dillaha	Virginia Polytechnic Institute

DISCUSSION

1.0 What are Buffer Strips?

Buffer strips are also frequently referred to as vegetative filter strips, grass strips, filter strips, buffer zones, riparian plantings and combinations thereof. For the purposes of this paper, they are defined as "bands of planted or indigenous vegetation situated downslope of cropland or animal production facilities to provide localized erosion protection and filter nutrients, sediment and other pollutants from agricultural runoff before they reach receiving waters" (Dillaha et al., 1989 and Dillaha et al., 1988). Traditionally, they have been located immediately adjacent to watercourses. However, more recently, it has been recommended that they be located wherever they will be most effective such as the lower boundary of a field (Dillaha et al., 1989). The various descriptive terms will be used interchangeably in this paper.

The majority of the research on buffer strips has been carried out at the University of Kentucky in Lexington, Virginia Polytechnic Institute in Blacksburg, and the University of Maryland in College Park.

Historically, buffer strips or zones have been recommended for protection of watercourses from logging (Grounewoud, 1977), construction (Environment Canada, 1980), strip mining (Barfield et al., 1979), as a part of overland flow systems for small feedlots (Stearns et al., 1982) and for the protection of fish habitat from urban pollution sources (MNR, 1987).

2.0 How Do Buffer Strips Work?

Filter strips aid in water quality improvement by changing the flow hydraulics. The two main mechanisms at work in buffer strips for surface water quality improvement are infiltration and deposition. By enhancing infiltration, fine particles or soluble pollutants in the runoff enter the soil profile preventing them from entering surface water bodies. Once runoff has entered the soil profile, pollutants such as nitrogen and phosphorus can be removed by a combination of physical, chemical and biological processes. Infiltration also reduces the sediment transport capacity by reducing the volume of runoff. Some filter strips for feed lots in the U.S. have been designed such that all of the runoff infiltrates. However, this approach has large land requirements and ignores other removal mechanisms (Dillaha et al., 1987).

Deposition is another important removal mechanism at work in buffer strips. As runoff enters a vegetative filter strip, its flow is retarded by the increased surface roughness and resistance of the vegetation. The decrease in velocity results in a decrease in the sediment transport capacity of the flow. If the resultant transport capacity is less than the inflow sediment load then sediment is deposited at the interface between the filter and the upslope area. This deposition wedge is typically 30-50 cm wide and occurs immediately upslope of the filter strip. Once this deposition zone fills up, then the deposition front moves downslope into the filter at 50 cm intervals until the filter is completely full. Once the filter has been completely inundated with sediment it ceases acting as a filter strip (Barfield et al., 1979 and Hayes et al., 1979, Dillaha et al., 1987). Sediment-bound pollutants are also deposited (Lee et al., 1989).

Other mechanisms presumed to be at work in vegetative filter strips are filtration of suspended solids, adsorption to plant and soil surfaces and absorption of soluble pollutants by plants. These mechanisms are not well understood (Lee et al, 1989 and Dillaha et al., 1987).

Flow must be slow, shallow and uniform through the grass buffer strips in order to provide sufficient contact time for these mechanisms to work (Dillaha et al., 1988 and Lee et al., 1989).

3.0 Effectiveness of Buffer Strips

The effectiveness of buffer strips in improving surface runoff water quality varies with many factors such as slope, slope length, volume and velocity of runoff water, the nature of the eroding sediment, vegetation type, height and density, filter width and the nature of the pollutant in question.

The majority of the research conducted to date has been on sediment and sediment-bound nutrients in herbaceous buffer strips. There has been very little work on soluble nutrients, pesticides or pathogens.

3.1 Sediment

The majority of the work to date has looked at the ability of grass buffer strips to remove total sediment, with a lesser amount of work on specific particle sizes. The majority of the experiments have involved the use of rainfall simulation on small "source" plots adjacent to grass buffer strips. Early work focused on runoff from feedlots and surface mines. More recent work has examined their effect on cropland runoff.

Neibling and Alberts (1979) found that buffer strips ranging in size from 0.6 m to 4.9 m wide removed over 90% of the total sediment. However, only 37%, 78%, 82% and 83% of the clay-sized fraction were removed by the 0.6m, 1.2 m, 2.4 m and 4.9 m filter strips respectively. Ninety-one percent of the sediment was deposited in the first 60 cm of the buffer strip.

Wilson (1967) examined the use of buffer strips to remove pollutants from water entering reservoirs and found that 10' was sufficient to remove the maximum percent of sand, 50' for silt and 400' for clay. There was an inverse relationship between the filtration length required and the particle diameter.

Young et al. (1980) found that a 27.4 m orchard grass buffer strip removed 66% of the total sediment while a sorghum-sudan grass buffer strip removed 82% of the total sediment from the runoff of a 13.7 m "simulated" feedlot plot.

Bingham et al. (1978) found that a fescue buffer strip down slope from a 13 m poultry manure treated plot required a 1:1 ratio between feedlot and buffer strip to reduce the pollutant loads to near background levels.

Magette et al. (1987) found that 4.6 m and 9.2 m filter strips removed 72% and 86% of the total sediment load respectively.

Dillaha et al. (1987) did find that vegetative filter strips were more effective for cropland runoff due to decreased runoff volumes (increased infiltration in the cropland vs. concrete or compacted feedlots) which resulted in a lower sediment transport capacity.

Paterson et al. (1980) found that 71% of the total sediment in the incoming runoff from surface applied dairy waste was deposited in a 35 m fescue filter strip. Dillaha et al (1989) found that 74% of the total sediment was removed in a 4.6 m filter strip and 87% in a 9.1 m strip. Dillaha et al. (1988) found that 81% and 91% of total sediment were removed by 4.6 m and 9.1 m filter strips respectively. However, the efficiency of the filter strip decreased with time and dropped an average of 9% between the first and second rainfall simulations. This indicates that the strips may become less effective in time due to sediment deposition. This would depend on the vegetation's ability to outgrow the deposited sediment and the depth of the sediment accumulated.

Dillaha (1989) also reported that buffer strips with cross-slopes which resulted in channelized flow were much less effective at removing sediment. Dillaha et al. (1988) reported that concentrated flow reduced buffer strip efficiencies by 40-95%. They concluded that shallow, uniform flow (sheet flow) was required in order for buffer strips to be effective in removing sediment. Buffer strips will not be very effective where water collects in natural drainageways prior to crossing the buffer strips. The researchers observed this in a survey of actual buffer strips in Virginia.

Herbaceous buffer strips have been effective in removing significant quantities of total sediment in controlled, small plot, experiments (strips of widths of up to 9.1 m removed between 71% and 91%). However, they are less efficient at removing the fine particle sizes (clay, silt and organic particles). The clay particles are highly reactive and are enriched in phosphorus and other chemicals (Dillaha et al., 1987).

These experiments are of a short-term nature and do not adequately represent what may be happening over the long-term. Inundation of vegetation by sediment and re-release of previously deposited nutrients may impact on their long-term effectiveness.

