BUFFER STRIPS AND WATER QUALITY : A REVIEW OF THE LITERATURE

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Water quality is one of the most important environmental issues facing agriculture today. The contamination of water bodies by sediments and nutrients is a major concern in Atlantic Canada. The contribution of agricultural activities to non-point source pollution depends on the landscape, the nature and the intensity of farm operations, as well as management practices. Many technologies and practices can be adopted in order to alleviate these problems. Water protection legislations requiring the use of vegetative buffers to protect surface water resources are being adopted in several jurisdictions.

The composition and function of a buffer strip will vary in relation to its proximity to a watercourse, the permanence of water flow, the type of soil and the purpose for which the buffer strip is being established or enhanced. For the purpose of this review, buffer strips are defined as an area of planted or naturally occuring vegetation located between a source of contamination and a water body (Dillaha 1989). This environment forms a special niche, rich in animal and plant life (Clary and McArthur 1992). It is usually composed of a wet, a transition and an upland area (Kovalchik and Elmore 1992).

The purpose of this document is to review the literature regarding buffer strips, and to present some general comments regarding their role, establishment, management and relative efficiency for water protection.

ROLE OF VEGETATED BUFFERS

Buffer strips are important to water quality, water quantity, streambank stability, and fish habitat (Hansen 1992; Gordon 1993; White 1993).

<u>Sediment retention</u>: A buffer strip favours the settling out of soil particles by restricting the flow of surface runoff and increasing the water infiltration rate (White 1993; Williams 1993; Forster and Abrahim 1985). However, buffer strips should not be used as a primary sediment control technology. Soil conservation practices must be in place , uphill from the strip, in order to minimize the amount of sediments reaching the buffer (Lemunyon 1991). Buffers will be most effective when used in complement to a sound land management system including nutrient management as well as runoff, sediment and erosion control practices (Welsch 1991).

Buffers are most effective as sedimentation and filtration areas when water flow is shallow and regular. These essential conditions are rarely met under natural conditions. Water usually seeks depressions, gullies, and ditches on its way to the watercourse. Field practices, such as tillage, may further concentrate water flow (Laroche et al. 1993). Concentrated or channelized flow can move sediment and its associated nutrients for 300 m or more (Belt et al. 1992). In cases where 50% or more of the runoff will cross the strip as concentrated flow, it may be necessary to perform some land shaping to redirect runoff to sheet flow (Lemunyon 1991), or to establish some support systems such as sedimentation basins.

Buffer strips should not be used as a sediment removal system when they are located in flood prone areas. Seasonal floods may flush them out and transport the previously trapped sediment particles into the watercourse (Chow 1994).

<u>Removal of nutrients</u>: By increasing the distance between the site of fertilizer application and the stream, the buffer will reduce the likelihood of nutrient contamination by agriculture. Waterborne nutrients can be removed by the buffer's vegetation as they leach through the soil. A forested buffer strip can effectively store large amounts of nutrients (Belt et al. 1992; Lowrance et al. 1985; Peterjohn and Correll 1984).

The soil and plants of the buffer have a limited capacity to absorb and cycle nutrients (Robinson 1991; Robinson and Primard 1992). Continual input of nutrients to the site could soon reach or exceed the system's capacity to absorb them. A saturated system could then become a source of pollution instead of a sink.

The presence of excessive amounts of phosphorus is often responsible for the eutrophication of watercourses. Under normal conditions, applied phosphorus is rapidly bound to soil particles and transported to the stream with eroded sediments. As the buffer area promotes the deposition of sediments, it will reduce the transfer of soil-bound phosphorus from the field to the watercourse (White 1993).

Even though dissolved phosphorus only represents a small portion of transported phosphorus, it can be a major source of concern for water quality (Laroche et al. 1993). Dissolved phosphorus may originate, in part, from organic residues and manure, and may be high even in the absence of sediment (Langdale et al. 1985). Buffer areas will only retain a small portion (less than 25% with a 9.1 m buffer) of the dissolved phosphorus transported out of the field (Dillaha et al. 1985) but larger vegetated filter areas (19.1 m) have been shown to remove up to 58% of the dissolved phosphorus (Table 1).

