"BEYOND THE PIPE"

The Importance of Wetlands and Upland Conservation Practices In Watershed Management:

Functions and Values for Water Quality and Quantity

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March 2001

Acknowledgements

Technical components of this report were reviewed by Dr. Kevin Devito at the University of Alberta, Dr. Gordon Goldsborough at the University of Manitoba, and Dr. Barry Warner at the University of Waterloo. Review and technical support was also provided by Dr. Brian Gray, Dr. Mike Anderson, Joel Ingram, and Dr. Karla Guyn.

Table of Contents

I. Executive Summary

Fresh water is a vital resource for human society. To ensure the long-term sustainability of water resources in Ontario, we must protect and enhance landscape features that ensure water quantity and quality in the future. Wetlands and riparian areas are natural watershed features that are critical for sustainable water resource management.

This paper focuses on the function and value of the wetlands, riparian areas, and permanent cover for securing the long-term supply and quantity of Ontario's drinking water resources. An overview of past and present policies protecting wetlands and riparian areas is presented including recommendations for policy change that will protect and enhance the quantity and quality of Ontario's water resources in the future.

Wetlands

The hydrological functions of wetlands include storage and eventual release of surface water, recharge of local and regional groundwater supplies, reduction in peak floodwater flows, de-synchronization of flood peaks, and erosion prevention. Position in the landscape, location of the water table, soil permeability, slope, and moisture conditions all influence the ability of wetlands to attenuate floodwaters. Wetland drainage reduces the capability of a watershed to attenuate runoff during flood conditions. Maintaining and restoring wetlands on the landscape reduces overland flow rates and therefore potential flooding.

Recharge of groundwater is an extremely important function of some wetlands; water percolates slowly from wetlands to aquifers. Interactions between wetlands and local or regional groundwater supplies are complex and site-specific and affected by the position of the wetland with respect to groundwater flow systems, geologic characteristics of the substrate, and climate.

Wetlands are extremely complex systems and several characteristics contribute to their roles as nutrient sinks. They retain nutrients in buried sediments, convert inorganic nutrients to organic biomass, and their shallow water depth maximizes water-soil contact and therefore microbial processing of nutrients and other material in the overlying waters. Wetlands can be effective nitrate sinks in agricultural landscapes (80% removal). Phosphorus retention in wetlands can also be significant (up to 92%) and is accomplished through adsorption onto particles, precipitation with metals and incorporation into living biomass.

Wetlands can reduce the impacts of sedimentation on water quality within watersheds. Hydrology is a primary determinant of the sediment-retention capacity of a wetland and controls the source, amount, and spatial and temporal distribution of sediment inputs. Percent of wetland area and position in the landscape are important for reducing sediment loads of water passing through the system.

Little information exists on the effects of the ability of natural wetlands to reduce microbial populations in water. The effectiveness of constructed wetlands to reduce pathogenic organisms from wastewater is high (up to 90% for coliforms). Natural wetlands are dominated by microbes (bacteria, fungi and algae) and plant life that are important for reducing pathogens.

Pesticide loss and dissipation occurs by degradative processes such as photolysis, abiotic hydrolysis and biodegradation, as well as by volatilization into air, adsorption onto soil, and outflow from the wetland. Pesticide fate is poorly understood, however, common pesticides disappear rapidly from wetlands primarily due to adsorption to organic matter.

Riparian Area Protection Programs

Conservation tillage leaves crop residue from harvest on the soil surface resulting in a decrease in soil erosion by as much as 90%. Conservation tillage practices can result in a reduction in herbicide runoff by 42-70%.

Riparian buffer strips can effectively control erosion by forming a physical barrier that slows the surface flow of sediment and debris, by stabilizing wetland edges and stream banks, and by promoting infiltration. The bulk of sediment removal occurs in the first few meters of the buffer zone and overall sediment removal can be >75%.

Buffer strips can effectively remove nutrients from surface water flow. The variety of vegetative cover in a buffer strip determines its efficiency in intercepting nutrients and sediments. Buffers can be effective in reducing both nitrogen (67-96%) and phosphorus (27-97%). Buffer strips can also trap a significant proportion of the pathogens (up to 74% of fecal coliforms). The key process for pesticide retention in buffer strips is infiltration. Buffer strips can reduce pesticides by 8-100%.

Policy

Ontario's current policies and regulations governing the management of surface and groundwater are fragmented and uncoordinated. A number of provincial departments have legislative responsibilities related to water, however, no single level of government has the mandate or resources to conduct careful science based planning of water management and development. As well, no provincial regulations have as their specific purpose, the protection of wetlands. Some riparian area programs exist, however, few provide financial support for activities that result in water quality improvements.

Wetlands and riparian areas can provide a "pre-treatment" function for source water arriving at water treatment facilities. Information in this report indicates that wetlands and riparian area management programs such as vegetated buffer strips and upland cover can effectively reduce contaminants before they reach surface and groundwater supplies. Broad-scale protection and restoration of wetland and riparian areas will subject our drinking water to two separate purification processes, natural within watershed processes and the final polishing at the water treatment plant. Diverting 1% of annual in-pipe treatment expenditures could add about 4% to Ontario's wetland inventory and have significant impacts for water quality improvement.

Conclusions

Information from Ontario, other parts of North America, and the world indicate that wetlands, riparian areas and upland vegetative cover provide important functions for sustaining freshwater resources including water quality improvement, surface water storage, and groundwater recharge. Southern Ontario's landscapes have been degraded due to encroachment by agriculture and urbanization and have lost a significant portion of their wetlands and riparian area cover. Therefore the ability of the landscape to provide a predictable supply of clean water may be significantly impaired. A first consideration should be to provide protection for the remaining wetlands and riparian areas that are providing water quality and quantity benefits within Ontario watersheds.

To ensure long-term sustainable water resources, strategies for water resource management must be addressed at the watershed and landscape scale. These solutions include securing and restoring natural features of the watershed including wetlands, riparian areas, and upland cover. Until individual watersheds have been evaluated and modeled to better understand the functions and values of wetlands and riparian habitats for water resource sustainability, these habitats should be protected.

A strong link between watershed management and policy is necessary to ensure the long-term sustainability of Ontario's water quantity and quality. An evolving water management policy framework that addresses management of water on a watershed basis is essential.

In examining the risk and economic contributions of wetlands/riparian areas we can conclude the following:

a) Wetlands/riparian areas have the capacity to significantly reduce contaminants in surface and groundwater.
b) Wetlands/riparian areas can reduce the variability in the quantity and quality of water sources.
c) Wetlands/riparian areas can improve source water quality for drinking water treatment.
d) The cost to restore wetlands is small relative to the costs of in-pipe treatment, provided that this restoration occurs on lands where land costs and rental are relatively low.
e) Wetland/riparian area restoration costs will increase in landscapes and watersheds with high land costs and therefore the value of protection and restoration should be assessed against a wide range of objectives and benefits.

Policy Recommendations

1) Create a Comprehensive Water Management Policy Framework Governing Surface and Groundwater

Without an overall water management strategy, the management and protection of wetlands and riparian areas will be inadequate. The province should enact policies that provide a framework for the comprehensive management watershed of surface and groundwater systems.

Within this integrated policy framework the province should:

2) Enhance Wetland Protection

The benefit of wetlands to water quality/quantity can be significant and therefore existing protection mechanisms of natural wetlands should be strengthened.

3) **Encourage and Enhance Wetland Restoration**

The potential for enhancement and restoration of natural wetland areas could mean a significant improvement in water quality.

4) **Encourage the Adoption of Riparian Area Protection Programs**

Riparian area protection programs can improve water quality in rural areas and should be an integral part of water quality improvement programs. The province should act as a leader in this regard creating the framework through which programs can be developed and implemented.

5) **Encourage and Improve Our Understanding of Watershed Management**

Further research on wetlands and riparian areas and their roles in water quantity and quality functions in southern Ontario is required to ensure sustainable water resources for Ontario. There is a need to determine the role and long-term sustainability of wetlands, riparian areas, and uplands to reduce and store surface water runoff, recharge groundwater supplies, and retain pollutants.

Immediate action is required to restore quality water supplies in Ontario. Sustainable water resource management requires focusing on individual watersheds and it is imperative that within those watersheds we move quickly to conserve existing landscape features (i.e. wetlands and riparian areas) that provide long-term benefits for water quality. Watershed management programs and policy must move forward now using the best available information. Successful implementation of policies and programs to ensure long-term water supply and quality will require insightful leadership from all levels of government, agricultural producers, and private citizens groups.

II. Introduction

Fresh water is a vital resource for human society. We depend upon water for drinking, hydropower, irrigation, cooling, and cleaning; for products such as food, plants, and minerals; and for services such as waste purification, transportation, and recreation (Naiman et al. 1995). Currently, freshwater resources are being depleted and degraded on a global scale; as a result, experts agree that research on freshwater ecosystems is paramount to prevent further losses and degradation.

Proper watershed functioning maintains high quality water supplies. Watersheds collect water as rainfall, snowmelt, and runoff; store it for varying lengths of time; and then discharge it as surface runoff or groundwater flow (Black 1997). Wetlands, streams, lakes, and groundwater are all vital components of watersheds; as such, it is important to understand each of these individual components within the larger context of watershed function. Several jurisdictions in Ontario have begun the process of identifying watershed functions in order to develop management plans to protect and enhance these functions while providing guidance for future development (e.g., Grand River Conservation Authority 1997).

Other jurisdictions have also concluded that watershed management is critical for water resource sustainability. The World Water Council's "Long Term Vision on Water, Life, and the Environment in the 21st Century" was designed to ensure sustainable water use for future generations. This process involved consultation and research on water resources at regional and global scales. Canada's vision is built upon, among other principles, integrated water and land resources management systems (Canadian Vision Consultation 1999). This will involve managing land and water by watershed units. Policymakers recognize that sound management practices implemented at the watershed level will protect ecosystem functions; hence, water resources will be protected as well. Watershed management is already an important component of protecting drinking water in many communities. For example, three upstate watersheds provide New York City's drinking water. In order to maintain and protect the high-quality water supply, New York City planners have developed a watershed protection plan as an alternative to the future need for a water filtration plant (Ehlers et al. 2000).

Wetlands are characterized by the presence of standing water, unique soil conditions and vegetation tolerant of standing water. They are a continuum within the landscape and interdependent with other landscape units (Bedford and Preston 1988; Mitsch and Gosselink 2000a); thus, alterations to the landscape affect wetland functions. Current scientific understanding acknowledges that landscape factors (i.e. topography, geology, and landscape configuration) and climate influence wetland functions and diversity (Hill and Devito 1997; Bedford 1999). The landscape mediates delivery of water, minerals, nutrients, sediments and biota to wetlands (Brinson 1993; Bedford 1999); it is these factors that determine wetland functions. For example, modifications to watershed hydrology or changes in land use affect how water, nutrients, sediments, and other pollutants are transported to wetlands and other landscape units (Bedford 1999).

Sedimentation and contaminated water supplies can all be attributed in some way to the mismanagement of the watershed (Black 1997). Changes in wetland and other aquatic system water quality often originate from disturbances to the surrounding landscape (i.e. row crops, livestock production, industry, urbanization). In constructing management approaches that improve watershed health, policy makers must keep in mind the influence that soil and cropping systems have within the watershed. Although wetlands and other aquatic habitats are resilient systems that improve water quality, these disturbances can result in changes to the biological, chemical, and physical properties of these systems (Castelle et al. 1994). Maintaining vegetative cover and buffers on the landscape is an important part of reducing or eliminating the impacts of agricultural and urban land use activities on wetlands and other aquatic systems.

Wetlands, uplands and riparian buffers are vital components of freshwater resource sustainability in North America. If we desire to understand the role of wetlands, uplands and riparian buffers in maintaining both the quantity and quality of water supplies, we must approach management and research from a holistic viewpoint, incorporating all components of the watershed and landscape.

A. Objectives

The objectives of this report are:

1. Provide an overview of the functions and values of wetlands for water quantity and quality with emphasis on Ontario.
2. Provide an overview of the benefits of permanent cover and riparian buffers for water quantity and quality.
3. Provide an overview of wetland and riparian area protection policies in Ontario.
4. Make recommendations for policy changes that will protect and enhance the quantity and quality of water resources in Ontario.

III. Wetlands

A. Wetlands of Southern Ontario

The glaciated regions of eastern Canada have wetlands that commonly occur in former glacial lake basins and along river and lake margins (Winter and Woo 1990). Vegetation ranges from cattail and sedge marshes to shrub and forested swamps. Subsurface stratigraphy (layering of deposits) can affect the formation of wetlands; stratigraphy of the peat itself and the stratigraphy of the underlying mineral substrate can impede drainage resulting in wetland formation (Winter and Woo 1990). Groundwater can also heavily influence the water supply in some wetlands, whereas in others it may not have any effect at all (Mitsch and Gosselink 2000, 134).

Many wetlands in Ontario occur in topographic depressions created by glacial erosion and deposition (Winter and Woo 1990). Wetlands can intercept the water table in such a way that they have only inflows and no outflows (Figure 1-a) (Mitsch and Gosselink 2000, 135). Other wetlands occur in areas of steep land slopes such as embankments or river valley walls where groundwater discharges directly to the land surface from the underlying soil or emerges from surrounding uplands creating an area of permanently saturated soil (i.e. discharge wetland)(Figure 1-b)(Hill 1990; Roulet 1990; Winter and Woo 1990, Mitsch and Gosselink 2000, 135). This occurs when the water level in the wetland is lower than the water table of the surrounding land. This type of wetland can be an isolated low point in the landscape, but most often it discharges excess water downstream as surface water or groundwater (Mitsch and Gosselink 2000, 135)(Figure 1-c). When the water level in a wetland is higher than the water table, groundwater will flow downward from the wetland to underlying water-saturated soil (i.e. recharge wetland)(Figure 1-d). When a wetland is above the groundwater of an area the wetland is referred to as being perched and loses water through infiltration into the ground and through evapotranspiration (Figure 1-e).

Climate has a major influence in wetland hydrology (Winter and Woo 1990). Precipitation is greater in eastern than western Canada and evaporation rates are among the lowest on the continent. High intensity rainfall events are most likely to occur in July, but flood peaks are usually attenuated because summer vegetation on upland areas fosters increased surface retention and infiltration (Watt et al. 1989, 19), thereby reducing runoff into the wetland. The influence of rainfall and associated inputs from upland areas is often most important when the upland vegetation is dormant, as in late fall and winter. This is especially evident in spring when spring rains coincide with snowmelt conditions.