3.2 Nutrients

Generally, buffer strips behaved similarly, with regards to sediment-bound nutrients, as they did for sediment although they were usually slightly less effective (Dillaha et al., 1989, Dillaha et al., 1987 and Magette et al., 1987). Dillaha et al. (1989) found that 69% and 82% of the total phosphorus and 63% and 76% of the total nitrogen were removed by 4.6 and 9.1 m grass strips. Ninety-three per cent of the phosphorus in the runoff was sediment-bound. Phosphorus can be dissolved orthophosphates, hydrolyzable polyphosphate or organic phosphorus or it can be sediment-bound (insoluble inorganic P compounds, sorbed or fixed P, organic P in plant or animal matter). The proportions of each in the runoff are controlled by the nature of the sediment and by kinetic factors such as turbulence and the flow rate of moving water (Lee et al., 1989).

Doyle et al. (1977) found that only 9%, 8% and 62% of the soluble phosphorus, 0%, 57%, and 68% of the soluble nitrogen were removed with 0.5 m, 1.5 m and 4.0 m filter strips. The ammonium concentration actually increased with increasing filter length presumably due to mineralization of organic nitrogen compounds previously trapped by the filter. Likewise Paterson et al. (1980) found that only 38% of the ammonium, 42% of the B0D and 7% of the orthophosphates were removed. Dillaha (1988) found that soluble nitrogen and phosphorus concentrations were often higher in the outflow. This was presumably due to release of nitrogen and phosphorus from sediment previously trapped in the filter.

Magette et al. (1987) reported that only 17% and 41% of the nitrogen and 51% and 53% of the phosphorus were removed by 4.6 and 9.2 m buffer strips when all the test runs were averaged. However, the results of individual tests varied widely. The researchers concluded that filter strips could not be relied upon as the sole means of reducing nutrient concentrations in overland flows.

These results are summarized in Table 2.

Herbaceous buffer strips are slightly less efficient in the removal of total phosphorus and nitrogen compared to total sediment (Dillaha et al., 1987, Magette et al., 1987, Dillaha et al., 1985, Magette et al., 1989, Magette et al., 1986). Based on the research conducted thus far, it would appear that buffer strips do not reliably remove soluble phosphorus and nitrogen from runoff. Dillaha et al. (1989) found that concentrations of phosphorus in the runoff which had passed through a filter 9.1 m wide were still sufficient to cause eutrophication.

The impact of buffer strips on potassium concentrations and loads in surface runoff has received very little attention by researchers. This is likely because the potassium level in water is not associated with a health risk.

3.3 Pathogens

There are many pathogenic microorganisms which are found in manure and which can survive in soil for lengthy periods of time. These can include bacteria, viruses and parasites. Salmonella bacteria can live in the soil for 7-168 days, Erysipilothrix bacteria for 21 days, Enterovirus 25-170 days, Poliovirus for 32 days and the parasite Ascaris Lumbricoidesova 700-2000 days (Barrington, 1991). These can affect human health when they enter surface water supplies through overland runoff.

There has been almost no research to date on the effect of buffer strips on the removal and survival of pathogenic microorganisms. Young et al. (1980) measured total coliforms, fecal coliform and fecal streptococci in feedlot runoff. Buffer strips between 21.34 and 27.43 m reduced total coliforms and fecal coliforms 69% and fecal streptococci 70%. Total coliform counts decreased with increasing buffer strip width. Young et al. (1980) calculated that a 35.44 m buffer strip would be required to reduce the Total Coliform count in runoff from a 13.72 m deep feedlot to <1000/100 ml (the primary contact recreation quality standard for that area).

According to Philipp et al. (1985) roots of some higher plants are thought to produce bactericidal compounds which kill pathogenic organisms. The researchers investigated the effect of a reed Phragmites communis in filter beds on the populations of Salmonella senftenberg, Ascaris suum eggs, coliforms and enterobacteriaceae in sewage sludge after passing through the filter beds. They did not find that the reed had a hygienic effect on sewage sludge.

Since filter strips are relatively effective in removing total sediment one could hypothesize that pathogens attached to soil particles will be deposited along with sediment. However, since many bacteria, viruses and parasites can live for lengthy periods of time they could be re-released into runoff flowing over the filter strips.

Bacteria and parasites can be removed by a combination of adsorption and predation when they enter the soil profile with infiltrating water (Loehr, 1984). Viruses are removed only by adsorption and can migrate through the soil profile into subsurface waters if the soil is very porous or the water table is high.

More research is needed on the effect of buffer strips on the existence and fate of pathogens in agricultural runoff water.

3.4 Pesticides

There has been very limited work to date on the effect of buffer strips on the removal of pesticides from runoff water. Asmussen et al., (1977) measured the 2,4-D concentration in field runoff upon entering and leaving a 24.4 m grassed waterway. They found that 70% of the 2,4-D was removed regardless of the antecedent soil moisture.

Many factors affect the fate of pesticides once they have been applied. The nature of the agrichemical will affect its mobility and availability and includes such properties as its water solubility, the degree and strength of its adsorption to soil particles, method of application--surface application vs. incorporation, the rate of application, its half-life.

Soil properties, climatic conditions and the length of time since application also affect the fate and transport of agrichemicals. Soil pH and texture can affect the mobility of the applied chemical and steep slopes provide increased opportunity for transport. Temperature affects the rate of break down, rainfall intensity can affect the opportunity for transport, and timing can affect how much is available for transport. Losses can be high if a large runoff event occurs within 2 weeks of application and it is the first runoff event since application (Ritter, 1988).

In general terms, products that are more water soluble will move primarily with runoff while those that are strongly adsorbed will move mostly with sediment. Pesticides with solubilities of 10 ppm or greater will tend to move primarily in the water phase of runoff (Ritter, 1988).

More work on chemicals known to move with surface runoff such as 2,4-D, metolachlor, MCPA, and atrazine (Frank, 1991) needs to be carried out in order to determine the effectiveness of buffer strips in eliminating them from surface water.

In addition to filtering pesticides from field runoff, buffer strips should minimize direct overspray of pesticides into watercourses by keeping sprayers back from the stream edge (Lovell and Van Dongen, 1991).

4.0 The Effect of Buffer Strips on Bank Stability

Buffer strips are thought to enhance the physical protection of stream banks by preventing the operation of tillage equipment to the edge of the bank, keeping heavy equipment from destabilizing the banks, reducing erosion of the streambank by decreasing the velocity of surface runoff entering the water course, and limiting the development of gullies extending back from the banks (Lovell, and Van Dongen, 1991).

There has been limited research to date on the effect of buffer strips on bank stability. Dillaha et al. (1987) visited existing cropland vegetative filter strips installed on 18 farms in Virginia. They observed that the buffer strips did "prevent localized channel erosion".