Nitrate-nitrogen concentrations of more than 10 ppm make water unsuitable to drink. Nitrogen also contributes to eutrophication of water bodies. Nitrate is very mobile and can be taken up by the vegetation. As reported by Peterjohn and Correll (1984), a one hectare forested buffer strip removed 45 kg of nitrogen in one year. Under less efficient conditions, uptake may be as low as 9.6 kg/ha per year (Lawrence et al. 1985).

Table 1: Effectiveness* of a 19 m vegetated buffer

Contaminant	Reduction level (%)
Suspended particles	89.7 %
Nitrate-Nitrogen	60.4 %
Total-Phosphorus	73.7 %
Dissolved-Phosphorus	58.1 %
Organic-Carbon	59.9 %

* Refers to the reduction in the concentration of the nutrient in the runoff water after it passed through the buffer strip.
Source: Peterjohn and Correll 1984.

Denitrification is the reduction of nitrates or nitrites to gaseous nitrogen. It often takes place in poorly drained soils. The bacteria involved in this process can return the nitrogen to the atmosphere. Under certain conditions, denitrification alone was enough to remove all of the N inputs from upland fields to the buffer strip (Lawrence et al. 1984; White 1993).

Although the buffer can effectively trap or convert much of the nitrogen lost from the field, crop utilization within the field clearly is the most environmentally acceptable alternative. Furthermore, nitrogen is a valuable input which should not be allowed to be transported away by the runoff.

Elimination of pesticides : Buffers can also play a valuable role in preventing the contamination of watercourses by certain pesticides. Soil-bound pesticides would be removed from the runoff through the sedimentation of soil particles (Williams 1985). For example, a substantial reduction in the concentration of 2,4-D can take place when the runoff passes through a grassed waterway. As well, a 9.1 m buffer area made it possible to reduce the atrazine content of an affluent by over 55% (Mickelson and Baker 1993).

It should be noted that the buffer's vegetation may be affected by the presence of certain pesticides. For example, Post (sethoxydim) is a commonly used herbicide in the production of potatoes. Its main function is to control grasses. The presence of this herbicide in the runoff may cause the disappearance of grasses from the buffer strip and significantly reduce the buffer's effectiveness.

Streambank stabilization : Plants are critical to the stability of streambanks. Above ground stems dissipate the erosive energy of the water flow, while the root mass improves soil cohesion and armours the embankment against the erosive effect of the water (Carlson et al. 1992). Different species provide differing levels of protection (Rosentrerer 1992). Trees and bushes provide more protection, from a stabilization point of view, than herbaceous species (Hansen 1992). The type of soil and the cohesiveness of the soil aggregates will also influence the stability of the embankment.

Biodiversity: It is necessary to maintain a buffer on the shore of lakes and watercourses in order to protect the aquatic environment and to maintain a cover for wildlife (Ministère de l'Énergie et des Ressources du Québec 1991). Vegetation, which overhangs or falls into a lake or stream, is a valuable source of nutrients and shelter (Nova Scotia Department of Natural Resources). The aquatic environment also hosts numerous fish, invertebrate, and plant species that can only occur in close proximity to the shoreline (Harper et al. 1992).

The adoption of infield conservation practices and a well designed and established buffer area will improve water quality and enhance the value of the watercourse as a habitat.

Water Temperature : Trees can assist in regulating water temperature by shading the watercourse and its shore. Loss of vegetation may increase water temperature by 2 to 10^0C(Belt et al. 1992). White (1993) reported that the loss of shading by clear cutting to a stream side in New Brunswick resulted in a 4.5^{o}C increase in stream water temperature. Such an increase in temperature may harm certain fish species (Belt et al. 1992). The size, depth and flow rate of the watercourse will influence its sensitivity to temperature shifts (Moore 1986).