There are five classes of wetlands recognized in Ontario: bog, fen, swamp, marsh, and shallow water (National Wetlands Working Group 1997). This classification system recognizes that hydrological processes dictated by climate and landscape factors largely determine wetland form (National Wetlands Working Group 1997). Bogs are typically acidic environments with low nutrient levels and are dominated by peat deposits. Precipitation, fog and snowmelt are the primary water sources. Sphagnum mosses form a surface carpet, and the water table is at or near the surface. Black spruce or tamarack may be present. Fens are also peatlands, but are less acidic and have greater nutrient supply than bogs due to groundwater and surface water movement through mineral soils. Grasses or sedges dominate the fen vegetation community, along with low shrubs. Swamps are wooded wetlands characterized by standing or gently flowing water. Marshes may be temporary or permanent. They exhibit standing or slowly moving water and are characterized by emergent herbaceous or woody vegetation that covers >25% of the surface area of the wetland. Water levels may fluctuate seasonally. Shallow water wetlands may also be temporary or permanent and are dominated by submerged and floating vegetation. The surface area of the wetland has <25% emergent herbaceous or woody vegetation.

Wetlands can also be evaluated according to their position in the landscape, or site type. Four different types are recognized: lacustrine, riverine, palustrine, and isolated (OMNR 1993). Lacustrine wetlands are associated with lakes. They can occur at the mouth of a river, at the shoreline of the lake but separated from the lake by a barrier beach, or exposed to the lake. Riverine wetlands are adjacent to streams and rivers. They may be located within the channel, adjacent to the stream, or on the flood plain. Palustrine wetlands occur upslope of riverine or lacustrine wetlands. They may or may not have an inflow, and have intermittent or permanent outflow. An isolated wetland receives nutrients from precipitation, overland flow, and groundwater.

Our understanding of wetland development has evolved since the initial classification scheme was adopted. Physical and chemical factors are presently thought to interact with biological processes to determine wetland characteristics (Winter and Woo 1990; Bedford 1999; Winter 1999; Price and Waddington 2000). For example, there is now emphasis on the influence of hydrology, topographic location, thickness and permeability of soils, underlying geological characteristics, regional climate, and other landscape characteristics on wetland functions (Winter and Woo 1990; Brinson 1993; Hill and Devito 1997; Bedford 1999; Winter 1999; Price and Waddington 2000).

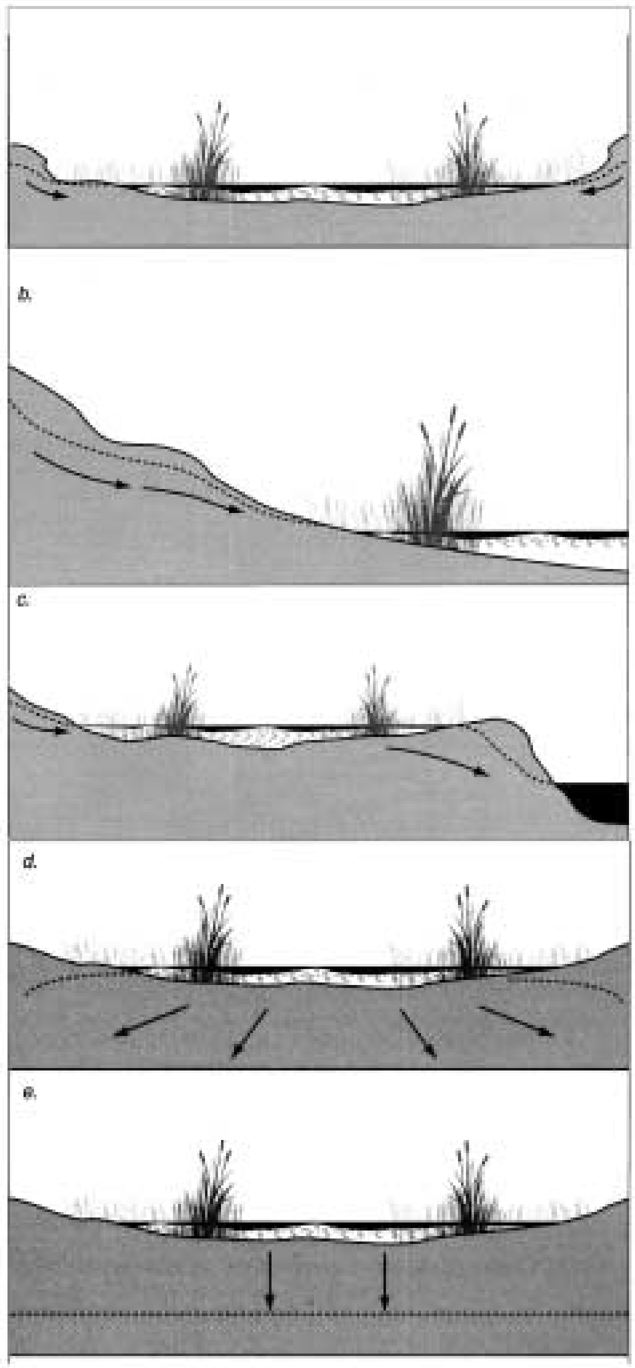

Figure 1. Possible discharge – recharge interchanges between wetlands and groundwater systems including: **a.** marsh as a depression receiving groundwater flow; **b**. groundwater spring or seep wetland or groundwater slope wetland at base of a steep slope; **c**. floodplain wetland fed by groundwater; **d.** marsh as a recharge wetland adding water to groundwater; **e.** perched wetland or surface water depression wetland (Mitsch and Gosselink 2000).

B. Hydrological Functions of Wetlands

The hydrological functions of wetlands include storage and eventual release of surface water, recharge of local and regional groundwater supplies, reduction in peak floodwater flows, de-synchronization of flood peaks, and erosion prevention (Carter 1986; LaBaugh 1986; Winter and Woo 1990; LaBaugh et al. 1998; Winter 1999; Mitsch and Gosselink 2000a; Price and Waddington 2000). Each situation is unique and dependent on local topography, climate, geology, and watershed characteristics.

In order to understand the hydrological functions of wetlands, it is necessary to have a working knowledge of wetland hydrology. Wetlands are dynamic, continuously receiving and losing water through interchange with the atmosphere, surface flow and groundwater (Winter and Woo 1990). Although significant advances have been made in our understanding of wetland hydrology in recent years (Winter and Woo 1990; Hill and Devito 1997; Winter 1999; Price and Waddington 2000) we have a limited understanding of wetland hydrology for the wide variety of wetland types that exist. This ultimately affects our understanding of many wetland functions, as water is the primary agent of material and nutrient transfer in and out of wetlands (Doss 1995, Hill and Devito 1997, Hill 2000). Many non-hydrological functions of wetlands depend on hydrology. For example, biogeochemistry in several Ontario wetlands and streams has been linked to hydrology (Hill 1990; Hill 1996; Devito et al. 2000a). Ultimately, hydrological characteristics that influence wetland chemistry are a function of climate and landscape features such as depth of permeable sediments, groundwater flow patterns, organic deposits, and geology (Hill 1996; Brinson 1993; Bedford 1999; Winter 1999; Devito et al. 2000a).

A wetland water budget is an equation in which the inputs, outputs, and change in storage of water in the wetland are balanced.

(Equation 1) $P + SWI + GWI = ET + SWO + GWO + S$
Where P = precipitation, SWI = surface water inflow, GWI = groundwater inflow, ET = evapotranspiration, SWO = surface water outflow, GWO = groundwater outflow, S = change in storage (Carter 1986).

Each component of the water budget can be complicated to measure and incomplete characterization of wetland hydrology is often the result of accumulated errors inherent in measuring each of these components of the water budget equation.

1. Water Storage and Flood Reduction

Flood reduction is an important wetland function, both environmentally and economically. Flooding causes undesirable effects downstream, such as erosion of shorelines and riverbanks, erosion of agricultural soil (by overland flooding), sedimentation of eroded soil further downstream, washout or siltation of fish spawning areas, and flooding of homes and businesses. The ability of wetlands in Ontario to store incoming water is highly variable. Position in the landscape, location of the water table, soil permeability, slope, and antecedent moisture conditions influence the ability of any given wetland to attenuate floodwaters (Carter 1986; Winter and Woo 1990; Devito et al. 1996; Cey et al. 1998).

Wetlands commonly retain surface inflow as the basin fills and then release the accumulated water during an extended period (Winter and Woo 1990). The degree of flow modification depends on the characteristics of the wetland basin and the timing and magnitude of flow. Where streams enter the wetland and then reappear at the lower elevation of the wetland outlet, there is a thorough mixing of surface and subsurface water and the flow pattern is greatly modified (Winter and Woo 1990). Wetland vegetation slows water flow significantly (Carter et al. 1978). As surface water enters a wetland, the vegetation can disperse the incoming water, reduces the flow velocity, and thus increases residence time of water in the wetland (Brown 1988). Streams flowing through a wetland along well-defined channels have less exchange with groundwater and the stream flow regime is little changed by the wetland (Woo and Valverde 1981).

Water storage in wetlands is underground in saturated soils or in surface depressions (Winter and Woo 1990). When the water table is low, considerable storage capacity is available in the unsaturated peat. Wetlands that are saturated may have little capacity to store water and any additional water may run off the wetland quickly (Verry and Boelter 1979; Winter and Woo 1990). Devito et al. (1996) found that during seasons with large water inputs, swamps were hydrologically connected to uplands and little runoff attenuation was observed. High antecedent moisture conditions can reduce the groundwater storage capacity in a catchment (Cey et al. 1998) resulting in greater water discharge to wetlands thereby reducing the ability of the wetland to attenuate storm conditions. During the dry season, wetlands are effective in retarding or preventing runoff, but water is not generally retained and released over a sufficiently long period of time to regulate seasonal stream flow (Winter and Woo 1990).

Runoff is also controlled by a number of factors such as slope, and soil type and permeability. Research in south-eastern Quebec suggests that slope-dependent seasonal waterlogging affects the retention and export of surface waters (D'Arcy and Carignan 1997). Steep basin slopes or large impervious areas maximize surface runoff and minimize infiltration capacity (Brown 1988), thereby increasing the amount of surface water reaching a wetland and thereby reducing its surface runoff storage capacity.

Taylor (1982) showed that small wetlands near Peterborough, Ontario, play a key role in controlling storm runoff. The wetland held back runoff in the summer months, when water levels were low. However, in the spring and fall, runoff was released downstream because the storage capacity of the wetland was exceeded. This highlights that flood reduction benefits of wetlands are often seasonal.

Bertulli (1981) simulated a flood on the Napanee River, Ontario under two scenarios: one with the existing wetland in place, and one without the wetland. The computer-simulated flood hydrograph showed that the presence of the wetland would reduce peak discharge from 150 cubic meters per second (m^3/s) to 80 m^3/s by extending the period of time over which the floodwaters moved through the river.

Positive benefits of maintaining wetlands in the landscape are well known. For example, the United States (U.S.) Army Corps of Engineers recommended the acquisition and protection of wetland areas along the Charles River in Massachusetts as the least expensive method of flood control (Carter et al. 1978). The large 1993 and 1995 floods in the Mississippi River Valley were linked to wetland drainage (Miller and Nudds 1996). They demonstrated that wetland drainage in the U.S. is correlated with greater river flow rates than in Canada, where landscape alteration is much less severe. Hey and Philippi (1995) suggested that the restoration of approximately 5.3 million ha in the Upper Mississippi and Missouri Basins would provide enough floodwater storage (approximately 1m deep) to accommodate the excess river flow associated with the disastrous flood in Midwestern United States of America (USA) in 1993. They concluded that an estimated 7% of the watershed would be sufficient to deal with even extreme event floods on a large scale.

Ludden et al. (1983) estimated the runoff storage capacity of wetland areas in the Devils Lake basin in North Dakota. They calculated that approximately 72% of the total runoff from a rain event with a two-year frequency, and 41% of the runoff from a rain event with a 100-year frequency, would be retained by these wetland depressions.

In addition to the effects of total wetland loss on stormwater runoff, wetland modification also influences runoff regimes. For example, wetland channelization, which often occurs in urban areas, leads to increased runoff and loading from a basin. Brown (1988) found that stormwater runoff from Lamberts Creek, Minnesota was highest in subwatersheds with channelized wetlands and steep slopes. The subwatershed with a large percentage of unmodified wetlands (94%) exhibited a long steady storm discharge (<0.5 m^3/s over 24 hours for a June storm) and low total runoff volume (0.01×10^6 m^3/km^2 for the 12 storms sampled). The sub-watershed with the highest degree of urban land use and wetland channelization had large peaks of discharge during storms (2.5 m^3/s over 2-3 hours), and the greatest total runoff (0.14×10^6 m^3/km^2).

Whiteley and Irwin (1986) reviewed a study of Beverly Swamp, north of Hamilton. They measured hydrologic inputs and outputs over one summer, and found that of the two creeks flowing into the wetland, the unchannelized stream delayed flood peaks by 20 to 30 hours and reduced peak flows. The stream with a well-defined channel did not provide flood attenuation benefits.

Research conducted in the Oak Ridges Moraine of Ontario has indicated that wetlands located on this unique geologic formation may not function in flood reduction; instead, they may actually be sources of rapid overland flow (e.g., Hill and Waddington 1993; Waddington et al. 1993; Cey et al. 1998). This is attributable to high water tables and groundwater discharge (95% of annual inputs come from underlying aquifer) to these wetlands.

2) Groundwater Recharge

Interactions between wetlands and local or regional groundwater supplies are complex and site-specific (Hill 1990; Winter and Woo 1990; Winter 1999, Devito et al. 2000a; Price and Waddington 2000). The interaction of wetlands and groundwater are affected by the position of the wetland with respect to groundwater flow systems, geologic characteristic of the substrate and climatic setting (Winter 1999). A wetland can recharge groundwater supplies, or it may be a site of groundwater discharge (Carter 1986; Hill 1990; LaBaugh et al. 1998) (Figure 2).