Dickinson et al. (1988) in a study of streambank erosion in Ontario stated that streambank erosion was dependent on "susceptibility of bank soil material to erode, the nature of the agricultural activity in the vicinity of the bank and the characteristics associated with the hydraulic shear forces of the stream flow". They developed an Agriculture Intensity Value, **Ag Index**, to describe the influence of land use on the banks. Woodlot and pasture without animals were given an **Ag Index** of 1 and 2 respectively, but intensive row cropping was given a value of 42.

Kandolf and Curry (1984) observed that where there was a loss of streamside trees due to a lowering of the water table from production wells between 1965 and 1980, the channel widened from 13 m to 35 m in 2 years. The bank was made up of unconsolidated sands and gravels which lacked cohesive strength without vegetation. Areas where there were no production wells did not lose their vegetation and subsequently did not suffer widening of the channel.

Researchers in the Agroforestry unit at the University of Guelph planted a 2 km stretch of Washington Creek, a degraded agricultural stream near Plattsville, Ontario, with a combination of poplar, alder, silver maple, black walnut, green ash and red oak in 1985. Studies into streambank stabilization, nutrient cycling, and biomass production have been ongoing. The researchers state that "after 5 years ... eroding banks have stabilized" although no data to support this finding is presented (Gordon and Williams, 1990).

5.0 Factors Which Affect Buffer Strip Effectiveness

There are many factors which affect the capacity of filter strips to remove pollutants from runoff including site factors, vegetation factors, rainfall and runoff factors and maintenance.

5.1 Soil and Site Factors

Site and soil factors such as the slope, soil characteristics and management of the land above the buffer strip, the width of the buffer strip, and the antecedent soil moisture influence buffer strip efficiency.

5.1.1 Slope

Although many researchers measured and recorded the slope of their runoff plots, only a few studies have actually tried to determine the effect of slope. Vanderholm and Dickey (1980) investigated design criteria for Vegetative Filter Systems for Feedlot runoff. These filter systems consisted of a settling basin, a distribution component and a vegetative filter area. They gave minimum buffer strip widths of 91.4 m (300') - 262 m (860') for slopes ranging from 0.5% to 4.0% for overland-flow systems (shallow, uniform flow). They did not recommend buffer strips for slopes of more than 4% due to "high velocities, reduced filter effectiveness and possible erosion". They based flow distances on the "principle that runoff from most small storms should be completely infiltrated into the soil of the vegetative filter area".

Dillaha et al. (1987) using rainfall simulations to generate cropland runoff observed that buffer strips adjacent to plots with the steepest slopes (16%) were less effective for sediment, nitrogen and phosphorus yield reductions than those with 11% slopes.

Although many researchers noted the slopes in their experiments, there has been little actual work done comparing slopes.

5.1.2 Land Use and Soil Characteristics Above the Filter

The volume of runoff and pollutant loads will be influenced by the land characteristics, the land use and its management upslope from the filter. Soil texture and structure affect the soil's erodibility and infiltration rate. Buffer strips are more effective at removing coarse sediments and aggregates than clay-sized or fine organic particles; therefore they would be more effective where upslope soils consist of primarily coarse sediments. Farming practices such as the type and number of tillage practices used, fertilizer management, type of crops grown and a variety of other land management practices affect the quality and quantity of surface runoff and therefore influences the effectiveness of buffer strips in improving runoff quality(Lee et al., 1989).

5.1.3 Antecedent Soil Moisture

The soil moisture status at the time of a rainfall event influences the runoff volume and hence capacity of the runoff to transport sediment and associated pollutants. Doyle et al. (1977) found that one particular natural rainfall event (out of a total of 5) on a saturated soil accounted for the majority of the sediment, nutrient and bacterial loads. The event resulted in the largest volumes and percent of rainfall as surface runoff during the experiment. The greater the runoff volume and associated load, the wider the buffer strip needs to be.

5.1.4 Buffer Strip Width

In general, the longer the strip is, the greater the reduction in runoff velocity, the greater the increse in infiltration, and the greater the reduction in sediment-carrying capacity and the greater the deposition, particularly the fine clay-sized particles. The recommended width is a function of many site-specific conditions such as slope, soil texture upslope from the filter strip, land use and management above the strip, soil erodibility above the strip, type of strip vegetation, degree of strip maintenance, size of drainage area and length of slope above the strip. As of yet there are no design criteria for determining the required width based on these factors. In general, the required strip width increases as slope and slope length above the strip increases and infiltration and particle size of the soil upslope decreases. These factors are discussed throughout this review.

5.2 Effect of Vegetation Characteristics

5.2.1 Vegetation Type

Vegetation in buffer strips generally consists of grasses, legumes, trees or a combination thereof. A limited amount of work has looked at the effectiveness of cornstalk residue strips in improving surface water quality.

Wilson (1967) states the following as being ideal characteristics for grass buffer strips; a deep root system to resist scouring if "swift currents" develop; dense top growth (well ramified); resistance to flooding and drought; ability to recover growth after inundation; yield economic return either through the production of seed or hay.

Only a few experiments have compared the effectiveness of different species. Wilson (1967) compared 6 grasses, Goars fescue, Panicum Colaratum, Blue Panicum, Coastal Bermuda grass, common Bermuda grass, and Sudan grass and 1 legume, Lahontan alfalfa. The buffer was 1000' long and had an average slope of 0.10%. Removal efficiencies over 2 years of experiments varied from a low of 60% and 65% for the Lahontan alfalfa and the Panicum Coloratum respectively to a high of 99% for the two Bermuda grasses.

Young et al. (1980) compared orchard grass (Dactylis glomerata L.), oats (Avena sativa L.), a mixture of sorghum-sudangrass (Sorghum vulgare L.-Sorghum sudanense L.) and corn (Zea mays L.) filter strips for improving the quality of feedlot runoff. The corn, orchard grass, sorghum-sudangrass and oats reduced solids by an average of 86%, 66%, 82% and 75%. Runoff was reduced by 82%, 81%, 61% and 41% for the corn, orchard grass, sorghum-sudangrass and oat plots respectively. The corn plot was the most effective in reducing soil and water losses. The slope was 4% and the corn was planted perpendicular to the slope.

Alberts et al. (1981) examined sediment nitrogen and phosphorus runoff in cornstalk residue strips of various lengths and residue cover levels. The 2.7 m strip with 50% surface residue cover reduced sediment load by 75% and the nutrient load by 70%. Reductions in sediment increased with increasing length and residue cover. The strips were more effective in removing the larger particles while silts and clays rich in nutrients tended to stay in suspension. The strips were much less effective during the second run of the experiment indicating that they may only be effective on a short-term basis. Interestingly, the 1-2 mm sized aggregates were deposited in the 30-50 cm directly upslope from the residue strip.

Buffer strips could also consist of trees and shrubs or a combination of grasses with trees and shrubs. No information on the differences in the tie-up or utilization of nutrients by different tree or shrub species in a stream-side planting could be found.