The amount of shade is more dependent on the height and density of the buffer strip than on its actual width. It is suggested that a dense 24 m buffer strip will maximize the shading effect, while a 17 m buffer will supply 90% of this maximum shade level (Belt et al. 1992).

Dissolved oxygen : The concentration of dissolved oxygen in water decreases with increasing water temperature. Eutrophication may also reduce the amount of dissolved oxygen. Trouts and salmons, which prefer cool well oxygenated water, are most affected by such changes (Belt et al. 1992).

The buffer will enhance the oxygenation of water by shading and reducing the amount of nutrients reaching the watercourse. As it jumps over or flows around large organic debris, the water will increase its dissolved oxygen content.

ESTABLISHMENT OF VEGETATED BUFFERS

The multiple stresses of grazing, upland soil erosion, recreation, road building, logging, mining and flooding have contributed to the degradation of many buffers. The rehabilitation or establishment of buffers should be an integral part of a sound conservation system. In the following sections, we will review some of the main factors which must be considered when rehabilitating or establishing a buffer strip.

Natural revegetation: Browsing may make the restoration of disturbed buffer areas more difficult (Kay and Chadde 1992). In fact, damage from grazing by deer was found to be one of the dominant cause for the failure of riparian area rehabilitation (Shaw 1992) and reforestation programs (Robichaud 1994). Release from heavy grazing pressure will favour the reestablishment of the natural vegetation, provided it has not been totally removed (Hansen 1992). Buffer strips that develop naturally will take upwards of seven years before they can effectively shade a watercourse (Feller 1981).

The size of the stream: Small meandering streams with flow rates of less than 1.5 m/s are easier to revegetate than larger ones. Once the bank has been fully revegetated, it will be able to withstand flow rates of 2.5 m/s. Larger streams, being more susceptible to ice flow damage and to undercutting of banks, will usually require structural modifications before a revegetation program can be implemented (Carlson et al. 1992).

Slope: The performance of the buffer strip will be affected by the bank's slope. Streambanks with slopes of less than 18.5% are far more susceptible to erosion from high water levels than steeper banks. Meandering watercourses may be susceptible to scouring and deposition, and may require further protection. However, the removal of irregularities may conflict with the maintenance of fish habitats. Embankments that have contributing areas with slopes steeper than 12% are not suitable to the establishment of buffer strips. In these cases, high velocity runoff flow greatly reduces the sediment trapping efficiency of the buffer. The shape of the slope will also influence the performance of the buffer. Buffer strips tend to be effective on uniform convex slopes (Lemunyon 1991).

Plant selection: Understanding the relationship between plants and their physical habitat makes it possible to select the most appropriate species for the establishment and rehabilitation of buffer areas (Hudak and Ketcheson 1992). Species, which are adapted to local conditions and frequently found in the area, should be favoured for the establishment or rejuvenation of a buffer (Beaulieu et al. 1988). A healthy buffer zone includes a mixture of healthy hardwood and softwood tree species with a crown cover of about 70%. An over-mature stand of any single species is generally not recommended as it may result in problems, such as the stream being blocked by an excessive number of fallen trees. Furthermore, over-shading by large trees may prevent the growth of grasses, shrubs, and other desired ground vegetation .

Table 2: Appropriate vegetation for the protection of watercourses

Objective	Plant selection criteria
Nutrient removal / transformation	Shrubs, trees and and persistent grasses
Sediment retention	High proportions of grasses and debris
Shoreline stabilization	Trees, shrub and/or deeply rooted vegetation
Shade / temperature of the water	Large dense trees and bushes
Biodiversity	Emergent or aquatic plants in the wetland area / trees on the shore

Source : Carlson et al. 1992

Trees and bushes play a dominant role in the stabilization of the embankment and in shading the watercourse, while grasses filter some contaminants out of the surface runoff (Table 2)(Carlson et al. 1992; Williams 1993). Deciduous trees have deeper root systems than most softwood species (Mahendrappa 1993). Dense shrubs and herbaceous plants may be more effective in reducing scouring and undercutting of banks in many situations (Carlson et al. 1992; Williams 1993). It may not be advisable to use deep rooted plants in proximity to tile drain outlets, as they may disrupt subsurface drainage networks (Beaulieu et al. 1988).