Recharge of groundwater is an extremely important function of some wetlands and occurs when water percolates slowly from wetlands to underground aquifers. Groundwater recharge occurs from many areas in the landscape, including wetlands (from seasonal to permanent) and uplands (Winter 1988; van der Kamp and Hayashi 1998). The water table is defined as the upper surface of the saturated zone, or groundwater, in soils. Movement of groundwater is related to soil permeability and local topography; and usually the water table conforms to surface topography. Groundwater moves from areas of high water or hydraulic pressure to areas of low hydraulic pressure, which may be downward, upward, or lateral. Permeability of surficial sediments and geologic formations is referred to as hydraulic conductivity, and is a measurement of the ability of water to move through a specific type of soil or deposit (van der Kamp and Hayashi 1998). Hydraulic conductivity of the materials overlying aquifers determines the rate of aquifer recharge. In general, glacial drift in the eastern part of North America is more permeable because the bedrock from which the drift is derived is more permeable (Winter and Woo 1990). The clay-rich glacial deposits of the Canadian prairies have a very low hydraulic conductivity (van der Kamp and Hayashi 1998) and therefore recharge to underlying aquifers is lower than in much of eastern Canada.

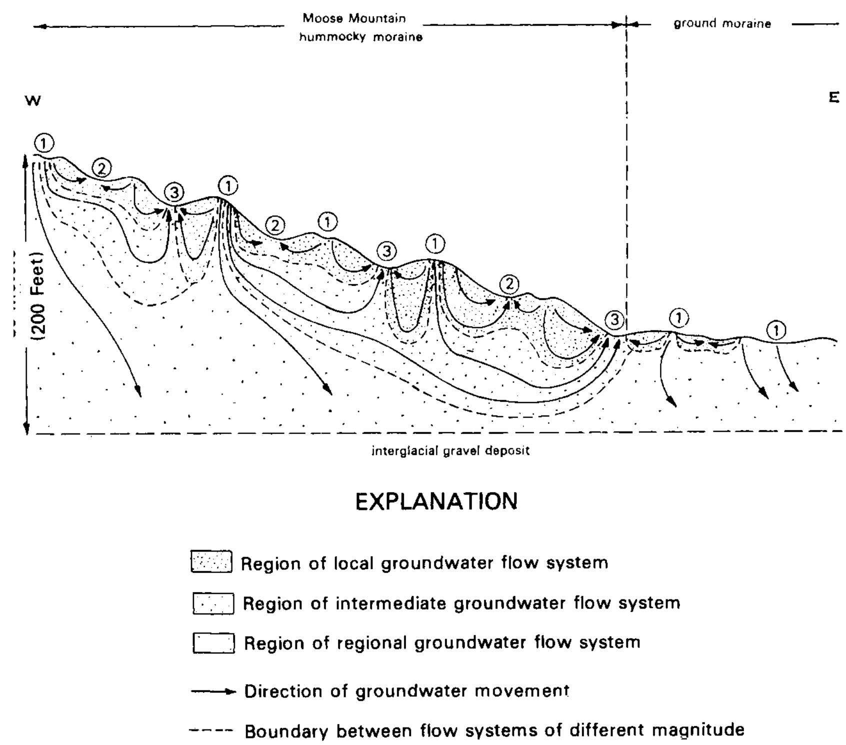

Figure 2. Diagrammatic section of the flow systems of Moose Mountain, Saskatchewan (1) recharge areas, (2) discharge area of local flow system, (3) discharge area of local and intermediate flow systems (Winter 1989).

Groundwater discharge is an important source of water to many wetlands in Ontario (e.g. Whiteley and Irwin 1986; Hill 1990; Roulet 1990; Hill and Devito 1997) and elsewhere (Drexler et al. 1999). The movement of groundwater into a wetland can be an important source of nutrients and dissolved minerals (Hill 1990, 1991). A series of papers describing the Oak Ridges Moraine in southern Ontario have shown that wetlands in this area are dependent on groundwater discharge from a large moraine aquifer that provides 95% of the annual input (Hill 1990; Hill and Devito 1997).

Groundwater discharge is also important for maintenance of baseflow in many streams during dry conditions. For example, Mill Creek in Ontario is sustained by groundwater discharge; rainwater recharges groundwater, which then flows into the valley, forms wetlands, and ultimately discharges into Mill Creek. This clean, cold water is crucial for the existence of a cold water fishery in the stream (Grand River Conservation Authority 1997).

Prairie potholes in the semi-arid portion of the northern prairies are known to be important for groundwater recharge (van der Kamp and Hayashi 1998). Local groundwater flow systems extend over large horizontal distances (hundreds to thousands of meters) around prairie wetlands. This is due to the high hydraulic conductivity of prairie soils within a few meters of the surface that results in seepage from the wetland. They concluded that these small wetlands are important for recharge of local groundwater supplies, but the effect on regional aquifers is less certain. They postulate that this may be due to the hydrogeology of glacial deposits. Extensive deposits of gravel and sand are highly permeable to water, and form the local and regional aquifers of the northern prairies. These deposits are isolated by the presence of aquitards, or areas of low permeability to water that consist of lacustrine deposits with high clay content. The low permeability of aquitards is the limiting factor to the recharge of underlying aquifers. For example, van der Kamp and Hayashi (1998) found published rates of aquifer recharge (from all sources) of 5-40 millimeters per year (mm/yr); estimates of recharge from prairie potholes range from 2-45 mm/yr. This overlap suggests that "wetlands may indeed be the main source of recharge to regional aquifers". The authors concluded that further research on prairie wetland hydrology was necessary.

Hydrology studies in Ontario have shown that groundwater recharge by wetlands is variable. Gehrels and Mulamoottil (1990) completed a comprehensive water budget for the Hidden Valley wetland in Kitchener, Ontario. They discovered areas of both groundwater discharge and recharge within the same wetland, confirming the often complex nature of wetland hydrology. Groundwater accounted for 36% of all water flowing into the wetland and 53% of all water discharging from the wetland. Whiteley and Irwin (1986) reviewed a study of the Beverly Swamp north of Hamilton, in which the authors found that of the two streams that enter the swamp, one recharged groundwater from June to September and the other continually received groundwater discharge. In another study reviewed by Whiteley and Irwin (1986), the authors found that the Telford peatland in southern Ontario recharged the regional watertable, with seepage of up to 135 mm. Research on the Oak Ridges moraine in southern Ontario conducted by Hill (1990) and Hill and Devito (1997) show that some wetlands in the region do not provide recharge to aquifers but receive significant groundwater discharge from an aquifer.

Although significant advances have been made in our understanding of wetland hydrology (Winter and Woo 1990; Winter 1999; Price and Waddington 2000) there is a definite need for more information on the factors influencing the hydrological functions of southern Ontario wetlands. Winter (1999) outlines the complexity of groundwater recharge and discharge by stating that streams, lakes and wetlands are integral parts of groundwater flow systems. Fluxes of water to and from groundwater reflect the positions of the surface-water bodies with respect to different-scale groundwater flow systems; local geologic control of seepage distribution through their beds, and the magnitude of transpiration directly from groundwater around their perimeters, which intercepts potential groundwater inflow or draws water from the surface-water body. Understanding the relative importance of all these factors for a given water body is needed for integrated water resource management (Winter 1999).

C. Water Quality Functions

Wetlands influence many aspects of water quality, including nutrients, suspended solids, pathogenic microbes, and anthropogenic pollutants such as pesticides. Because of their high biological productivity, wetlands can transform many pollutants into harmless byproducts via natural processes (Kadlec and Knight 1996, 3). This quality makes them ideal for processing wastewater, and as a result, constructed wetlands have become common for primary, secondary, and tertiary treatment of sewage.

Natural wetlands have been the subject of much investigation with respect to water quality functions. Early studies have focused on the effects of a wetland's position in the landscape on downstream water quality (e.g. Whigham et al. 1988; Johnston et al. 1990; Detenbeck et al. 1993; Weller et al. 1996). There is an ongoing debate about whether wetlands located further upstream within a watershed relative to others have a greater impact on water quality and flood protection (DeLaney 1995); however, there is evidence that the greater the wetland area, the greater the benefits. For example, Detenbeck et al. (1993) evaluated the effect of "wetland mosaics" on surface water quality of 33 lakes in Minnesota. They derived 27 variables using Geographical Information Systems (GIS) to describe land use, soils, topography, and wetlands, and found that wetland area, agriculture land use, urban land use, herbaceous wetlands, and forest described most (85%) of the variance in surface water quality (nutrients and suspended solids). They concluded that water quality is high in lakes with nearby wetlands, and in lakes with forested watersheds. Johnston et al. (1990) conducted a similar study on the effect of wetlands on stream water quality, and again found that water quality was correlated with the proximity of wetlands. Conversely, Devito et al. (2000b) found that total phosphorus (TP) in boreal lakes was higher in those with larger areas of surrounding wetlands area due to near-surface hydrologic flushing to the lake. Landscape processes are variable and will produce site-specific biogeochemical functions (Hill and Devito 1997).

To determine the effectiveness of wetlands for improving water quality it is important to have an in-depth understanding of wetland nutrient cycling. Often, wetland water quality studies focus only on the chemical concentration of water as it enters and leaves the wetland (Kadlec and Kadlec 1978). In these studies, measurement of water quality is in terms of mass per unit volume; for example, the concentration of total suspended solids (TSS) or total nitrogen (TN) is measured in milligrams per liter (mg/l). The difference between inflow and outflow is then attributed to removal by the wetland. Instead, a mass balance, or budget, for each constituent is preferable (Kadlec and Knight 1996). A mass balance of a given nutrient in a wetland includes measurements of inputs via hydrologic pathways and outputs via hydrologic and atmospheric pathways. Measurement of cumulative flux into storage compartments (soils, vegetation, and plant litter) is preferable; however, rates of flux and turnover times are difficult to measure *in situ*. Instead, measurements of standing stocks are more common, giving a snapshot of the retention of nutrients or sediments (Johnston 1991). In order to compare removal efficiencies of wetlands, nitrogen or phosphorus inputs must be measured in terms of mass per unit area of wetland per year. Mass balances are often calculated for the growing season only, ignoring fall and winter inputs and outputs. This leads to incomplete mass balances, and possibly to incorrect conclusions. Hydrology has a direct influence on the retention or export of nutrients and sediments (e.g., Devito and Dillon 1993a); thus, it is impossible to compute a mass balance without first completing the hydrologic characterization, or water mass balance, of the wetland (Kadlec and Knight 1996).

1. Nutrient Assimilation

Wetlands are extremely complex in their ability to assimilate nutrients depending on their position in the landscape, watershed hydrology, groundwater flow path, and sediment type, location and permeability (Hill 1996, Devito et al. 2000, Hill 2000). Similar wetlands can have quite different biogeochemical behaviour because of how they are linked to their watersheds (Hill and Devito 1997; Bedford 1999). Several wetland characteristics contribute to their roles as nutrient sinks. In general, they accumulate organic matter, retaining nutrients in buried sediments; they are usually isolated from high-energy hydrodynamics (waves, currents, etc.) so promote sedimentation of organic matter; and their shallow water depth maximizes water-soil contact and therefore microbial processing of this litter (Mitsch et al.1989).

Seasonal patterns of nutrient uptake and release further contribute to a wetland's ability to improve water quality. During the growing season, uptake and immobilization by microflora (bacteria and algae) and macrophytes retain nutrients; the dieback of plants in the fall releases nutrients to the water column through decomposition when they cannot be used for primary productivity (Mitsch et al. 1989). Conversely, uptake by plants and other aquatic organisms results in the conversion of inorganic nutrients to organic nutrients which can result in a net export of nutrients from a wetland during certain seasons (Devito and Dillon 1993a; Devito and Dillon 1993b; Devito et al. 1989).

a) Nitrogen

Nitrogen is the focus of water quality concerns in southern Ontario where large amounts of fertilizers are used on high input crops such as corn and soybeans (MacDonald 2000). In a potato growing region near Alliston, ON, Hill (1982) reported nitrate contamination >10 mg/l (the maximum allowable concentration in drinking water in Ontario (OME 2000)) of a shallow water-table aquifer underlying a sand plain and suggested that fertilizers are the major source of nitrate (NO_3^-) contamination. On the prairies of North America, up to 50% of the nitrogen in fertilizers applied to crops may be lost in runoff, primarily in the form of nitrate (Neely and Baker 1989). Excess nitrate in runoff can then enter surface waters, contributing to eutrophication, or leach into groundwater where it may contaminate drinking water sources. High levels of nitrate in drinking water can be toxic to humans causing methylglobanemia, or blue baby syndrome, wherein the oxygen carrying capacity of hemoglobin is blocked, causing suffocation (Naiman et al. 1995). Seventeen percent of Ontario farmland is at high risk for nitrogen contamination of waterways (Figure 3), particularly in southwestern Ontario, the Lake Simcoe region, and the South Nation watershed (MacDonald 2000). In a survey of drinking water wells in Ontario townships where over 50% of land area was under agricultural production, Goss et al. (1998) found that 14% of farm wells contained nitrate levels greater than the maximum allowable concentration in drinking water. Thus, Ontario's groundwater resources are not only at risk, but are already showing signs of nitrate contamination.

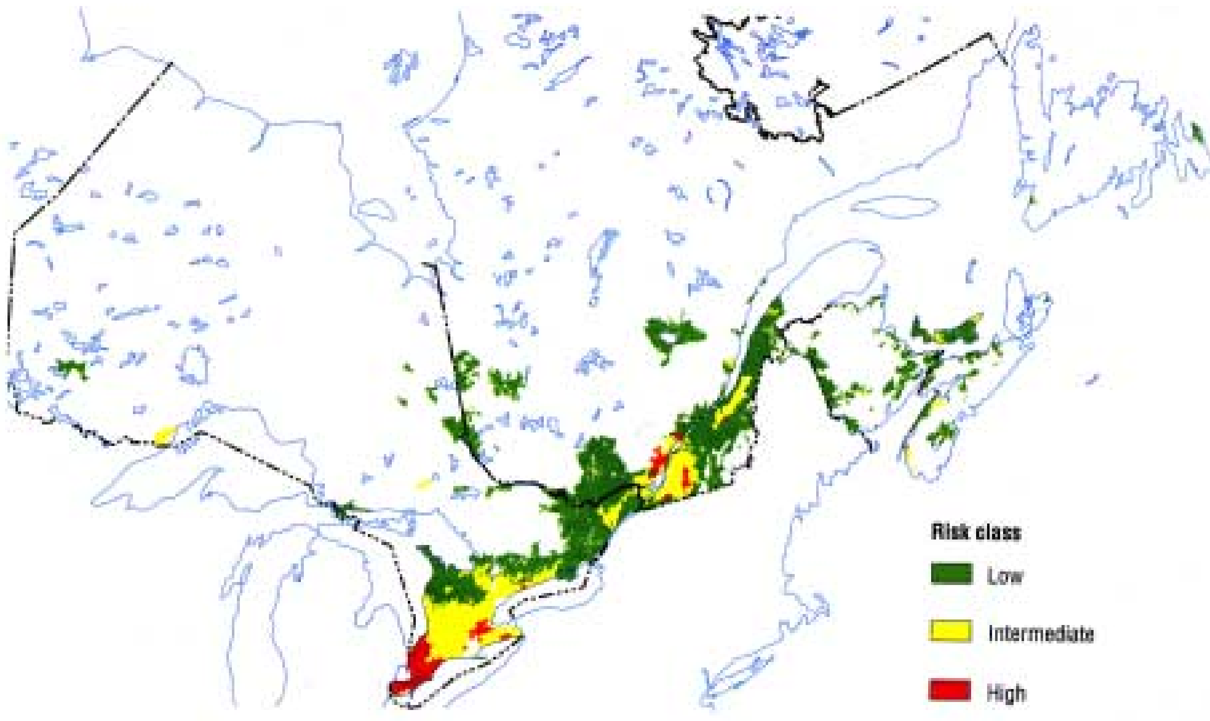

Figure 3. High, intermediate, and low farm areas at risk for nitrogen contamination in southern Ontario (MacDonald 2000).