In addition to their effectiveness in "filtering" sediment and nutrients, vegetation suitable to the growing conditions should be chosen. Species mixes recommended for grassed waterways should give some guidance. Creeping red fescue, brome grass, Kentucky bluegrass, white Dutch clover, bird's-foot trefoil, and tall fescue are recommended in the OMAF factsheet 82-063, "Grassed Waterways" (Arnold et al., 1982). Grasses that bunch such as orchard grass and timothy are not recommended for grassed waterways. Alfalfa or an alfalfa-grass mixture could be useful where the land owner desires livestock feed. These grass and legume species and others suitable for Ontario conditions such as clover and reed canary grass should be evaluated for their ability to act as filters.

Species and seeding mixtures recommended in Virginia are given in Table 3 (Dillaha et al., 1986).

Kao et al. (1975) found that alternating bare soil strips with grass strips maintained high trapping efficiencies and eliminated the need to disturb the grass strips to remove sediment since the sediment would be trapped in the bare soil portion if the "appropriate width ratio of grass to bare ground strips is selected".

5.2.2 Vegetation Density and Height

Since a reduction in flow velocity which is necessary to bring about deposition, one of the two major removal mechanisms, is dependent on increased roughness and resistance, vegetation density is important. Although many researchers stated the importance for maintaining a dense vegetation (Dillaha et al., 1986) no population densities have been presented.

The height of the vegetation is also an important consideration since this affects the surface roughness and the likelihood that the grass will bend over during a flow event. Heights of 10-15 cm have been recommended in the literature (Dillaha et al., 1986).

5.3 Rainfall and Runoff Factors

One important consideration in our temperate climate in Ontario is the timing of runoff relative to the growth stage of the vegetation. For example in an experiment in Michigan, the most substantial runoff event occurred in early March and was the result of a combination of the melting of the snow pack (6 cm water equivalent) and several light rain storms (Aull et al., 1980). What effect does vegetation have during the winter when it is not actively growing? None of the work to date has addressed this very important question.

As the size and intensity of a rainfall event increases, the percentage becoming runoff also tends to increase. This generally results in increased sediment and nutrient loads and increased submergence of the vegetation in the buffer strip (Westerman and Overcash, 1980 and Wilson, 1967). Wilson (1967) observed that the filtration efficiency was "markedly reduced" when the grass was submerged.

5.4 Long-Term Effectiveness and Maintenance

Dillaha et al. (1986) surveyed buffer strips on 33 Virginia farms to determine how effective actual buffer strips were. First of all, 29% of the filter strips had excessive weed growth. This tended to shade out the desirable species and result in reduced ground cover. Mowing/spraying/reseeding would have helped. In 19% of the buffer strips, using the filter strips as turn rows or roads had damaged the vegetation. Filter strips should also be protected from damage by livestock.

Dillaha et al. (1986) observed that filter strips which had been mowed regularly were thicker and healthier. There was also a tendency for grass strips to get narrower each year as farmers ploughed out the edge. This should be avoided in order to maintain an effective width.

The buffer strips should be located with care. Dillaha et al. (1989) in their visits to actual buffer strips found 15% were higher than the adjacent land from which they were supposed to be receiving water. Ploughing parallel to the buffer edge left a furrow in which water tended to concentrate and then cross the filter strip at a low point. This results in concentrated flow which greatly reduces the buffer strip's effectiveness in removing sediment, nutrients or other pollutants (Dillaha et al., 1989). Some filter strips had filled with sediment. This caused them to act like terraces such that water tended to flow parallel to the buffer until it reached a low point and crossed as concentrated flow.

5.5 Other Considerations

Thirty-six percent of the actual buffer strips visited were judged to be "totally ineffective". The most common problem was concentration of runoff in natural drainageways prior to entering the buffer strip. The researchers concluded that "vegetative filter strips are not appropriate for fields with extensive internal drainageways unless the filter strips extend up into the fields and parallel to the drainageways forming grassed waterways".

6.0 Effect of Forest Buffer Strips on Water Quality

Forest buffers have been recommended for many years for the protection of streams from the logging of trees and building of logging roads. Van Groenewoud (1977) recommended 15 m (50') buffers be left on flat terrain and 65 m (200') on moderately sloping terrain.

There has been less research to date on the effects of forest buffer strips or wooded riparian vegetation on water quality from agricultural runoff. Cooper et al. (1987) attempted to determine the amount of sediment deposited in two riparian areas over a 20 year period. The watersheds were 800 ha and 1400 ha in size. Half of each watershed was cultivated land. Using a combination of Cesium 137 sampling techniques and morphological data, they determined that 15-30 cm of sediment was deposited at the field-forest edge. In the flood plain swamp adjacent to the stream, less than 5 cm of sediment had accumulated. Sediment deposited at the forest edge was predominantly sand while the flood plain swamp deposition was primarily silt and clay. Estimates indicated that 84-90% of the eroded sediment had stayed in the watershed.

Doyle et al. (1975) and Doyle et al. (1977) applied dairy manure at a rate of 90 metric tonnes/ha to the surface of a silt loam soil. There was a forest buffer area downslope of the manure-treated area with mixed deciduous trees and honey suckle ground cover with a 35-40% slope. Following natural rainfall, water samples were collected at 0 m, 3.8 m, 7.6 m, 15.2 m and 30.5 m into the forest buffer. The greatest decrease in total soluble N, P and K concentrations occurred between 0 and 3.8 m. There was no significant difference in the concentrations between 3.8 and 30.5 m. The authors also found that a 3.8 m buffer strip significantly reduced fecal coliforms and fecal streptococci counts. There was also no significant difference in forest buffer strip effectiveness between 3.8 m and 30.5 m on the removal of bacteria.

Schnabel (1986) found that nitrate concentration decreased by more than 50% during transit through 16 m of a riparian zone near a small stream in Pennsylvania. He concluded it was likely due to biological processes, namely denitrification. Schnabel states that the extent of biological processes "depends on biomass, kinetics of biological processes, morphology and hydrology of the watershed, extent of the near-stream zone and contact time between solution, roots and microbes".

Other researchers have attempted to look at nutrient dynamics in the entire watershed including the upland cropped area, forested riparian area and the stream itself (Peterjohn and Correll, 1984, Schnabel, 1986, Lowrance et al., 1983, Lowrance et al., 1984a and 1984b and 1984c, Yates and Sheridan, 1983)). Lowrance et al. (1983, 1984a, and 1984b and 1984c) studied nutrient budgets for the Little River

Watershed in Georgia. Upland agricultural soils were separated from the stream by riparian mixed hardwood vegetation including red maple, tulip trees and black gum. Only 6 to 33 % of the nitrogen entering the watershed in precipitation left in streamflow (streamflow accounted for over 99% of the flow out of the watershed). Uptake of nitrogen by woody vegetation and microbial denitrification to gaseous forms were credited with the removal of nitrogen.

The nitrogen entering the riparian zone was primarily in the inorganic form (82%). However, nitrogen in the streamflow was primarily in the organic form (80%) indicating that the nitrogen remaining was converted from inorganic to organic forms.