The adoption of fast growing hybrid poplar may significantly reduce the length of the establishment period of the buffer, and increase the nutrient uptake capacity of the buffer. In an experiment conducted near Kitchener, Ontario, 4-year-old hybrid poplars were found to reduce the exposure of sunlight in the middle of a stream by 40% (Gordon 1993). Furthermore, poplars have been shown to remove up to 99% of the nitrate present in the runoff water (Haycock and Pinay 1993). This plant species can thus play an important role for embankment stability, shade and nutrient filtration.

Grasses are better adapted for filtering and absorbing nutrients than are legumes. First, they produce a large mat of superficial roots, which extract nutrients from infiltrated runoff before they enter the water table. Second, legumes tend to get much of their nitrogen from the atmosphere, while grasses will use available soil nitrogen (Lemunyon 1991). Plant uptake of N will vary from one grass species to another (Table 3). For example, orchard grass is an effective filter as it takes up a lot of nitrogen (Robinson and Primard 1992).

Table 3: Nitrogen content of harvested shoots

Species	Variety	Nitrogen content of harvested shoots (k/ha)
Orchard grass	Comet	159
	Crown	141
	Dawn	109
	Pennlate	115
	Potomac	124
	Rancho	121
Reed Canary grass	Palaton	111
Tall Fescue	Kentucky 31	81

Source: Robinson and Primard 1992

It is important to note that the selected vegetation type must be able to withstand flooding by water and sediments. Plant growth must be fast enough to survive the deposition of sediments. It may be advantageous to have plants that vegetatively extend their growth with rhizomes or stolons, such as creeping red fescue, because they help maintain vegetation on top of the newly deposited sediments (Lemunyon 1991).

Establishment of plants: When revegetating disturbed streambanks, roots and cuttings should be started in nurseries to favour survival. Cuttings should be harvested in the spring from dormant 2 to 4-year-old plants. Cuttings 30-50 cm long and more than 1 cm in diameter produce the best results. Roots and shoots from cuttings can be expected to appear 10-15 days after planting (Hansen 1992).

It may be possible to plant large cuttings of easily rooting species, such as willows or poplars, directly into the embankment. For this technique to be successful, there must be sufficient moisture for root development. Planting the cuttings down to the summer water table depth will ensure the highest survival rate (Carlson et al. 1992).

Specific physical conditions must be taken into account when seeding a buffer strip. Buffer areas are often narrow, irregularly shaped corridors, which may not be accessible to conventional planting equipment (Platts et al. 1987). The watercourse management guide published by the Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec presents three main approaches (Beaulieu et al. 1988):

- Broadcast seeding is used when embankments are not too steep or smooth. It is quite common for a significant portion of the seeds to end up at the bottom of the embankment. To minimize this, it may be necessary to roughen the surface to be seeded. Maximum establishment will be achieved when broadcast seeding takes place shortly after the soil has been tilled.

- Well calibrated and adjusted mechanical seeders allow for even distribution and good incorporation of the seeds. Most producers who cultivate forages or cereals would have appropriate seeding machinery.

- Hydroseeding allows for the establishment of plants on very smooth and steep slopes. In this case, the seeds are mixed in an organic fibrous paste which is spread on the surface area. The paste consists of wood and other organic fibres. When dealing with very steep slopes, a sticky additive can be added to the paste in order to increase its adherence. This has proven to be highly effective on clay soils.

Planting location: The best locations for planting new shrubs can be identified by noting and imitating the placement of surrounding vegetation. It is important to plant trees and shrubs close enough to the stream in order to facilitate water uptake. However, a careful balance is required as they could get washed away by high water events if planted to close to the watercourse. Understanding soil moisture regimes and stream hydrology will facilitate the design and establishment of a performant buffer strip (Rosentrerer 1992).