Nitrogen retention in wetlands is accomplished primarily by assimilation by plants and microbes and denitrification. The form of nitrogen most readily available for uptake by wetland microorganisms and plants is ammonium (NH_4^+). It is produced by microbes during organic matter decomposition. Ammonium can be absorbed by plants or microorganisms and the nitrogen incorporated into organic matter (Figure 4). As a positively-charged ion it can also be immobilized onto negative soil particles (Mitsch and Gosselink 2000b, 172). In the soil, ammonium diffuses upward to the thin oxidized layer at the sediment-water interface. There, ammonium is oxidized through the process of nitrification to nitrite (NO_2^-), then to nitrate. Nitrate must be reduced to ammonium by plants or microbes before it can be used in their growth (Mitsch and Gosselink 2000b, 172). Alternatively, nitrate can undergo denitrification to nitrogen gas (N_2) that is lost to the atmosphere. Organic nitrogen, ammonium and nitrate are summed to calculate total nitrogen. In wetland soils and biota, nitrogen is present primarily as organic nitrogen (Kadlec and Knight 1996).

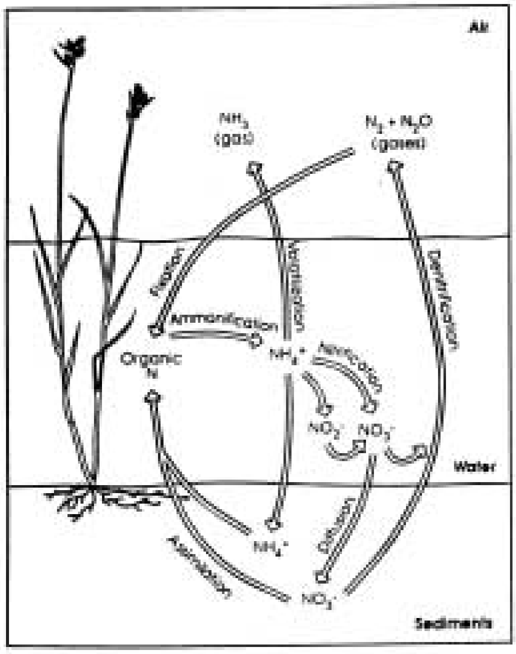

Figure 4. Simplified wetland nitrogen cycle (Knight and Kadlec 1996).

There is evidence that wetlands are effective nitrate sinks in agricultural landscapes (Crumpton and Goldsborough 1998; Mitsch and Gosselink 2000b, 707). Crumpton and Goldsborough (1998) reviewed several studies of prairie potholes receiving sustained nitrate loads, and found that upwards of 80% of nitrate loading could be lost through denitrification. Earlier studies of freshwater wetlands also demonstrate the importance of denitrification on the prairies (Neely and Baker 1989) and elsewhere (Sloey et al. 1978).

A number of studies on the effectiveness of wetlands to assimilate nitrogen have been conducted in Ontario. Research by Hill (1990) on a perennial discharge wetland on the Oak Ridges moraine north of Toronto showed that groundwater flow paths and water chemistry can have an important effect on the ability of a riparian/wetland zone to retain nitrogen. Riparian/wetland zones are transitions between terrestrial and aquatic environments and are identified as wetlands when the land is saturated with water long enough to be the dominant influence on soil and vegetation (Hill 2000). Hill (1990) provided information on the importance and complexity of groundwater entering the wetland for nutrient attenuation: (1) shallow groundwater emerges as springs near the base of the hillslope producing surface rivulets which cross the wetland to the stream; (2) deep groundwater flows upward through organic soils and enters the rivulets within the wetland; and (3) deep water enters the rivulets through bed and bank seepage. Variations in ammonium and nitrate concentrations in the swamp outlet were strongly influenced by differences in the local and regional groundwater contribution (Hill 1990). Local groundwater had high nitrate concentrations (100-180 micrograms per liter (µg/l)) whereas regional groundwater had only trace nitrate concentrations (<10 µg/l) (Hill 1990; Hill and Devito 1997). Chemistry was affected by the pathway taken by groundwater on its way to the stream and also by flow paths within the near stream zone. Ammonium was immobilized by microbes in aerobic rivulets, however, little ammonium depletion occurred in groundwater that flowed upward through reduced subsurface organic soils and around the stream perimeter. Biological transformation involving nitrate uptake or denitrification was not important during transport through the riparian/wetland zone. Nitrogen retention in riparian/wetland zones is complex and dependent on groundwater flow paths and chemistry.

A number of studies have been conducted on the nutrient retention of beaver ponds and conifer swamps in the Precambrian Shield of central Ontario (Devito and Dillon 1993a; Devito and Dillon 1993b; Devito et al. 1989). Precambrian Shield wetlands effectively retained nitrate (43-70%) and ammonium (88-95%) on an annual basis; however, net export of organic nitrogen resulted in low net retention of total nitrogen. Nutrient retention coincided with low stream flow, increased evapotranspiration and biotic uptake during the summer (Devito et al. 1989). Net nutrient export occurred during the winter and spring when stream flows were highest and biotic uptake was low (Devito et al. 1989; Devito and Dillon 1993a, b). In beaver ponds, Devito and Dillon (1993a) suggest that initial accumulation of forest floor material and input of organic matter by beaver may be important to nitrogen dynamics representing a long-term source of nutrients to the pond water and outflow. Devito et al. (1989) suggests that wetlands on the Precambrian shield are not major nutrient sinks but they do retain the biologically important forms of this nutrient.

Hill and Devito (1997) compared two Precambrian Shield wetlands with a wetland located in a headwater catchment on the Oak Ridges moraine (i.e. studied by Hill 1990, 1991) to show how a hydrological-chemical interaction perspective can explain different patterns of element retention and outflow chemistry in contrasting hydrogeological settings. The three wetlands are along a physiographic continuum that extended from glacial erosional landscapes with thin overburdens to areas of extensive glacial deposition. They found that southern Ontario landscapes, with thick sequences of glacial deposits, contain several scales of groundwater flow. They concluded that interactions between hydrology and chemistry within the context of basin hydrogeology can explain differences in the role of wetlands as sources, sinks, and transformers of mineral elements.

Hill (1996) reviewed the role of the riparian/wetland zone in agricultural landscapes in regulating the transport of nitrate in groundwater flow from uplands to streams. Most early studies of riparian/wetland zones that remove nitrate occur in landscapes with impermeable layers near the land surface. In this setting, groundwater follows shallow subsurface horizontal pathways that increase water residence times and contact with vegetation roots and organic rich riparian/wetland soils, facilitating rapid nitrate removal through plant uptake and denitrification (Hill 1996). He concluded that the ability of the riparian/wetland zone to remove nitrate varies in relation to landscape hydrogeology and that climate and hydrogeology need to be considered. Devito et al. (2000a) also studied nitrate removal in a riparian/wetland zone on the Boyne River floodplain receiving contaminated groundwater and outline the complexity of groundwater flow and its effect on nitrogen attenuation. They found that nitrate-rich groundwater was able to pass beneath the riparian/wetland peat and flowed laterally in a 2- to 4-m thick zone of permeable sand across the floodplain to the river. Denitrification occurred in the sand aquifer as groundwater interacted with buried channel sediments and surface water recharged from peat to the deeper sands. Devito et al. (2000a) indicate that the ability of riparian/wetland zone to remove nitrate is complex and dependent on depth of permeable riparian/wetland sediments, groundwater flow path and the location of organic-rich subsurface sediments.

Recent work in Ontario by Cey et al. (1999) has also provided information on the ability of riparian/wetland zone to reduce nitrate and the complex nature of groundwater flow and nutrient attenuation. Cey et al. (1999) studied groundwater flow and geochemistry in the riparian/wetland zone of a small agricultural watershed near London. They found that increased recharge at the riparian/wetland zone, as compared to the artificially drained field, caused nitrate-rich groundwater from the adjacent field to be diverted downward beneath the wetland where it was attenuated by denitrification in the downward moving groundwater.

In a review of studies on the effects of riparian/wetland zones on stream chemistry in Ontario and elsewhere, Hill (1996, 2000) outlined the complexity of riparian/wetland systems and their ability to affect water quality. He concluded that riparian/wetland systems exhibit a wide range of retention ability depending on their position in the landscape and watershed hydrology, and that nitrate removal would vary with differences in hydrogeologic setting and climate.

Mitsch et al. (2000) reviewed the nitrogen retention of wetlands (primarily constructed wetlands) and concluded that nitrate retention was clearly temperature (season) dependent. In the cold climate of the eastern USA, nitrate retention rates in constructed wetlands are on the order of 10 to 40 g-nitrogen/m^2/yr and are sustainable for the treatment of non-point source (NPS) pollution.

Mitsch and Gosselink (2000a) reviewed a number of studies that estimated the area of wetlands required in a watershed to improve nutrient retention (nitrogen and phosphorus) and general water quality. Several examples from Midwestern USA and Scandinavia suggest that a range of 3-7% (average approximately 5%) of temperate-zone watershed should be in wetlands to provide adequate water quality values for the landscape.

b) Phosphorus

Phosphorus enrichment of surface waters, whether by agricultural runoff or by wastewater effluent, and the resultant increase in primary production lead to many undesirable effects on aquatic systems. These include blooms of nuisance algae that clog water intakes, increased turbidity of water bodies, decline of aquatic macrophytes due to shading, and many other water quality concerns. According to Mitsch and Gosselink (2000b, 183), phosphorus retention is considered one of the most important attributes of natural and constructed wetlands. The ability of wetlands to retain phosphorus is key to determining downstream water quality (Reddy et al. 1999).

The primary forms of phosphorus that are biologically available for uptake by wetland plants and microorganisms are soluble inorganics (i.e. orthophosphates) (Mitsch and Gosselink 2000b, 184). Orthophosphate, or ortho-phosphorus, is the most common form of dissolved phosphorus, and is estimated by measuring soluble reactive phosphorus (SRP) in the water column. Total phosphorus is the sum of phosphorus dissolved in the water plus particulate phosphorus, which includes organic phosphorus, algal and bacterial phosphorus, and phosphorus sorbed to suspended solids (Kadlec and Knight 1996). All forms of organic phosphorus, as well as insoluble inorganic phosphorus, are not available for uptake by primary producers. They must first be transformed to ortho-phosphorus (Mitsch and Gosselink 2000b, 186).

Phosphorus retention in wetlands is accomplished by three mechanisms: (1) adsorption onto peat and clay particles; (2) precipitation of insoluble phosphates with metals (iron, calcium and aluminum) under aerobic conditions; and (3) incorporation into living biomass of bacteria, algae, and macrophytes (Mitsch and Gosselink 2000b, 186). Phosphorus is fixed as aluminum and iron phosphates in acidic soils, bound by calcium and magnesium in alkaline soils, and most bio-available at slightly acidic to neutral pH (Reddy et al. 1999). The clay-phosphorus complex is particularly important because much of the phosphorus brought into wetlands is sorbed to clay particles. The primary means of net long-term storage of phosphorus is through wetland soil/sediment accretion (Kadlec and Knight 1996). Most wetland macrophytes obtain their phosphorus from the soil and therefore the sedimentation of phosphorus sorbed onto clay particles is an indirect way in which the phosphorus is made available to the biotic components of the wetland (Mitsch and Gosselink 2000b, 187). Plants transform inorganic phosphorus to organic forms that are stored in organic peat, mineralized by microbial activity, or exported from the wetland.

When wetland soils are flooded and conditions become anaerobic, several changes in the availability of phosphorus result (Mitsch and Gosselink 2000b, 187). The iron and aluminum content of a wetland soil has an important influence on the ability of a wetland to retain phosphorus (Mitsch and Gosselink 2000b, 187). Under anoxic conditions, iron is reduced resulting in a release of phosphorus that was previously held as ferric phosphate compounds and aluminum phosphates.

Johnston (1991) reviewed the retention of phosphorus (based on input-output) of several wetlands in the US with no direct anthropogenic inputs and found that percent retention ranged from 9 to 80%. Schaefer et al. (1996) quantified the role of wetlands in buffering rural NPS phosphorus in the Eramosa River watershed in southern Ontario. They estimated that wetlands remove 92% of the phosphorus received directly from overland runoff which translates to 46% reduction in potential phosphorus loads to the Eramosa River.

In a study of the Hidden Valley wetland in Kitchener, Ontario, Gehrels and Mulamoottil (1989) measured a mass balance for phosphorus. In this case, they found that the wetland retained total phosphorus, but exported plant-available ortho-phosphorus. Annual total phosphorus inputs exceeded outputs by 100%; ortho-phosphorus outputs were 22% greater than inputs. They concluded that internal wetland processes were transforming sediment-bound phosphorus to ortho-phosphorus, resulting in greater phosphorus availability to plants downstream. However, the majority of this export occurred in the fall, suggesting that potential eutrophication downstream of the wetland would be negligible because the growing season had ended due to low water temperature.

Studies conducted on beaver ponds and conifer swamps in the Precambrian Shield of central Ontario suggest that nutrient retention of readily-available soluble reactive phosphorus can be significant on an annual basis, however, none of the study wetlands retained significant quantities of total phosphorus resulting in low net retention of total phosphorus (Devito and Dillon 1993a; Devito and Dillon 1993b; Devito et al. 1989). During the summer, nutrient retention coincided with low stream flow, increased evapotranspiration and biotic uptake (Devito et al. 1989). During the winter and spring, nutrient export occurred when stream flows were highest and biotic uptake was low (Devito and Dillon 1993a; Devito and Dillon 1993b; Devito et al. 1989). Organic phosphorus was released from sediments and senescent vegetation during winter and spring. In a review of riparian/wetland zones effects on stream chemistry, Hill (2000) stated that high seasonal concentrations of soluble reactive phosphorus in riparian/wetland zone groundwater may result from mobilization of phosphorus when iron and manganese oxides are reduced under anoxic conditions. Therefore, some riparian/wetland zones may not retain phosphorus during baseflows.