Two high flow events accounted for 19% of the total annual flow. These events accounted for 19% of the sediment load and 30% and 27% of the annual sediment-associated nitrogen and phosphorus respectively. This may indicate that nutrient-rich sediments were delivered directly to the stream during intensive storms.

Only 3% of the watershed was tile drained at the time of the study in 1979. Tile flow is rapidly transported directly into the receiving stream without the benefit of riparian transformation of nutrients (Kovacic et al., 1990).

Kovacic et al. (1990) looked at subsurface flow in both perennial grass (reed canary grass, Phalaris arundicae) and forest (mature cottonwoods, Populus deltoides) buffer strips downslope from an intensive row cropping area. They found that nitrate concentrations in subsurface flow in the forest buffer were reduced by 94% in 10 m (32'). Nitrate concentrations in the grass buffer were reduced by only 50% 14 m (45') into the buffer. It took an additional 25 m (83') for a total of 39 m (128') to reduce nitrate concentrations by 90%.

Researchers have attempted to estimate nutrient budgets and measure sediment deposition in natural riparian areas. It is difficult to estimate nutrient budgets for watersheds due to the complexity of subsurface flow paths and the number of transformations that can occur with nutrients such as denitrification, mineralization and nitrification of nitrogen.

The work which has been done thus far indicates that forest buffer strips can improve surface water quality through deposition of sediment and removal of bacteria and nutrients. The work done to date also indicates that subsurface flow water quality improves as it passes through the riparian zone.

However, many questions remain unanswered. The tie-up or transformation of nutrients in the riparian zone will depend on many factors.

Tile lines emptying directly into watercourses will bypass the "filtering capacity" of the riparian or buffer zone.

Nutrients may only be tied up for the short-to-medium term. Deciduous trees drop their leaves each fall. This is a significant source of detritus and will contribute nutrients to the watercourse (Kaushik, 1981). In addition, trees and other near-stream vegetation in riparian plantings eventually die and the material is broken down releasing carbon, phosphorus, nitrogen etc. back into the system and potentially into the watercourse.

The age of the trees will affect the rate of nutrient uptake. Several researchers have recommended that riparian zones need to be selectively managed and harvested in order to maintain high rates of nutrient uptake (Lowrance et al., 1984c, 1985); however, no data or guidelines have been presented thus far.

Other benefits of harvesting would include production of fuel wood and timber for the land owner which could be an added incentive for the conversion of farmland to riparian plantings.

Nutrient dynamics will also depend heavily on local hydrogeological and soil characteristics such as soil texture, drainage, presence of impermeable layers, hydraulic conductivity etc.

As of yet, there has been very little work on the capacity of different species to tie up nutrients or on their suitability for the riparian area.

Researchers at the University of Guelph have constructed an artificial riparian zone using sealed plywood boxes filled with a loam soil and set on a 4% slope. Carolina poplar (Populus spp.) and Shrub Willow (Salix spp.) were planted in the boxes. Water with a constant nitrate concentration (10 ppm or 20 ppm) was supplied to the two boxes. Three tree densities were used--0, 1 or 2 cuttings per box for poplar and 0, 2 or 4 per box for willow (Gordon and Williams, 1990 and 1991).

Under the controlled conditions of the experiment, the trees did lower the concentration of nitrate (O'Neill, 1991). As the tree density increased, the nitrate concentration decreased more quickly. The effectiveness of clones vs. whips is also being evaluated. The whips were more effective in utilizing the nitrogen early on because they already had roots.

Research is currently ongoing at Oregon State University as well. There, 1400 fast-growing cottonwood cuttings were planted along an agricultural stream, Oak Creek in 1989. In 1990, alder seedlings were added. The researchers are looking at the trees ability to extract nitrogen from groundwater prior to its entering the creek. The researchers cite other advantages of riparian plantations including shading of the stream to lower water temperature and improve fish habitat and the provision of cover for wildlife habitat. No results are currently available (Emmingham, 1991).

As of yet, there are no guidelines for the restoration of riparian areas for water quality improvement. More research isolating the various components of the riparian ecosystem is needed.

7.0 Existing Models and Design Criteria

Most of the work involving the development of analytical procedures to model vegetative filter strips has been done at the University of Kentucky for erosion control in surface mining areas (Barfield et al., 1979, Hayes et al., 1979, 1984, Tollner et al., 1977, 1982). Barfield et al. (1979) presented a steady-state model for homogenous sediment for determining the **sediment-**trapping efficiency under varying flow rates, sediment loads, particle sizes, flow durations, channel slopes and media density. Hayes et al. (1979) extended the model for unsteady flow and non-homogeneous sediment. Hayes and Hairston (1983) evaluated the Kentucky Filter Strip Model against actual field data and got good agreement under those particular conditions.

Kao et al. (1975) using artificial media in lab studies developed width ratios of grass to bare ground in order to prevent buffer strips from being inundated with sediment and becoming ineffective. These ratios need to be verified in the field under varying site conditions.

SEDIMOT II (SEdimentology by DIstributed MOdel Treatment), is a simulation model developed by researchers at the University of Kentucky. Subroutine GRASS, describes the runoff discharge and sediment size distribution (Lee, 1987). A phosphorus transport component has been incorporated into the model called GRAPH (GRAss PHosphorus). It was verified using rainfall simulation. According to Lee et al. (1989) sediment concentration, yield and trapping efficiencies were simulated well but total suspended solids were overestimated by 7% for the 4.6 m filter strip and 13% for the 9.1 m filter strip. The model is an event-based model and does not necessarily describe long-term effectiveness. According to Dillaha

(1989), GRAPH is the only available filter strip design model which considers both sediment and nutrient transport of which only phosphorus has been considered so far. The model has had limited testing and needs further field testing and verification before it could be recommended for wide spread use (Lee, 1987).

Several researchers have attempted to use CREAMS, a field scale model for **C**hemical, **R**unoff and **E**rosion from **A**gricultural **M**anagement **S**ystems as a tool for evaluating buffer strips (Williams and Nicks, 1988 and Flanagan et al., 1986). Flanagan et al. (1986) using data from a 20 year rainfall study for Louisiana under the conditions of a 9.1 m buffer strip, 5% slope, slope length of 91 m, and fall ploughed corn on a silt loam soil found a good fit between the observed and predicted trapping efficiencies under the field conditions. The authors presented a table for the design of buffer strips under a specific set of conditions.

William and Nicks (1988) evaluated CREAMS for a 1.6 ha wheat watershed in Oklahoma using buffer strip widths of 3-15 m, slopes of 2.4-10% and convex and concave slopes. The buffer strip effectiveness depended on strip length, surface roughness, the slope and slope length. The authors concluded that CREAMS is a "useful tool" for evaluating vegetative filter strip effectiveness in reducing sediment yield. CREAMS does not consider long-term effectiveness of buffer strips and cannot accommodate the effects of concentrated flow (Dillaha, 1989). Although CREAMS does contain nutrient submodels, their use with vegetative filter strips has not been reported (Dillaha, 1989).