Tree and shrub density: Tree and shrub spacing will vary according to species and planting technique. Plant spacing may be as large as 2 m when resorting to stump planting (Carlson et al. 1992). The density of shrubs and underwood should be increased along the edge of the buffer area and when the strips intersect gullies (Lukisha 1972).

Width of the buffer strip: The width of a buffer may vary from 3 m for bank stabilization purposes, with no less than 1 m above the embankment (Gonthier and Laroche 1992) to as much as 45 m for habitat purposes (Carlson et al. 1992). A number of factors may affect the width of the buffer strip, they are:

- steepness of adjacent slopes
- requirement for floodplain protection
- increase in large organic debris
- nutrient and sediment load of incoming runoff
- intensity of surrounding production systems (pastures require narrower buffer strips than potato fields)
- need to stabilize stream temperature
- need to provide wildlife access
- sensitivity of stream and lake
- water use (drinking water)
- vegetation mix of buffer

The presence of sensitive or endangered species in or around a watercourse may require wider buffer areas. For example, Idaho's legislation requires a 23 m vegetated buffer area for streams which support trouts, a sensitive species, versus a 1.5 m buffer for those that do not.

Buffers of up to 20 m in width withheld 98% of the sediment delivered from a cultivated area that had a slope length of up to 130 m (Heede 1990). In general, researchers conclude that a forested buffer width of 12 to 20 m should be sufficient to protect watercourses used as a source of drinking water (Nieswand 1990; Barfield et al. 1979; van Groenewoud 1977).

A number of jurisdictions and researchers have established a link between the slope of the embankment and the width of the required buffer (van Groenewoud 1977). It has been suggested that between 0.7 and 1.5 m of additional buffer would be required for a 1% increase in slope (White 1993; Nieswand et al. 1990).

Fixed minimum buffer strips are simpler to implement and manage than variable width buffers. On the other hand, variable width buffers can be adapted to the characteristics of the site and may prove to be more effective. Washington, Oregon, Idaho and California have all adopted variable width buffer strip policies under their respective *Forest Management Acts* (Belt et al. 1992). Through a modelling exercise, Phillips (1989) has shown that the width of the buffer could vary between 5 and 73 m depending on the erosivity of contributing areas, on the intensity of surrounding land use practices and on the sensitivity of the water body. In its recommendations, the *USDA Forest Service* suggests that buffers of 25 to 50 m should be maintained depending on the sensitivity and slope of the target environment (Welsch 1991).

MANAGEMENT OF VEGETATED BUFFERS

Management requirements will be dependent on the purpose for which the buffer strip was established. This section highlights the dominant management issues associated to specific functions.

Welsch (1991) described a system in which the buffer area is divided in three management zones : a forage production zone of 6 m, a managed forest zone of 18 m and an undisturbed zone of 5 m. While the width of each of these areas could vary in accordance with specific site conditions, this type of management system can offer a flexible avenue for land use planners. Such an approach would make it possible to meet environmental goals, while maintaining a productive use of part of the area covered by the buffer.

Weed control : Weeds may compete with desired species and may even choke them out. They may also provide a habitat for rodents which can attack the bark of trees. Some weed control programs, such as mulching or planting with less problematic species, may be necessary.

Wood production : Buffer strips can represent a valuable resource for agricultural producers and small woodlot owners. A number of documents show that the selective harvesting of trees from part of the buffer strips should be permitted (Kovalchik and Elmore 1992; Lawrence et al. 1984; Belt et al. 1992). Proper stream side forest management requires periodic harvesting of trees to maintain nutrient uptake while minimizing soil disturbance and protecting drainage conditions (Lawrence et al. 1984; Belt et al. 1992). The use of proper management and extraction technologies may make this an environmentally and financially sustainable practice.