Mitsch et al. (1989) studied the Old Woman Creek wetland in Erie County, Ohio with respect to phosphorus retention. Nutrient levels in runoff entering the Old Woman Creek wetland are high; phosphorus loading is estimated to be 12 - 23 g-phosphorus/m^2/ yr. Ortho-phosphorus concentrations in the stream entering the wetland was found to be significantly greater than that leaving the wetland. Because flow data and total phosphorus were not measured, the net retention of phosphorus could not be calculated, but was estimated to be 5-7 g-phosphorus/m^2/yr, or 30-39%. If their estimation was correct, and if other Lake Erie wetlands retain phosphorus similarly to the Old Woman Creek, the authors concluded that the existing wetlands on the lake could be retaining 75-100 tons/yr, or about 3.5 - 5% of the total NPS loading of phosphorus to the lake. Restoration of one-fourth of the original wetland area could possibly lead to a 24 - 33% reduction in phosphorus loading to western Lake Erie (Mitsch et al. 1989). Reeder (1994), in a study on the same wetland, found that phytoplankton productivity could account for gross uptake of up to 15 g-phosphorus/m^2/ yr. Macrophytes, which have traditionally been cited as critical components of maintaining water quality, accounted for only 0.1 g-phosphorus/m^2/yr. Reeder concluded that wetlands dominated by deep water and phytoplankton may be efficient traps for phosphorus in runoff.

Wang and Mitsch (1998) studied phosphorus retention in a tributary watershed of the Laurention Great Lakes and estimated that about 15% of the watershed area should be in wetlands to provide phosphorus retention benefits. This would result in a reduction of two-thirds of the existing phosphorus load to Saginaw Bay from the watershed.

In a review by Mitsch et al. (2000) that focused on the nitrogen and phosphorus retention of wetlands (primarily constructed wetlands), they concluded that phosphorus retention was highly variable from site to site (ranged 0.4 to 47 g-phosphorus/m^2/yr) depending on soil chemistry, ambient water quality and water column productivity. Sustainable phosphorus retention, at least in constructed wetlands, appears to be in the range of 0.5 to 5 g-phosphorus/m^2/yr.

2. Sediments

Sedimentation is a primary water quality concern in Canada and the U.S. In fact, excessive sediment loading from eroding land is considered the major pollutant of wetlands, lakes, rivers, and estuaries in the U.S. (Gleason and Euliss 1998). Of ten states reporting causes of wetland degradation to the United States Environmental

Protection Agency (U.S.E.P.A.), nine states cited sedimentation or siltation as the most widespread cause of degradation followed by filling/draining and flow alterations (U.S.E.P.A. 2000).

Sediment consists of particles of all sizes, from fine clay particles to silt, sand, and gravel. Sedimentation and siltation of these particles and organic matter can cause damage to aquatic ecosystems, including clogged fish gills, suffocation of bottom-dwelling (benthic) organisms, reduction in fish reproductive habitat (benthic substrata), reduced water clarity, reduced primary productivity due to physical burial and reduced light availability, transport of chemicals attached to sediment particles, and the gradual infilling of water bodies (Gleason and Euliss 1998; U.S.E.P.A. 2000). Water bodies located in agricultural landscapes are prone to receiving high sediment loads due to alteration of wetland catchment areas and cultivation of grasslands that once protected soils from erosion (Gleason and Euliss 1998).

Hydrology is a primary determinant of the sediment-retention capacity of a wetland (Brown 1988, Johnston 1991). Hydrology controls the source, amount and spatial and temporal distribution of sediment inputs to wetlands and other receiving water bodies (Johnston 1991). As water flows into a wetland, the vegetation disperses the water and reduces flow velocity, and therefore increases the retention time of the water in the wetland (Winter and Woo 1990). Reduced water velocity and increased retention time have a positive effect on sedimentation rates (Brown 1988; Hammer 1993). Particle size and soil properties of the surrounding watershed also influence sedimentation rates (Boto and Patrick 1978). Re-suspension of sediment will depend on the hydrological characteristics of the wetland, wetland size, area of open water, and wind and wave action. The most widely used representation of sedimentation in wetlands is percent removal of total suspended solids.

Constructed wetland systems are effective for sediment removal (e.g. Kadlec and Knight 1996, 331; Mitsch and Gosselink 2000b). Sediment retention ranges between 49 to 98% in surface-flow and subsurface-flow constructed wastewater wetlands (Mitsch and Gosselink 2000b, 708). Kadlec and Knight (1996, 331) found that reduction of suspended solids in wastewater and stormwater ponds ranged from 66-92%.

Natural wetlands have also been the subject of sediment removal investigations. Depressional wetlands (i.e. closed basin with no outlet) retain all of the incoming sediment (Novitzki 1979; Gleason and Euliss 1998). Slope wetlands also retain sediment if water velocities decrease substantially within the wetland area (Novitzki 1979). In Wisconsin, watersheds containing 40% wetland and lakes had sediment loads 90% lower than watersheds with no wetlands or lakes; only 5% of the wetlands were found to be responsible for trapping up to 70% of the sediment (Novitzki 1979). Novitzki (1979) determined that sediment retention could be maximized by maintaining a 10% cover of wetlands within a watershed. Other researchers have shown that the position of riparian/wetlands in the watershed can be more important than the extent of wetland area in terms of reducing sediment and nutrient loads; i.e. downstream wetlands have a greater effect on water quality (Johnston et al. 1990).

Brown's (1988) study of the Lamberts Creek, Minnesota watershed showed that, in the subwatershed with natural, unmodified wetlands, there was a net retention of suspended solids within the basin. In contrast, the subwatershed with the highest degree of wetland channelization produced substantial suspended solids loading downstream. Phillips (1989) concluded, based on studies of American, Australian, and European basins, that 14-58% of total upland sediment production is stored in wetlands

Despite the benefits of sediment retention to downstream rivers and lakes, excessive sediment loads can be harmful to natural wetlands (Gleason and Euliss 1998; Crosbie and Chow-Fraser 1999). In a review of studies on the sedimentation of wetlands, Gleason and Euliss (1998) indicated that wetlands in agricultural landscapes have shorter topographic lives than wetlands in grassland landscapes. When wetlands fill with sediments they lose their capacity to perform most natural wetland functions. As stated earlier, Crosbie and Chow-Fraser (1999) found that watershed land use affected water quality in 22 Great Lakes wetlands. Wetlands in primarily agricultural watersheds exhibited high turbidity, suspended solids, and nutrient levels, whereas those in forested watersheds were clear and nutrient-poor. They suggest that forested buffer zones and agricultural best-management practices may ameliorate water quality in wetlands surrounded by agricultural lands. The trade off between the importance of sediment removal as a water quality benefit and maintaining the topographic life of wetland basins needs to be integrated into management strategies of wetlands and watersheds (Gleason and Euliss 1998).

3. Pathogens

Many infectious diseases are transmitted through animal and human feces. Waterborne pathogens of serious risk to humans include strains of bacteria such as *Escherichia coli*, *Salmonella typhi*, *Campylobacter* species, and others; viruses such as enteroviruses, Hepatitis A, and others; and the protozoans *Entamoeba histolytica*, *Giardia intestinalis*, and *Cryptosporidium parvum* (Kadlec and Knight 1996; WHO 2000). These pathogens are persistent in water supplies due to their ability to survive outside of host organisms. Fecal contamination of natural surface and groundwater can be a serious problem in agricultural landscapes dominated by livestock production, and in highly populated areas where secondarily-treated wastewater characterized by abundant pathogens is often discharged directly to rivers, streams, or lakes. For example, in southern Ontario, Goss et al. (1998) found that over 34% of domestic wells in agriculturally-dominated landscapes contained levels of coliform bacteria greater than the maximum allowable concentration in Ontario drinking water (OME 2000). Natural bacteria populations are generally low in wetlands but they may be variable and seasonally high in certain wetlands because of wildlife populations (e.g. staging waterfowl) (Kadlec and Knight 1996, 539).

The ability of constructed wetlands to reduce populations of pathogenic microorganisms in wastewater effluent has been demonstrated globally (e.g., Kadlec and Knight 1996; Schreijer et al. 1997; Stott et al. 1997; Hill and Sobsey 1998; Decamp and Warren 2000; Neralla and Weaver 2000). Many of the processes that reduce pathogen populations in natural systems are equally or more effective in wetland treatment systems (Kadlec and Knight 1996, 535). Structurally and functionally, most wetlands are dominated by naturally-occurring populations of microbes and plant life (Kadlec and Knight 1996, 154). Microbial populations in wetlands include the diverse flora of bacteria, fungi and algae that are important for nutrient cycling and biological processing. In addition, zooplankton grazers may be an important pathogen removal mechanism in wetlands during certain seasons. Macrophytes are essential because they provide surface contact area for microbes that mediate most of the nutrient and pollutant transformations that occur in wetlands (Hamilton et al. 1993). Vegetated wetlands appear to be more effective for pathogen removal than facultative ponds and other natural treatment systems that have less physical contact between pathogens and solid surfaces (Kadlec and Knight 1996, 543). Treatment wetland removal efficiencies are nearly always greater than 90% for coliforms and greater than 80% for fecal streptococcus (Kadlec and Knight 1996, 540).

4. Contaminants

The ability of wetlands to degrade and remove contaminants such as pesticides, metals, landfill leachate, and urban stormwater runoff has been examined in natural wetlands (e.g. Fernandes et al. 1996; Goldsborough and Crumpton 1998), and to a much greater extent in constructed wetlands (e.g. Hammer 1989; Kadlec and Knight 1996). Pesticides are chemicals that are toxic to living organisms, and are targeted at either plants (herbicides), fungi (fungicides), or insects (insecticides) (Goldsborough and Crumpton 1998). Landfill leachate and urban stormwater runoff often include mixtures of toxic substances including metals, household chemicals, hydrocarbons, salt, and sand.

Pesticide use in Canada has been on the rise since World War II, with a 500% increase in treated land from 1971 to 1991 (Goldsborough and Crumpton 1998). Of the 5.6 million ha of total farm area in Ontario in 1996, 2.0 million ha, or over 35%, received herbicide applications, an 11% increase over 1991 (Statistics Canada 1997).

Transport of pesticides into water bodies occurs by direct overspray, by aerial drift of pesticide droplets, by wind drift of particulates to which pesticides are adsorbed, by dissolution in surface water runoff, snowmelt, or groundwater (Waiser and Robarts 1997; Goldsborough and Crumpton 1998), or by accidental spills. Various studies of pesticide residues in wetlands of the Great Plains have reported moderate to high frequencies of detection, up to 100% in the case of the herbicide 2,4-D in Saskatchewan farm ponds (Grover et al. 1997). Although Nebraska wetlands surrounded by cropland had significantly greater atrazine concentrations, 94% of the sampled wetlands contained detectable levels of herbicides (Frankforter 1995), regardless of surrounding land use. Frank et al. (1990) compiled results of pesticide surveys conducted in rural ponds in Ontario between 1971 and 1985. Landowners contacted the Ministry of Agriculture or Environment when they suspected a pond had been contaminated by pesticides. Of the 211 ponds sampled, 132 or 63% were contaminated by at least one pesticide.

Pesticide loss and dissipation occurs by degradative processes such as photolysis, abiotic hydrolysis and biodegradation, as well as by volatilization into air, adsorption, and outflow from the wetland (Goldsborough and Crumpton 1998). Photolysis of a pesticide occurs when the molecular bonds are broken by UV energy. Hydrolysis is the process of decomposition due to a chemical reaction with water. Biodegradation is the breakdown of pesticide molecules by microbial processes. Goldsborough and Crumpton (1998) argue that wetlands have specific characteristics that increase pesticide dissipation through photolysis and adsorption as compared to other water bodies. The high levels of biological productivity in wetlands results in profuse submersed and emergent plant growth. This increases the availability of surface area for adsorption, plant sequestration, microbial degradation, and exposure to light. Many studies have shown the ability of submersed macrophytes to remove pesticides and thus prevent further negative effects on aquatic biota (e.g., Brock et al. 1992; Karen et al. 1998). Highly organic wetland sediments also are preferential adsorption sites for pesticides (e.g. Brock et al. 1992). The shallow nature of wetlands increases light penetration, and thus increases the potential for photolysis. Wetlands in agricultural landscapes have high potential for intercepting and dissipating pesticides.

In a review of the distribution and environmental fate of pesticides in prairie wetlands, Goldsborough and Crumpton (1998) conclude that pesticide fate is poorly understood, complicated by the large variety of pesticide compounds, limited information on pesticide transformation products, and the difficulty of studying pesticide fate in the complex wetland matrix. Pesticide dissipation studies indicate that half-lives (time for residues to decrease by 50%) can range from less than a day to several months depending on the pesticide, it's chemical properties and a number of wetland characteristics. There are a number of mitigating factors including hydrology, amount of vegetation, water depth, microbial populations and area of organic sediments. In general, common pesticides of surface and groundwater disappear rapidly from wetlands, primarily due to adsorption to organic matter in sediments and decomposing litter. Formation of persistent pesticide-humus complexes leaves little chance for desorption of the parent pesticide (Goldsborough and Crumpton 1998).

Wetlands are able to attenuate landfill leachate and urban stormwater runoff. Fernandes et al. (1996) used models to predict the long-term migration of contaminants in landfill leachate into a wetland 300 meters downstream, near Pembroke, Ontario. Their models predicting the long-term migration of contaminants used input parameters such as area, soil porosity, groundwater velocity, hydraulic gradient, etc. Prior hydrogeological studies of the area showed that the transport of leachate from the landfill to the wetland occurred via groundwater recharge and surface water flow. Maximum contaminant concentrations in the surface stream occurred in the 1980s, but have decreased or remained stable since then. Wetland water quality has remained stable despite receiving contaminated runoff. This indicated that the wetland has been attenuating landfill leachate for the twenty years of landfill operation. They found that the low hydraulic conductivity of the thick organic soil would limit the migration potential of various ions. Zinc, lead, and an organic contaminant (pentachlorophenol) were found to be immobile in the soil, and thus would not migrate from the point of entry into the wetland. The authors concluded that the wetland soil has the potential to prevent or reduce migration of several contaminants commonly found in leachate.