According to Dillaha (1989) models for the design of filter strips should consider their long-term effectiveness. The model should consider the effect of internal drainageways and concentrated flow, the build up of degradable organic material and the fate of nutrients and their potential for re-release into the flow. Dillaha et al. (1989) suggests the following models in order to accommodate the effects of internal field drainageways: ANSWERS, AGNPS, and the watershed version of WEPP.

GRAPH is the most comprehensive simulation model developed to date but it is event-based and only considers sediment and phosphorus. A model should also simulate nitrogen, pathogen and pesticide transport and removal in runoff water.

A conference was held in March 1989 in the United States to develop updated technical standards for vegetative filter strip design and use (Dillaha, 1989). The proposed standards define vegetative filter strips as vegetated areas which are designed to remove sediment, nutrients, pathogens, organic materials, pesticides and other contaminants from surface runoff by filtration, deposition, infiltration, absorption, adsorption, decomposition and volatilization. The new standard does not require that vegetative filter systems be located immediately adjacent to streams but instead may be located where they will be most effective such as the lower boundary of a field or within a field.

According to Dillaha (1989) a handbook of procedures for vegetative filter strip design was to be prepared and made available by 1991. According to James Krider, National Environmental Engineer, United States Department of Agriculture in Washington, D.C. the Handbook of design procedures is in draft form and should be available later this year. The design criteria allow buffer strips to be designed according to site-specific conditions but only consider sediment and surface flow. According to Krider, there is insufficient information available at this time for other pollutants or subsurface flow.

RESEARCH NEEDS

More research is needed in several key areas in order to utilize buffer strips effectively in Ontario.

1. How can they be used effectively in the upland areas of the province where flow tends to concentrate in natural drainage ways prior to entering watercourses?
2. How effective are buffer strips during the winter and early spring when vegetation is dormant?
3. What is the ability of limited-width buffer strips in removing fine particles? This is of particular importance in the lowland areas of the province with heavy clay soils such as Essex, Lambton and Haldimand counties.

4. Most experiments have been short-term. What is the long-term effectiveness of buffer strips? What is the fate of organic material trapped in the filter? Are nutrients re-released into runoff flows? What impact do buffer strips have on subsurface water quality due to increased infiltration of runoff water and associated pollutants?
5. Simple design criteria which consider particle size, nitrogen, phosphorus, pathogens and pesticides over the long-term under various site-specific conditions such as topography and soil texture are needed in order to utilize buffer strips effectively.
6. What is the effectiveness of buffer strips with respect to the removal of pathogens (if they are a problem) and pesticides?
7. What tree and herbaceous species are most suitable for vegetative filter strips here in Ontario?.

CONCLUSIONS

Buffer strips are "bands of planted or indigenous vegetation situated downslope of cropland or animal production facilities to provide localized erosion protection and filter nutrients, sediment and other pollutants from agricultural runoff before they reach receiving waters". They may include grasses, legumes, trees, shrubs and various combinations thereof.

The two major removal mechanisms are deposition and infiltration. The vegetation in the filter strip increases surface roughness which decreases the flow velocity. Decreasing the velocity of the runoff in turn reduces the sediment carrying capacity of the runoff. If the resulting sediment carrying capacity is less than the sediment load, deposition will occur. Infiltration also reduces the sediment carrying capacity of the runoff by reducing the volume of the flow. Soluble nutrients and fine particles move through the soil profile with infiltrating water where they may be removed by a combination of physical, chemical and biological processes.

Experimental observations have shown that the bulk of the gross sediment deposition occurs in a 30-50 cm zone immediately upslope of the buffer strip. Once this deposition zone fills, a new zone is created 50 cm into the buffer strip. A deposition wedge continues to move downward until the buffer strip is completely filled.

The majority of research to date has involved short-term controlled experiments using runoff generated by simulated rainfall on small "source" plots with adjacent herbaceous buffer strips. This research has shown that grass buffer strips can be effective in the removal of gross sediment and to a slightly lesser extent, sediment-bound nutrients provided that the flow is shallow and uniform (under the conditions of the experiments). The ability of the buffer strips to remove the highly reactive fine clay, silt and organic particles is much less clear.

The efficiency of buffer strips in removing soluble nutrients is highly variable. On some occasions, the concentration of soluble nutrients was actually higher in the outflow than in the inflow. This was presumably due to the re-release of nutrients from previously trapped sediments. Buffer strips cannot be relied upon as the sole means of removal for soluble nutrients.

There has been limited work to date on the impact of buffer strips on pathogenic bacteria, viruses and parasites in surface runoff. One study showed that 70% of the fecal coliforms and fecal streptoccoci in feedlot runoff were removed in a grass buffer strip. More research with various buffer widths and vegetation types is required in order to judge their effect on known pathogenic organisms occurring in agricultural runoff.

Currently, there is very little information available regarding the capacity of buffer strips to remove pesticides from surface runoff. One study showed that a 24.4 m grassed waterway did reduce the concentration of 2,4-D in runoff water by 70%. The removal of pesticides from surface runoff will depend to a large extent on the solubility of the pesticide and the degree and strength of adsorption to soil particles.

More recently, researchers have been attempting to determine the influence of riparian vegetation with trees on both surface and subsurface water quality. It is thought that excessive nutrients in both surface and subsurface runoff will be tied up by the trees. Denitrification in the sediments adjacent to the streams may remove significant quantities of inorganic nitrogen from subsurface water. Riparian zones are highly complex and it can be difficult to isolate the effects of the various processes occurring. Research is ongoing at the University of Guelph with trees in artificial riparian zones to isolate the impact of trees on nitrate concentrations in the soil. More research is needed in this area. Buffer strip effectiveness depends on the conditions at each site: slope, length of slope above the buffer strip, soil type of eroding sediment, runoff volume and velocity, vegetation species, height and density, buffer strip width and more.

Observations of actual on-farm grass buffer strips in Virginia indicated that they were not effective in hilly areas where surface runoff concentrated in natural drainageways and crossed the buffer strips as concentrated flow.

In order to maintain high trapping efficiencies, thick, dense vegetation must be present in the filter strips. Mowing, fertilization (and possibly spraying) are necessary on a regular basis. Vegetative filter strips should not be used for grazing, traffic or turn lanes since this destroys the vegetation. Runoff water tends to concentrate in plough furrows parallel to the edge of the buffer strip and then cross at the low areas as concentrated flow. Leaving a furrow parallel to the buffer edge should be avoided. Ploughing too close to the edge of the buffer should be avoided in order to maintain the width.

Visual observations of actual buffer strips and natural riparian areas have shown that the watercourse banks are protected from localized erosion. Tillage implements are kept back from the edge, heavy machinery off the banks and the roots of vegetation stabilize the soil.

Many questions regarding the use of buffer strips for removal of pollutants from surface water remain to be answered. Most of the experimentation with herbaceous buffer strips has involved rainfall simulation over a period of a few weeks. What is their long-term effectiveness? What effect does the accumulation of sediment in the filter have? What is the fate of nutrients and organic material trapped in the filter? Are they re-released into runoff flows?