In North America, a number of jurisdictions presently allow the extraction of trees from part of the buffer strip. It is necessary in most cases to maintain a 3 to 5 m undisturbed zone on the shores of water bodies. It may also be necessary to practice some form of management to ensure the rejuvenation of populations and to foster the presence of a healthy undergrowth. All plants experience a decrease in growth rate with age. An increase in the age of the plant of 5 years may correspond to a reduction in average shoot growth rate of 50 % (Kovalchik and Elmore 1992). In order to maximize long term biomass production and nutrient uptake, a balance must be maintained between the number of plants at each growth stage.

The option or obligation to selectively harvest trees does not usually include the right to enter the buffer with heavy machinery. For example, in Quebec where logging is allowed within the buffer, access by heavy machinery is prohibited to prevent excessive disturbance of the duff or organic layer of the soil (Ministère de l'Énergie et des Ressources du Québec, 1991). Certain precautions must also be taken to prevent the displacement of sediments from the buffer strip to the watercourse by logging. Once cut and branched, the logs can be extracted using a cable system, a winch or a horse. Foresters from both New Brunswick and Newfoundland have used cable extraction systems for distances of up to 25 m successfully (Moore 1986).

Pruning: If streambank stability is the primary objective, periodic pruning of bushes and hardwood trees can be considered to maintain or increase stem density.

Forage production: The filtering efficiency of the grassed area will depend on the presence of a dense, healthy grass cover in the upland part of the buffer. Mowing early in the summer and in the fall at a height of 15 cm will promote the densification of the grass stand (USDA 1989). Harvesting part of the grass cover provides some productive value out of the grassed filter area, and controls the spread of weeds from the buffer to the field (Laroche et al. 1992). Removing vegetation keeps the plants healthy, growing and absorbing nutrients.

Fencing: Fences can be installed to exclude livestock from the buffer area (Carlson et al. 1992). The moist soil conditions found in riparian areas make them very susceptible to compaction by livestock and wildlife.

Field practices: It is important to avoid disturbing established buffer strips by inappropriate agricultural practices. Equipment must be operated carefully to prevent herbicide drift, which may kill the vegetative cover. The effectiveness of the buffer will depend on the use of best management practices for soil erosion control, as well as fertilizer and pesticide management in upland fields (Ag. Canada / OMAF 1991).

Sediment removal: Sediment that has built up in the buffer must be removed periodically in order to maintain its effectiveness. A buildup of 10 cm is enough to block and redirect overland flow. This may lead to the concentration of the runoff at low points. When removing the excess sediments, one must take care not to create depressions which could concentrate the flow. Sediment removal will be of little value if preventative conservation practices are not adopted to prevent the recurrence of excessive buildup.

Fertilization: The buffer's vegetation depends on the nutrients transported by the runoff for its fertilization. A lack of runoff may in some cases result in nutrient deficiencies. It may then be necessary to fertilize and lime the buffer in order to maintain the desired vegetative stand and limit the presence of invading weeds (Lemunyon 1991).

Access road: The buffer strip should not be used as an access road. Repeated trampling by machinery may destroy a significant portion of the vegetated cover. Furthermore, the weight of the equipment on the top of the embankment may cause it to fail. The maintenance of a minimum no-access area from the watercourse is an essential safety measure.

Crossings: When properly designed and established, crossings will keep the livestock out of the water without restricting the normal flow of the watercourse. Submersible (fjords) or mid-level crossings could be considered, on a seasonal basis, for moving equipment from one side of a watercourse to another.

CONCLUSIONS

Buffers have been shown to significantly reduce the amount of nutrients and sediments entering a watercourse. Nonetheless, they should not be viewed as an alternative to infield conservation technologies, but rather as a complement. Infield technologies will also have the advantage of optimizing the productive value of the soil and other agricultural inputs.

It is important to note that several factors may affect the buffer's effectiveness. It is necessary to maintain sheet flow. Local topographic conditions or surrounding farming practices may favour the concentration of flow which may in turn significantly reduce the effectiveness of the buffer as a filter.

Land planners should consider the establishment of multi-purpose buffers. In such a system, forage production could be emphasized in the filtration area, logging could be allowed in the transition area, and no disturbance would be tolerated in the protected area.

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