D. Summary

The hydrological functions of wetlands include storage and eventual release of surface water, recharge of local and regional groundwater supplies, reduction in peak floodwater flows, de-synchronization of flood peaks, and erosion prevention. Many wetlands are known to provide any or all of these functions; each situation is uniquely dependent on local topography, climate, geology, and watershed characteristics. The ability of wetlands in Ontario to store large amounts of incoming water is highly variable. Position in the landscape, location of the water table, soil permeability, slope, and moisture conditions influence the ability of any given wetland to attenuate floodwaters. Wetlands commonly retain part of surface inflow and release the water during an extended period resulting in a peak flow lag behind the initial peak runoff into the wetland. As surface water enters a wetland, the vegetation can disperse the incoming water, reduces the flow velocity, and thus increases residence time of water in the wetland. Water storage in wetlands is underground or in surface depressions and when the water table is low considerable storage capacity is available. Wetlands that are saturated may have little capacity to store water. Wetland channelization reduces the ability of a wetland to attenuate runoff during flood conditions. Maintaining and restoring wetlands on the landscape reduces river flow rates and flooding.

Recharge of groundwater is an extremely important function of some wetlands; water percolates slowly from wetlands to aquifers. Movement of groundwater is related to soil permeability and local topography. Groundwater recharge occurs from many areas in the landscape, including wetlands (from seasonal to permanent), uplands, and areas of extreme permeability such as sand deposits. Interactions between wetlands and local or regional groundwater supplies are complex and site-specific. Some wetlands receive significant groundwater discharge. The interactions of wetlands and groundwater are affected by the position of the wetland with respect to groundwater flow systems, geologic characteristics of the substrate and climate.

Wetlands are extremely complex systems and several characteristics contribute to their roles as nutrient sinks. They accumulate organic matter, retain nutrients in buried sediments, convert inorganic nutrients to organic biomass, promote sedimentation of solids, and their shallow water depth maximizes water-soil contact and therefore microbial processing of nutrients and other material in the overlying water. Wetlands can be effective nitrogen sinks in agricultural landscapes (Table 1) due to assimilation by microbes and denitrification. Other wetlands may retain nitrate and ammonium but may export organic nitrogen. Phosphorus retention in wetlands is accomplished through adsorption onto organic peat and clay particles, precipitation of insoluble phosphates with metals and incorporation into living biomass. Phosphorus retention rates for wetlands can be significant (Table 1), however, under anoxic conditions previously retained phosphorus can be released. Wetlands are hydrologically, chemically and biologically linked to the landscape in which they occur and have variable nutrient-retention efficiencies depending on their position in the landscape, watershed hydrology, hydrogeologic characteristics and climate.

Wetlands can reduce the impacts of sedimentation on water quality within watersheds (Table 1). Hydrology is a primary determinant of the sediment-retention capacity of a wetland and controls the source, amount, and spatial and temporal distribution of sediment inputs. Wetland vegetation is important because it disperses the water and reduces flow velocity that increases the retention time of the water in the wetland, resulting in increased sediment deposition. Percent of wetland area and position in the landscape are important for reducing sediment loads.

Little information exists on the effects of the ability of natural wetlands to reduce microbial populations in water. The effectiveness of constructed wetlands to reduce pathogenic organisms from wastewater is high (Table 1). Natural wetlands are dominated by microbes (bacteria, fungi and algae) and plant life that are important for reducing pathogens.

Pesticide loss and dissipation occurs by degradative processes such as photolysis, abiotic hydrolysis and biodegradation, as well as by volatilization into air, adsorption, and outflow from the wetland. High levels of biological productivity in wetlands result in profuse submersed and emergent plant growth that increases the availability of surface area for pesticide adsorption, plant sequestration, microbial degradation, and exposure to light. In general, common pesticides of surface and groundwaters disappear rapidly from wetlands (Table 1), primarily due to adsorption to organic matter in sediments and decomposing litter.

Table 1: Range of percent retention for nitrogen, phosphorus, sediment, coliforms and pesticides in wetlands.

	% Retention
Nitrogen - Nitrate	up to 80
- Ammonium	up to 95
Phosphorus	up to 92
Sediment	up to 70
Coliforms (Constructed Wetlands)	up to 90
Pesticides	<1 day - several months[1]

[1]Time for residues to decrease by 50%

IV. Permanent Cover

A. Upland Conservation Programs

Sustaining agriculture and watershed ecosystems requires the improvement of surface and groundwater quality while still maintaining farm profitability and rural vitality (Rickerl et al. 2000). Two upland conservation programs that have demonstrated this mix are the ‘best management practice’ of conservation tillage and the Conservation Reserve Program (CRP) of the United States.

Conservation tillage (e.g., no-till) leaves significant crop residue such as stems, stalks and leaves on the soil surface from harvest time to the next planting. Surface cover protects the soil from raindrop impact so soil detachment is reduced and water is less available for overland flow. The crop residues slowly decompose to add organic matter to the soil. Soil erosion can decrease by as much as 90 to 98% as a result of conservation tillage practices (Seta et al. 1993; Clausen et al. 1996).

Conservation tillage practices can reduce surface runoff by up to 99% (Edwards et al. 1988). Cracks, roots, channels, and wormholes all combine to increase the infiltration capacity of the soil. Earthworms, through their burrowing activity, play an important role in this phenomenon. One to ten percent of rainfall during storm events flows away from the surface through these holes. Burrows and large soil pores are destroyed in tilled and altered soils (Edwards et al. 1989).

Baker et al. (1995) reviewed all the published studies from 1990 to 1995 that investigated herbicide runoff from no-till and found a reduction in herbicides of 70%. Buffer strips added to minimum till practices further reduced herbicides in runoff by an average of 46%. They stated that the effectiveness of surface crop residue in reducing herbicide runoff will depend on the site and weather conditions.

The CRP was initiated in the United States in 1985 with the intention of retiring highly erodible/marginal farmlands to permanent grass cover (Randall et al. 1997). The Program was established to reduce erosion, protect soil productivity, reduce sedimentation, improve water quality, and improve wildlife habitat. Through a series of annual payments, CRP was designed to help landowners and operators conserve and improve soil and water resources on their farms and ranches while still maintaining an economic return. By the end of 2000, 13.5 million hectares were enrolled in CRP. This program has reduced erosion by more that 22% in the United States even though less than 10% of cropland is enrolled (Ribaudo et al. 1990). It has created 13,600 km of buffer strips (i.e. vegetated areas around wetlands and along watercourses) and 700,000 ha of grassland habitat. Table 2 shows the projected reductions in erosion, nutrient discharge and the US dollar savings resulting from water quality improvement from land enrolled in CRP (Ribaudo 1989; Ribaudo et al. 1990).

Table 2: Projected reduction in erosion, nutrient discharge and the US dollars savings resulting from water quality improvement from land enrolled in CRP.

	Erosion Reduction		Total Suspended Solids		Total Kjeldahl Nitrogen		Total Phosphorus		U.S. Dollars
Regions by States	**Area: 1000 ha**	**Soil Saved million Kg**	**million Kg**	**% Reduced**	**10,000 Kg**	**% Reduced**	**10,000 Kg**	**% Reduced**	**Saved (millions)**
IA;MO;IL;IN;OH	3095	123,551	62,668	12	25,309	12.1	4816	11.9	746
MN;WI;MI	1533	29,872	10,490	14.2	6066	13.1	560	11.4	415
PA;NY;MD;NJ; CT;MA;NH;ME	295	8230	3729	3.7	1666	2.8	406	3. 0	191
ND;SD;NE;KS	3897	71,530	34,525	11.0	12,508	14.4	2560	13.3	267

V. Buffer Strips

Referred to as buffer strips, riparian buffers, or grass/vegetated filter strips, these are areas of native or replanted vegetation that lie between lands subject to human alteration and naturally occurring waterways (Castelle et al. 1994). Buffer strips physically act as holding areas, where the presence of vegetation reduces surface runoff by improving infiltration, enhancing evapotranspiration, and intercepting rainwater (Flannagan et al. 1989; Munoz-Carpena et al. 1993; Mendez et al. 1999). This decrease in water runoff velocity as water moves through the buffer allows for sediment and associated pollutants to deposit in the buffer. This results in a reduction in surface runoff and associated pollutants to down-slope riparian systems (Hayes et al. 1979; Foster 1982). Riparian buffers also have a cooling effect on the water temperatures in adjacent riparian zones (such as streams), the result of shading of surface water runoff as it moves over land. This has been shown to have a beneficial impact on the population of certain fish species in Ontario (Barton et al. 1985). By combining the needs of various wildlife species, the goals for nutrient retention and the land availability, buffer strips could be effectively integrated in the landscape (Fennessy and Cronk 1997).

A. Sediment Removal and Erosion Control

Buffers control erosion by blocking the flow of sediment and debris, by stabilizing wetland edges and stream banks, and by promoting infiltration (Shisler et al. 1987). They form a physical barrier that slows surface flow rates and mechanically traps sediment and debris. Roots maintain soil structure and physically retain erodible soil. Wilson (1967) concluded that buffer width, sediment load, flow rate, slope, grass height, and density all affect sediment removal.

The size of the buffer required is determined by a number of factors: the type of vegetation present; the extent and impact of the adjacent land use; and the functional value of the receiving wetland. Variations in these factors will affect each buffer's capacity to improve surface water quality as water moves through the buffer. Since the slope of a buffer strip is difficult to manipulate, altering the buffer width seems the most promising means to optimize effectiveness. An insufficiently small buffer may put an aquatic resource at risk where an excessively large one will unnecessarily pull land out of agricultural use unnecessarily (Castelle et al. 1994).

The buffer width required for efficient nutrient/sediment removal has been debated (Fennessey and Cronk 1997). Subsurface flows are more effective than surface flows for nitrate removal, and removal increases as buffer width increases. Many studies have found the bulk of nitrate sediment removal occurs in the first few meters of the buffer zone (Dillaha et al. 1989; Peterjohn and Correll 1984; Ghaffarzadeh et al. 1992). Conditions for denitrification are particularly optimum at the receiving edge of a buffer because carbon (required as an energy source) is abundant and vegetative growth is often most dense at the edge of the strip where nitrate enters (Fennessey and Cronk 1997).

Ghaffarzadeh et al. (1992) studied the effectiveness of two, 9.1 m grass vegetated filter strips for sediment removal. They found that 85% of the sediments were removed with no difference in sediment removal in either of the 2 buffers beyond a distance of 3.1 meters. Neibling and Alberts (1979) found sediment discharge reduced by over 90% in a 5 m grass buffer. Clay transport was reduced by 83%. Ninety-one percent of the incoming sediment load was removed in the first 0.6 meters of the buffer strip. Magette et al. (1989) found a 66% reduction in sediment passing through a 4.6 m grass buffer.

B. Nutrient Assimilation

Johnes et al. (1996) estimate 95% of cattle wastes, 85% of pig wastes and 90% of poultry wastes are returned to the land. Of this, up to 17% of nitrogen and 3% of phosphorus are thought to reach drainage networks. These numbers reflect trends occurring in North America and in Europe, particularly in the Netherlands and the United Kingdom. Wherever there is intensive cropping and livestock production occurring great potential exists for nutrient loading of receiving watercourses (Heathwaite et al. 1998; Cey et al. 1999).

In Ontario, water and sediment quality for 22 wetlands in the Great Lakes basin was researched by Crosbie and Chow-Fraser (1999). Concentrations of phosphorus, nitrogen, and inorganic suspended solids increased predictably as agriculture became the dominant land use in the respective watersheds. Their research found that the use of forested buffer strips in agriculturally dominated watersheds lead to measurable improvements in the water quality of downstream wetlands and streams. These findings were echoed by research in South Dakota by Rickerl et al. (2000). Four wetlands, two buffered by pasture grass and two not buffered from upland agriculture, were compared for water quality. Concentrations of nitrate and phosphorus were significantly less in the buffered wetlands. They also detected more storage of nitrogen and phosphorus in the plants of the 2 wetlands that were not buffered from the surrounding uplands.

The variety of vegetative cover in a buffer strip may determine its efficiency in intercepting nitrate, ammonia or phosphorus (Fennessey and Cronk 1997). Forested buffer strips are more efficient in removing nitrate than herbaceous buffer strips (Haycock and Pinay 1993, Correll 1991, Vought et al. 1991). The roots and root exudates of the trees put more organic carbon in the soil profile providing the primary source of carbon required for the denitrification of nitrate (Schipper et al. 1991). Grass buffers appear to be more effective than mixed grassed buffers (grass plus forest buffers) for removing total organic nitrogen plus ammonium and sediments from surface water (Gilliam et al. 1997). Phosphorus retention appears to be maximized when buffer strips contain both woody and herbaceous vegetation (Vought et al. 1994, Osborne and Kovacic 1993).

1. Nitrogen

The mechanisms for nitrate removal by buffer strips are complicated, but vegetation uptake in the roots and anaerobic microbial denitrification in the saturated zone of the soil are considered to be the main mechanisms (White et al. 1997). Relatively narrow buffers seem to be very effective in reducing the amount of nitrate as surface waters move through them. In Wisconsin, Madison (1992) found that 4.6 m and 9.1 m grass vegetated filter strips reduced ammonium and nitrate by approximately 90 and 96%, respectively. Mander et al. (1997) compared a wet meadow/grey alder buffer strip (11 m and 20 m, respectively) to a wet meadow/grey alder/grass buffer (12 m, 28 m, and 11 m, respectively) in Estonia. The grey alder/wet meadow strip removed 67% of the total nitrogen and the wet meadow/grey alder/ upland grass combination was capable of removing 96% of the nitrogen. Dillaha et al. (1989) reported that a 4.6 m and a 9.1 m grass filter strip in Virginia removed an average of 54 and 73% of nitrogen. Young et al. (1980) found that the average reduction in total nitrogen associated with solids from feedlot runoff was 84% over 2 years using a 41 m cropped buffer system in Minnesota.

2. Phosphorus

Inputs of phosphorus are often essential for profitable crop and livestock production, however its export in watershed runoff can accelerate the eutrophication of receiving waters (Sharpley et al. 2000). The efforts to reduce phosphorus losses from agricultural systems needs to balance off farm phosphorus inputs in feed and fertilizer with outputs in harvested products (Sharpley et al. 2000). This minimizes soil phosphorus inputs in excess of crop requirements. This approach combined with other practices such as crop residue management, conservation tillage and buffer strips can further reduce phosphorus loss via surface runoff and erosion (Chambers et al. 2000; Uusi-Kamppa et al. 2000).