What is their effect during the winter and early spring when vegetation is not actively growing? This is a very important question regarding their suitability under Ontario's climatic conditions.

If soluble nutrients (nitrate in particular) move downwards with infiltrating water, what is their fate? What impact does this have on the quality of subsurface water?

More information is needed on the suitability of grasses, legumes and trees grown in Ontario. As of yet, there are no simple design criteria for the various conditions that consider sediment, phosphorus, nitrogen, pesticides and pathogens over the long-term. A package needs to be put together for Ontario's soil, topographic, and climatic conditions. Aspects of the existing models discussed in Section 7.0 could be incorporated into the model.

Buffer strips have been shown to be effective in reducing gross sediment concentrations and to a lesser extent sediment-bound nitrogen and phosphorus in controlled experiments. The nature of the buffer strip that will be most effective will be dependent on a number of site-specific conditions such as topography, size of the watershed, soil texture, land use and more.

In addition, if buffer strips are to continue to perform they must be actively managed to maintain a dense, thick, healthy vegetative cover that will continue to trap sediments and nutrients.

BIBLIOGRAPHY

Alberts, E.E., W.H. Neibling and W.C. Moldenhauer. 1981. Transport of Sediment, Nitrogen and Phosphorus Through Cornstalk Residue Strips. Soil Sci. Soc. Am. J. 45(6):1177-1184.

Arnold, J., T.H. Lane, and W.T. Dickinson. 1982. Grassed Waterways. OMAF factsheet 82-063.

Asmussen, L.E., A.W. White Jr., E.W. Hauser, and J.M Sheridan. 1977. Reduction of 2,4-D Load in Surface Runoff Down a Grassed Waterway. J. Environ. Qual. 6(2): 159-162

Aull, G., P. Loudon and B. Gerrish. 1980. Runoff Water Quality Enhancement with a Vegetated Buffer. ASAE Paper No. 80-2538. Am Soc. Agr. Eng. St. Joseph, Mi.

Barfield, B.J., E.W. Tollner and J.C. Hayes. 1979. Filtration of Sediment by Simulated Vegetation I. Steady-State Flow With Homogenous Sediment. Transactions of the ASAE pp 540-548.

Barrington, S. 1991. Characteristics of Livestock Manures. Proceedings: Canadian Agricultural Research Council National Workshop on Land Application of Animal Manure June 11-12, 1991 Ottawa

Bingham, S.C., M.R. Overcash, P.W. Westerman. 1978. Effectiveness of Grass Buffer Zones in Eliminating Pollutants in Runoff From Waste Application Sites. ASAE Paper No. 78-2571, St. Joseph, MI

Cooper, J.R., J.W. Gilliam, R.B. Daniels and W.P. Robarge. 1987. Riparian Areas as Filters for Agricultural Sediment. Soil Sci. Soc. Am. J. 51:416-420.

Dickinson, W.T., R.P. Rudra and G.J. Wall. 1988. Nomographs and Software for Field and Bank Erosion. ASAE Paper No. NAR 88-406.

Dillaha, T.A., J.H. Sherrard, D. Lee, S. Mostaghimi, V.O. Shanholtz. 1985. Sediment and Phosphorus Transport in Vegetative Filter Strips: Phase I, Field Studies. ASAE Paper No. 85-2043.

Dillaha, T.A., J.H. Sherrard, and D. Lee. 1986. Virginia Water Resources Research Center - Virginia Polytechnic Institute and State University. Bulletin 153.

Dillaha, T.A., R.B. Reneau, S. Mostaghimi, V.O. Shanholtz and W.L. Magette. 1987. Evaluating Nutrient and Sediment Losses from Agricultural Lands: Vegetative Filter Strips. United States EPA CBP/TRS4/87.

Dillaha, T.A., J.H. Sherrard, D. Lee, S. Mostaghimi, V.O. Shandholtz. 1988. Evaluation of Vegetative Filter Strips as a Best Management Practice for Feed Lots. J. Water Pollution Control Federation. 60:1231-1238.

Dillaha, T.A. 1989. Water Quality Impacts of Vegetative Filter Strips. ASAE Paper No. 89-2043 St. Joseph, MI

Dillaha, T.A., R. Reneau, S. Mostaghimi and D. Lee. 1989. Vegetative Filter Strips for Agricultural Nonpoint Source Pollution Control. Transactions of the ASAE Vol. 32(2): 513-519.

Doyle, R.C., D.C. Wolf, D.F. Bezdicek. 1975. Effectiveness of Forest Buffer Strips in Improving the Water Quality of Manure Polluted Runoff. In Managing Livestock Wastes Proceedings of the 3rd International Symposium on Livestock Wastes ASAE, St. Joseph, MI pp. 299-302.

Doyle, R.C., G.D. Stanton and D.C. Wolf. 1977. Effectiveness of Forest and Grass Buffer Strips in Improving the Water Quality of Manure Polluted Runoff. ASAE Paper No. 77-2501 St. Joseph, MI

Emmingham, B. 1991. Oregon State University. Personal Communication.

Environment Canada. 1980. Environmental Code of Good Practice for General Construction. Report EPS 1-EC-80-1.

Flanagan, D.C., W.H. Neibling, G.R. Foster and J.P. Burt. 1986. Applicability of CREAMS in Filter Strip Design ASAE 86-2043

Frank, R. 1991. Groundwater Quality. Proceedings of the Innovative Farmers Workshop Jan 15-16, 1991 Guelph pp. 20-25.

Gordon, A. and P. Williams. 1990. Agroforestry Research and Development, Environmental Biology, University of Guelph. 1989-90 Annual Report.

Gordon, A. and P. Williams. 1991. Agroforestry Research and Development, Dept. Env. Biology, University of Guelph. 1990-91 Annual Report.

Hayes, J.C., Barfield B.J. and R.I. Barnhisel. 1979. Filtration of Sediment by Simulated Vegetation II. Unsteady Flow With Non-Homogenous Sediment. Transactions of the ASAE 22(5): 1063-1067.

Hayes, J.C. and J.E. Hairston. 1983. Modeling the long-term effectiveness of vegetative filters as on-site sediment controld. ASAE Paper No. 83-2081 St. Joseph, MI

Hayes, J.C., B.J. Barfield and R.I. Barnhisel. 1984. Performance of Grass Filters Under Laboratory and Field Conditions. Transactions of the ASAE 27(5): 1321-1331.

Kandolf, G.M. and R.R. Curry. 1984. The Role of Riparian Vegetation in Channel Bank Stability: Carmel River, Cal.
Wainer, R.E. and K.M. Hendrix (eds). California Riparian Systems -Ecology, Conservation, and Productive Management. University of California Press.