Uusi-Kamppa et al. (2000) determined that grassed buffer zones, with widths up to 16 m, effectively reduced total phosphorus in runoff from agricultural land in both long-term and short-term experiments in Norway, Finland and Sweden. Retention of total phosphorus in buffers varied from 27 to 97%. Most phosphorus remained in the upper layers of the buffer zones regardless of buffer width. They recommended wider buffer zones in areas with poor soil infiltration and higher soil erosion (heavy clay soils).

In Estonia, Mander et al. (1997) found that the grey alder/wet meadow strip (11 m and 20 m, respectively) removed 81% of the phosphorus and a wet meadow/grey alder/grass (12 m, 28 m, and 11 m, respectively) combination was capable of removing 97% of the phosphorus. Dillaha et al. (1989) reported that a 4.6 m and a 9.1 m grass filter strip removed an average of 61 and 79% of phosphorus in Virginia. Madison et al. (1992) trapped 99.9% of phosphorus using a 9.1 m filter strip in Wisconsin. He found no improvement in the trapping efficiency of phosphorus by increasing the buffer strip beyond 9.1 m.

Young et al. (1980) found that the average reduction in total phosphorus associated with solids from feedlot runoff was 83% over 2 years using a 41 m cropped buffer system in Minnesota. Other research has shown that a 1:1 ratio of grass vegetated filter strip size to waste production area (cumulative surface area of animal pens) could result in a 90 to 100% reduction in nutrients level in runoff to adjacent riparian systems (Bingham et al. 1980; Overcash et al.1981).

C. Pathogens

Bacteria loss in runoff from freshly manured soil can be as high as 90% (Crane et al. 1983). Earlier research by Dickey and Vanderholm (1981) and Walker et al. (1990) suggested that buffer strips alone would not reduce bacterial levels to water quality guidelines. Coyne et al. (1995) found that 9 m buffers trapped up to 74% of fecal coliforms shortly after rain events on soil fertilized with fresh poultry waste. However, they noted that this 74% reduction in fecal coliforms resulted in more than 200 fecal coliforms/100 ml, thereby exceeding the minimum drinking water standards of 0/100ml set in Ontario. Young et al. (1980) evaluated a cropped buffer system over 2 years and found a reduction of 69% for total coliforms and fecal coliforms and 70% for fecal streptococcus.

Entry et al. (2000) studied 30 m mix of grass and forested buffer strips applied with swine wastewater in Georgia. Vegetation type in the buffer strips usually did not affect survival of total and fecal coliform bacteria in the soil. However, they found that decreasing soil moisture and increasing soil temperature substancially decreased survival of total and fecal coliform bacteria at different soil depths (0-5, 5-15, 15-30 cm). Soil moisture (dry) and temperature (>28 C) will effectively decrease survival rates of pathogenic bacteria. They recommended that waste applications to agricultural lands be conducted during optimal periods of warm-dry weather when soils are dry and bacteria are less likely to be transported. They also suggest that the buffer strip vegetation should have high evapotranspiration rates to reduce soil moisture. Selecting the appropriate vegetation type and increasing the buffer strip width can improve the efficiency of buffer strips for reducing pathogens (Jim Entry, US Department of Agriculture, personal communication).

Techniques are currently being developed to reduce pathogens in animal wastewater before they reach buffer strips and when used along with vegetative buffers may effectively reduce the input of pathogens from animal confinement areas to water resources (Entry and Sojka 2000; Sojka and Entry 2000).

D. Pesticides

Herbicides are the most frequently detected pesticides in surface waters. The amount of pesticides applied, their solubility, persistence, degree of soil adsorption and their location in the soil profile determines their concentration in the sediment and water (Fawcett et al. 1994). The amount of pesticide transfer in runoff water depends on the soil adsorption properties of the pesticide. Most herbicides have intermediate adsorption to the soil and are lost primarily with surface water runoff (Baker and Laflen 1983; Gaynor et al. 1995). Of the total amount lost, 60 to 90 % of common herbicides such as atrazine, alachlor, cyanazine and metolchlor are lost in this water phase (Fawcett et al. 1994).

Gril et al. (1997) and Patty et al. (1997) reviewed the findings from a study in France on the ability of 6, 12, and 18 m grassed buffer strips to reduce lindane, atrazine and its metabolites in surface water runoff. Averaged between the different sized buffer strips, lindane and atrazine were reduced 72 to 100% and 44 to 100%, respectively. Grass buffer strips (20.1 m) in Iowa retained 11 to 100% of the atrazine, 16 to 100% of metolachlor, and 8 to 100% of cyanazine (Arora et al. 1996). Ranges in these percentages were the result of rainfall duration and intensity. Herbicide retention was less during peak flows and increased as the runoff event progressed (i.e. at lower flow rates). Infiltration was the key process for retention of the moderately adsorbed herbicides. Benoit et al. (1999) found a rapid degradation of the herbicide isoproturon (ISP) in a 5 m grass buffer strips down-slope from cropland in France. They found the half-life for ISP was 72 days in the cultivated soil compared to 8 days in the buffer strip soil. In addition to the shorter half-life of ISP, a large proportion of the ISP residue in the buffer strip bound to the soil and was no longer available to loss through surface water flows.

E. Summary

Sustaining agriculture and watershed ecosystems requires the improvement of surface and groundwater quality while still maintaining farm productivity. Conservation tillage leaves crop residue from harvest on the soil surface resulting in a decrease in soil erosion by as much as 90%. Conservation tillage practices can result in a reduction in herbicide runoff by 42-70%.

Vegetated buffer strips can effectively control erosion by forming a physical barrier that slows the surface flow of sediment and debris, by stabilizing wetland edges and stream banks, and by promoting infiltration. The required width of a buffer size is determined by the type of vegetation present; the extent and impact of the adjacent land use; and the functional value of the receiving wetland. Many studies have found the bulk of sediment removal occurs in the first few meters of the buffer zone; sediment removal can be significant (Table 3).

Buffer strips can effectively remove nutrients from surface water flow. The main mechanisms of nitrate removal is by vegetation uptake in the roots and anaerobic microbial denitrification in the saturated zone of the soil. Relatively narrow buffers seem to be very effective in reducing nitrogen (Table 3). Phosphorus retention can be effective (Table 3) in buffer strips that contain both woody and herbaceous vegetation, grasses and cropped buffer systems. Buffer strips can trap a significant proportion of the pathogens (Table 3), however, remaining levels often exceed minimum drinking water standards. Low soil moisture and high soil temperature substancially decrease survival of total and fecal coliform bacteria. The key process for pesticide retention in buffer strips is infiltration. Grass buffer strips can reduce pesticides significantly (Table 3).

Buffer strips are an essential practice in watershed protection, however, they should be viewed as a secondary best management practice. In-field management practices such as conservation tillage and upland conservation are important for pollution control because they prevent pollution at its source.

Table 3: Range of percent retention for sediment, nitrogen, phosphorus, pesticides and coliforms in buffer strips.

	% Retention
Sediment	75 - 91
Nitrogen	67 - 96
Phosphorus	27 - 97
Pesticides	8 - 100
Coliforms[1]	70 - 74

[1]fecal coliform

VI. Wetland Loss

North American wetlands are extremely important ecosystems that have been drained, filled, harvested for peat and other products, inundated with pollutants, and generally seen as unproductive wastelands since European colonization began. It is only within the last several decades that some functions and values of wetlands have been identified and valued in our society, leading to their preservation and protection by legislation such as the Federal Wetlands Policy of 1991. This policy and others do not provide complete protection for wetlands and therefore need to be further strengthened to enhance protection measures.

Snell (1987) reviewed wetland loss and found that the original wetland area in Ontario south of the Precambrian Shield in 1982 had been reduced by 68% with 933,000 ha remaining. In southwestern Ontario (counties Essex, Kent, Lambton, and others) over 90% of original wetland area had been converted to other uses; in 8 counties, less than 5% of the total area is made up of wetlands (Figure 5). Most of the wetland losses were attributed to agriculture. Using a similar mapping methodology, Whillans (1982) found significant coastal wetland losses on Lake Ontario in the areas of Hamilton (74%) and Toronto (100%). Total wetland losses for the Canadian shoreline of Lake Ontario were calculated to be 43%. He cites similar studies on other Great Lakes, and concluded that the Great Lakes have lost 75% of the historical wetland area that was associated with their shorelines. Most remaining wetlands have been degraded in some way; only a small percentage of original wetland area consists of high quality, ecologically intact sites (Bedford 1999).

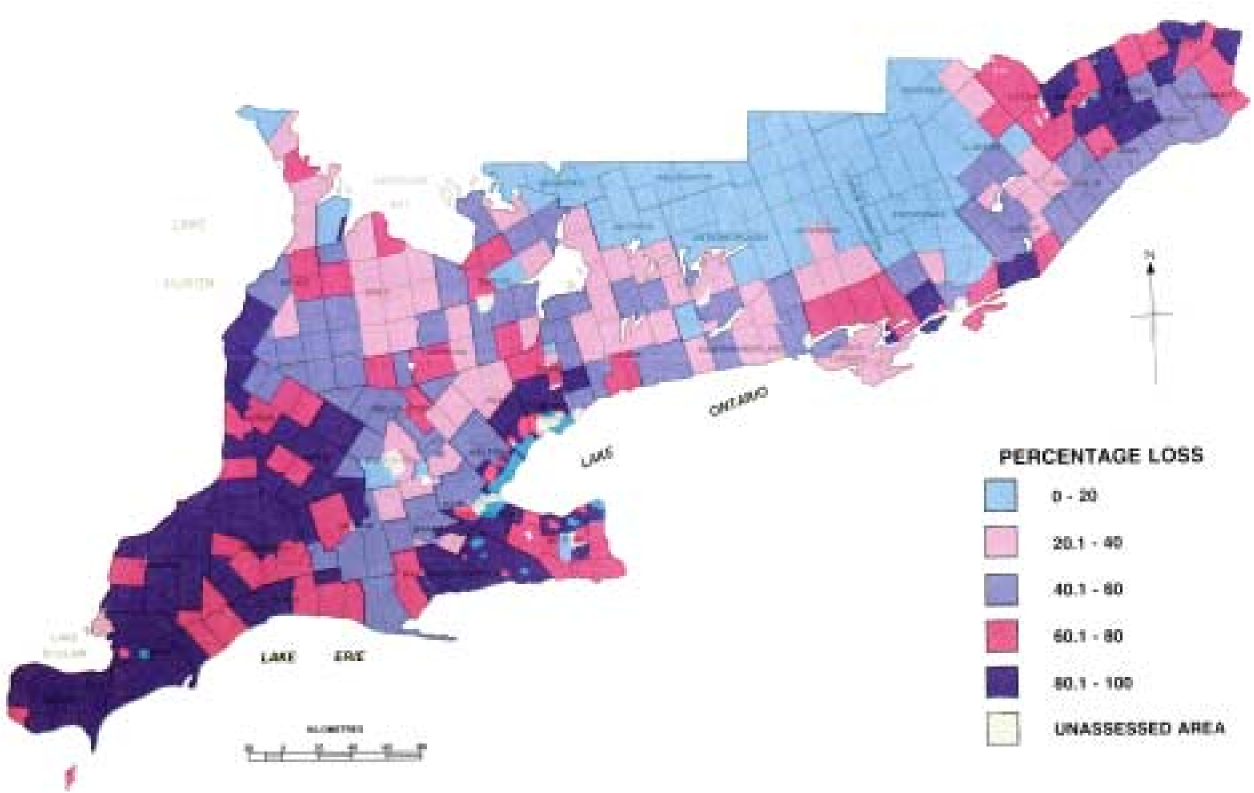

Figure 5. Wetland loss in southern Ontario (Snell 1987).

VII. Policy

A. Wetland Protection in Ontario

1. Federal Policies and Legislation

Federal involvement in natural resource management is limited by the Constitution Act 1967, which accorded the majority of management responsibilities to the provinces. However, one federal policy and one legislated Act provide protection for wetlands. They are as follows:

The *Federal Wetlands Policy, 1991*- the policy requires an environmental review through the Canada Environmental Assessment process for projects supported by federal resources that potentially impact wetlands.

The *Canada Fisheries Act, 1985* – The Act provides for fisheries habitat protection and where wetlands are judged to provide fisheries habitat, they can receive protection through this legislation. Great Lakes coastal wetlands and interior associated wetlands with lakes receive the most protection because of their value as fish habitat.

2. Provincial Policies

Ontario's current policies and regulations governing the management of surface and groundwater are fragmented and uncoordinated. A number of provincial ministries have legislative responsibilities related to water, however, no single level of government has the mandate or resources to conduct careful science-based planning of water management and development. Municipalities have the authority to manage water within the *Municipal Act, 1990*. Ontario's conservation authorities have a broad mandate to develop resource conservation programs and a provincially funded mandate related to flood and erosion control. By default, to the extent that groundwater and surface water is managed at all, it is done at the local level.

The following are provincial policies and regulations that provide protection for wetlands:

Planning Act, 1990 - Section 3 of the Act provides for the province to articulate values of provincial interest and to create policies to protect those values. The province has articulated a range of areas of interest to which provincial policies will apply and wetlands are contained within that grouping. Wetlands judged to be of provincial significance, based on a provincial evaluation system can receive protection under this legislation. The provincial evaluation system for wetlands takes water management, natural heritage, first nation and other values into consideration.

Under the Act, local governments must "have due regard to" the protection of wetlands identified as provincially significant. However, provincial wetland protection policies do not provide complete protection for provincially significant wetlands. Lands designated "agricultural" within a municipal land use plan are exempt from the application of the wetlands protection policy.

Section 3 of the Act does contain a policy regarding water quality and quantity protection however; this policy lacks any form of implementation direction and does not reference the contribution of wetlands and riparian areas to water quality and quantity management.

Local governments may develop and adopt wetland protection policies that provide wetlands with protection even if they are not judged to be provincially significant. The decision to protect these wetlands and the nature of the protection offered depends solely on local government decision. Relatively few municipalities have chosen to invoke their own wetland protection policies (e.g. City of Ottawa).

The Lakes and Rivers Improvement Act, 1990 – This Act requires provincial approval for the manipulation of water in a stream, lake or watercourse. Wetlands adjacent to watercourses and lakes may be protected as a result of protection to these water bodies.