Kao, D., B.J. Barfield, and AE Lyons. 1975. On-site Sediment Filtration Using Grass Strips. National Symposium on Urban Hydrology and Sediment Control pp. 74-82

Kaushik, N.K. 1981. From Forest to Fish Biology of Woodland Streams in Water Pollution and Management Reviews Ed. C.K. Varshney
South Asian Publishers Pvt Ltd., New Delhi pp. 18-39

Kovacic, D.A., L.L. Osborne, B.C. Dickson. 1990. The Influence of Riparian Vegetation on Nutrient Losses in a Midwestern Stream Watershed. Water Resources Center, University of Illinois Project No. S-1117. Sept. 1990.

Lee, P. 1987. Simulation of Phosporus Transport in Vegetative Filter Strip (Phd. Thesis). Virginia Polytechnic Institute.

Lee, D., T.A. Dillaha and J. Sherrard. 1989. Modeling Phosphorus Transport in Grass Buffer Strips. J. Env. Eng. Vol 115(2) April
pp 409-427.

Loehr, R.C. 1984. Land Treatment and Stabilization of Wastes In Pollution Control for Agriculture (Second Edition). Dept. of Agricultural Engineering, Cornell University, Ithaca, N.Y., Academic Press, Inc., Orlando pp. 287-337.

Logan, T.J. 1988. An assessment of Great Lakes Tillage Practices and Their potential impact on water quality. pp. 270-281. T.J. Logan (ed.) In Effects of Conservation Tillage on Groundwater Quality. Lewis Publisher, Chelsea, MI.

Lovell, B. and P. Van Dongen. 1991. Buffer Strips. OMAF Farmland Conservation Bulletin.

Lowrance, R., R. Todd, L. Asmussen. 1983. Waterborne Nutrient Budgets for the Riparian Zone in an Agricultural Watershed. Agricultural Ecosystems and the Environment 10 371-384.

Lowrance, R., R. Todd and L. Asmussen. 1984a. Nutrient Cycling in an Agricultrual Watershed I. Phreatic Movement. J. Environ. Qual. 13(1) 22-26

Lowrance, R., R. Todd and R. Asmussen. 1984b. Nutrient Cycling in an Agricultural Watershed II Streamflow and Artificial Drainage. J. Environ. Qual. 13(1) 27-32

Lowrance, R., R. Todd, J. Fail Jr. O. Hendrickson Jr., R. Leonard, L. Asmussen. 1984c. Riparian Forests as Nutrient Filters in Agricultural Watersheds. BioScience Vol 34 (6): 374-377

Lowrence, R., R. Leonard and J. Sheridan. 1985. Managing Riparian Ecosystems to Control Nonpoint Pollution. J. Soil and Water Conservation. Jan-Feb 1985 p. 87-91

Magette, W., R.B. Brinsfield, R. Palmer, J.D. Wood. 1986. Vegetated Filter Strips for Nonpoint Source Pollution Control: Nutrient Considerations. 86-2024

Magette, W., R.B. Brinsfield, R. Palmer, J.D. Wood, T.A. Dillaha and R.B. Reneau. 1987. Vegetative Filter Strips for Agricultural Runoff Treatment. U.S. EPA CBP/TRS 2/87

Magette, W.L., R.B. Brinsfield, R.E. Palmer and J.D. Wood. 1989. Nutrient and Sediment Removal by Vegetated Filter Strips. Transactions of the ASAE 32(2):663-667.

Miller, M.H. and A.C. Spires, 1978. Contribution of Phosphorus to the Great Lakes from agricultural land int the Canadian Great Lakes Basin. PLUARG (Pollution from Land Use Activities Reference Group) Report to the International Joint Commission. Windsor, Ontario 55p

Ministry of Natural Resources. 1987. Guidelines on the use of "Vegetative Buffer Zones" to Protect Fish Habitat in an Urban Environment.

Neibling, W.H. and E.E. Alberts. 1979. Composition and Yield of Soil Particles Transported Through Sod Strips. ASAE Paper No. 79-2065. Soil Particle Size.

O'Neill, G. 1991. University of Guelph, graduate student, Dept of Agroforesty. Personal Communication.

Paterson, J.J., J.H. Jones, F.J. Olsen, G.C. McCoy. 1980. Dairy Liquid Waste Distribution in an Overland Flow Vegetative-SoilFilter System. Transactions of the ASAE 973-984.

Peterjohn, W.T. and D.L. Cornell. 1984. Nutrient Dynamics in an Agricultural Watershed: Observations on the Role of the Riparian Forest Ecology 65(5) 1466-1475

Philipp, W., A. Lang and D. Strauch. 1985. Bacteriological and Parasitological Investigations of Filter Beds Covered with Reeds on the Survival of Salmonellas and Ascaris Eggs <u>In</u> Inactivation of

Microorganisms in Sewage Sludge by Stabilisation Processes eds. D. Strauch, A.H. Havelaan, and P. L'Hermite. Elsevier Applied Science Publishers New York, USA pp 168-176.

Ritter, W.F. 1988. Reducing Impacts of Nonpoint Source Pollution from Agriculture: A review. J. Environ. Health A23(7): 645-667.

Schnabel, R. 1986. Nitrate Concentrations in a Small Stream as Affected by Chemical and Hydrologic Interactionn In the Riparian Zone in Watershed Research Perspectives. ed. D. Correll. Smithsonian Environmental Research Centre.

Stearns, L.J., E.O. Ackerman, and A.G. Taylor. 1982. Illinois Vegetative Filter Design Criteria. ASAE Paper No. 82-2613.

Tollner, E.W., B.J. Barfield, and J.C. Hayes. 1982. Sedimentology of Erect Vegetal Filters. Proceedings of the American Society of Civil Engineers (ASCE) Vol. 108, No. HY12. December pp. 1518-1531

Tollner, E.W., B.J. Barfield, C. Vachirakornwatana, and C.T. Haan. 1977. Sediment Deposition Patterns in Simulated Grass Filters. Transactions of the ASAE 20(5):940-944

Vanderholm, D.H. and E.C. Dickey. 1980. Design of Vegetative Filters for Feedlot Runoff Treatment in Humid Areas. Transactions of the ASAE 23(3): 681-687.

Van Grounewoud, H., 1977. Interim Recommendation for the Use of Buffer Strips for the Protection of Small Streams in the Maritimes. Canadian Forestry service Dept. of Fisheries and the Environment Maritimes Forest Research Centre Information Report M-X-74

Westerman, P. and M. Overcash. 1980. Dairy Open Lot and Lagoon-Irrigated Pasture Runoff Quantity and Quality. Transactions of the ASAE, 23, 1157-1164.

Williams, R.D. and A. Nicks. 1988. Using CREAMS to Simulate Filter Strip Effectiveness in Erosion Control. J. Soil Water Cons. Jan-Feb 108-112

Wilson, L.G. 1967. Sediment Removal From Flood Water by Grass Filtration Transactions of the ASAE 10(1):35-37.

Young, R.A., T. Huntrods, W. Anderson. 1980. Effectiveness of Vegetated Buffer Strips in Controlling Pollution from Feedlot Runoff. J. Environ. Quality. (9)3: 483-487.