The Public Lands Act, 1990 - The Act requires provincial approval for disturbance of public lands. Lands under water (lakes, rivers, streams) are for the most part considered to be public lands. Wetlands adjacent to watercourses and lakes may be protected as a result of protection to these water bodies.

Ontario Water Resources Act, 1990 - The Act requires the permission of the Ontario Ministry of the Environment for the taking of over 50,000 liters/day of water from a surface or groundwater source. Wetlands that are hydologically connected to the source may be protected from excessive water removal.

Flood Plain Regulations, 1990 - These regulation were created by the Province and are administered by Ontario's *Conservation Authorities Act, 1990*. These regulations require the permission of the local conservation authority for encroachment on a defined flood area, for filling in hazardous areas, and for the manipulation of a watercourse. Wetlands can receive protection because they are included in a hazardous or flood area.

These regulations are oriented to the management and protection of water and may, in an indirect way, afford wetlands some protection. None of these have as their specific purpose, the protection of wetlands. Although there are a number of competing planning processes articulated by the Province, there are few science-based linkages between wetlands protection and water quality.

3. Other Instruments for Protection.

Many non-government organizations (NGO's), and public sector agencies at all levels, with an interest in wetlands protection, including Ducks Unlimited, have developed strategies to protect wetlands. These include outright acquisition, often in private and public partnership. The North American Waterfowl Management Plan (1986) and its implementing device in eastern Canada- the Eastern Habitat Joint Venture (EHJV) provide a vehicle for international support of migratory waterfowl habitat protection of which acquisition is an important component. At a provincial level initiatives such as the Strategic Lands Initiative and Ontario's Living Legacy provide resources for wetlands acquisition in partnership with NGO organizations. Local government can support senior government initiatives in this regard and at times have initiated acquisition schemes with their own resources.

Other instruments include wetland conservation easements; partial acquisition through acquisition of development rights and land trusts that are formed for the explicit purpose of acquiring and managing pieces of landscape.

4. Constructed Wetlands

Recognition that a wetland environment can have positive benefits to water quality is evidenced in the use of constructed wetlands, often in specific applications to improve water quality resulting from specific land uses or industrial processes. They are presently used within the Province to treat feedlot runoff and milk house waste and are also used in combination with other treatments to treat municipal sewage waste. They represent a considerable potential to aid in the treatment of surface water runoff from land and resource uses that could potentially impair water quality; however, to date this potential has not been realized in any broad-spectrum fashion.

B. Riparian Area Management

Riparian areas are defined, for the purpose of this report as areas adjacent to rivers, streams, lakes and wetlands. Riparian area protection programs are activities that provide for permanent landscape cover on riparian areas and include buffer strips and permanent cover practices on erodable lands.

In the 1990's the Ontario Ministry of the Environment (MOE) developed a cooperative program partnership with Ontario's Conservation Authorities. The program was entitled Clean Up Rural Beaches (C.U.R.B.) and provided technical support and funding support for landowners that adopted programs to reduce contamination of streams, rivers, and lakes that were located upstream from rural beaches. The program included techniques such as restricting cattle access to streams and creation of riparian buffer strips. Although the program provided improvements in water quality, provincial support for the program was discontinued in 1996.

Presently, there are a select number of programs operating in the Province that focus on riparian protection. The rural water quality program in the Grand River watershed is supported by local governments (e.g., Regional Municipality of Waterloo, County of Wellington) and seeks to make improvements to water quality in the Grand River, the source of water for urban municipalities within the Region of Waterloo.

The South Nation River watershed, east of Ottawa, has a Clean Water Committee that directs local private and public funds to landowner projects that will improve water quality and fisheries habitat.

The Ontario Ministry of Agriculture and Food has approved a program entitled "Healthy Agricultural Futures" a component of which deals with rural water quality. The Agricultural Environmental Stewardship Initiative, a federally supported program, developed through the Agricultural Adaptation Council, and the Ontario Farm Environmental Coalition has initiated development of a program that can potentially provide funding for best management practices, landowner training and education for rural landowners related to water quality improvement in rural areas.

While programs exist, few provide financial support for on site activities that result in water quality improvements. The multitude of participants from all levels of government has resulted in landowner confusion over what financial and technical supports are available and this in turn has resulted in a lack of focus on improving water quality in rural areas.

C. A Case for the Protection and Restoration of Wetlands and Riparian Areas

Below, we argue that: (1) wetlands and riparian areas can play an important role in reducing the variability of water quality, and (2) that an investment in wetland and riparian area protection and restoration is probably a cost-effective way to improve water quality.

1. Wetlands and Riparian Areas as Water Quality Support Systems.

The scientific literature indicates that wetlands, buffer strips, and permanent vegetative cover provide important watershed functions including water quality improvement, surface water storage, and groundwater recharge. Good watershed management ensures that natural landscape features are intact and as a result these features ensure the long-term sustainability of water quality within that watershed. In effect, wetlands and riparian areas provide a “pre-treatment” function for source water arriving at drinking water treatment facilities. This means that broad-scale protection and restoration of wetland and riparian areas will subject our drinking water to two separate purification processes, natural within watershed processes and the final in-pipe treatment at the water treatment plant. Natural system water treatment will also ensure that the affect of in-pipe treatment system failure is minimized. Because source water will be cleaner as a result of wetland and riparian area protection, they serve as a sort of “insurance” against in-pipe treatment failure and the introduction of unexpected pollutants.

2. Funding Natural Verses In-Pipe Water Treatment – A Comparison

In-pipe is defined as a man-made water treatment facility. How many wetlands and riparian areas does Ontario need? Unfortunately a definitive determination of how much wetland and riparian area is needed was beyond the time and resources available in preparing this report. However, the overall declining water quality in many of southern Ontario’s watersheds suggests a strong case can be made that current inventories of wetlands and riparian areas are too small. Protecting and restoring these areas may represent a cost-effective way to improve water quality.

The following calculations provide a comparison of the cost of wetland restoration versus in-pipe treatment as strategies for improving drinking water quality.

Ducks Unlimited has experience restoring nearly 12,000 ha of wetlands in southern Ontario. Their records indicate that this restoration can be accomplished at a cost of approximately $136.00/ha/yr. During the period 1995-1997 annual municipal expenditures on water services was $2.09 Billion (Ontario Ministry of Municipal Affairs and Housing 1998) of which 51% was directed at water supply. In year 2000 the water supply budget of the Regional Municipality of Durham Water was estimated to consist of 47% treatment costs and the remainder distribution costs (Regional Municipality of Durham 2000). If we assume that this Municipality has costs similar to those of the rest of southern Ontario (which is a statement made within the budget report made to the Durham Council) then we estimate that Ontario municipalities spend approximately $500 million/yr on in-pipe drinking water treatment.

To get a sense for the implications of these numbers, suppose that we were to divert 1% of annual spending on in-pipe water treatment to wetland restoration. This would potentially enable restoration of approximately 37,000 ha of wetlands ($5 million/$136.00). Our most recent information (i.e., 1982) indicates that wetlands cover 933,000 ha or about 10% of southern Ontario. This area represents a 68% decline from the original wetland area. In addition, the distribution of the remaining wetlands is not uniform; in many counties in the southwest, less than 5% of the area is wetlands. Diverting 1% of annual in-pipe treatment expenditures could increase Ontario’s wetland inventory from 10% to 14%. With strategic restoration programs, a 4% increase in wetlands in Ontario could have significant impacts for water quality improvement.

We could also divert the same 1% of our in-pipe water treatment costs to wetland restoration in areas that we must rent for \$370/ha/yr before we restore it to wetlands. (The rental rate is consistent with a purchase price of about \$8,600/ha, a reasonable rate for productive agricultural land in south-western Ontario, but well below the rate for most urban or suburban land). In this case, we would restore approximately 9,900 ha (\$5 million/(\$370.00+\$136.00)). Even with high land rental rates, we would be able to restore a significant area of wetlands that would potentially provide significant water quality improvements. Although these are crude estimates they do suggest that wetland and riparian area protection and restoration may be a cost-effective way to improve drinking water quality.

Unfortunately, the greatest amount of wetland and riparian area loss has been in landscapes and watersheds with high land prices that are dominated by intensive agriculture and urban development. As a result, the value of wetlands and riparian areas for the protection and maintenance of drinking water may very well be greatest in these landscapes and watersheds.

There are a number of other implications of wetland and riparian area protection and restoration aside from improving the quality of in-pipe source water. First, there are a significant number of people (approximately 35% of the population) living in Ontario who do not obtain their water from designed water treatment and distribution systems. These individuals rely on ground water from shallow private wells as drinking water sources. Should these sources become contaminated, these individuals will be forced to switch to another source of drinking water. Similarly, rural communities receive their drinking water from groundwater sources including aquifers. If these water sources become contaminated, the capital outlay associated with providing safe drinking water is likely to be significant. In addition, the costs of remediating groundwater and aquifer contamination will be significant and therefore inexpensive preventative measures such as protecting and enhancing wetland and riparian areas that provide insurance against groundwater contamination are sensible.

Second, much of Ontario’s population relies on lakes for its drinking water and the quality of the water is dependent on the health of the watershed. Protection and restoration of wetlands and riparian areas will ensure that source water for the lake is protected. Watershed based programs that protect the quality of source water for the lake would seem a sound policy.

Third, wetlands and riparian areas can also provide a number of other benefits such as flood control, erosion prevention and potential climate change mitigation. The scientific community has for a number of years been indicating that we can expect impacts associated with climate change such as:

- reduction in groundwater and soil moisture
- decline in Great Lakes water levels, stream levels, and wetland areas
- decline in water quality and quantity
- more intense and shorter duration rainfall events
- increased periods of drought

Environment Canada (J. Klaassen, presentation to Eastern Ontario Model Forest, February, 2001). There is a need for adaptive strategies to deal with the potential impacts of climate change. Increased wetlands and riparian areas will retain more water on the landscape and in doing so may reduce the impact of flooding from intense rainfall events by releasing stored water slowly. The anticipated impacts of climate change are also expected to increase the variability of source water quality. Wetlands and riparian areas can mitigate this impact.

VIII. Conclusions and Policy Recommendations

A. Conclusions

Information from Ontario, other parts of North America, and the world indicate that wetlands, riparian areas and upland vegetative cover provide important functions for sustaining freshwater resources including water quality improvement, surface water storage, and groundwater recharge. Southern Ontario's landscapes have been degraded due to encroachment by agriculture and urbanization. Many regions have lost a significant amount of their wetlands and riparian area cover and therefore their ability to provide a predictable supply of clean water may be significantly impaired.

Because the contribution of these areas to water quality and quantity is not precisely known, a first consideration should be to provide protection for the remaining wetlands and riparian areas that are providing water quality and quantity benefits.

Our current policies do not sufficiently protect wetlands and riparian areas.

To ensure long-term sustainable water resources, strategies for water resource management must be addressed at the watershed and landscape scale. These solutions include securing and restoring natural features of the watershed including wetlands, riparian areas, and upland cover. Until individual watersheds have been evaluated and modeled to better understand the functions and values of wetlands and riparian areas for water resource sustainability, these areas should be protected.

What has become clear during the preparation of this report that the contribution of wetland and riparian areas to water quality and quantity is unique depending on the area and watersheds in question. We must deal with water quantity and quality issues on a watershed basis. Each watershed is a unique unit in which uplands and lowlands are linked hydrologically (van der Valk and Jolly 1993). The spatial distribution of natural and human affected features within an individual watershed affect water quantity and quality. Because each watershed is an unique entity, the impact of land use and land-use changes on water quality can best be examined within an individual watershed. Bringing appropriate experts together with land users to develop a watershed management plan will be critical to ensure sustainable water quantity and quality.

Another important issue is to identify major information gaps in our understanding of effective watershed management for water quantity and quality benefits in southern Ontario. Monitoring programs that provide constant feedback are essential for improving our understanding of program effectiveness and complex watershed processes that affect water quantity and quality.

A strong link between watershed management and policy is necessary to ensure the long-term sustainability of Ontario's landscapes for water quantity and quality benefits. An evolving water management policy framework that reflects and leads the management of water on a watershed basis is essential.

A better understanding of wetlands and riparian areas within surface and groundwater systems would allow water managers to identify the overall water quality benefits of wetlands and riparian areas within a watershed.

In examining the risk and economic contributions of wetlands/riparian areas we can conclude the following:

a) Wetlands/riparian areas have the capacity to significantly reduce pollution in surface and groundwater. Further, this benefit is of greatest importance where wetlands, riparian areas, and drinking water supply are closely linked.
b) Wetlands/riparian areas can reduce the variability in the quantity and quality of drinking water sources.
c) Wetlands/riparian areas can improve source water quality and reduce drinking water treatment.
d) The cost to restore wetlands is small relative to the costs of in-pipe treatment, provided that this restoration occurs on lands where land costs and rental are relatively low. Wherever marginally profitable, low intensity agriculture is practiced on drained wetlands, this land could probably provide a more valuable service to society if it were restored to wetlands. This is particularly true if the land in question lies in a watershed that is a direct source for drinking water.
e) Wetland/riparian area restoration costs will increase in landscapes and watersheds with high land costs. However, it is these areas where most wetland and riparian area loss has occurred and therefore the value of protecting and restoring may be most needed. In these high land priced landscapes the value of protection and restoration should be assessed against a wide range of objectives and benefits, not solely a drinking water objective.

Wetlands and riparian area protection and restoration can be a very cost-effective way of safeguarding drinking water supplies in southern Ontario.

B. Policy Recommendations

Wetlands are extremely complex ecosystems and much about their behavior is uncertain or difficult to observe and document. Consequently, decisions about wetlands policy must inevitably be made while we are uncertain about important characteristics and benefits of wetlands. Uncertainty, however, does not mean that no decision can be made. Indeed, to make no decision, and hence to proceed with the status quo, would mean that very real cost-effective water quality/quantity benefits and opportunities would be lost.

Given the information and evidence in this report, we advance the following policy recommendations:

1) Create a Comprehensive Water Management Policy Framework Governing Surface and Groundwater

The scope of our report has focused on wetlands and riparian area protection. It is our contention that without an overall water management context the management and protection of these areas will be inadequate. Current policy towards water development is governed by a patchwork of somewhat independent statutes, policies and implementation tactics. The province should enact policies that provide a framework, based on the watershed, for the comprehensive management of surface and groundwater systems. These policies would:

a) Provide for a water management planning system, with all the attendant requirements (i.e. standards, policy leadership, monitoring and information management, evaluation, and implementation) that incorporate wetlands and riparian area protection as a component part.
b) Provide for policy leadership associated with the management of water. Policy leadership must above all else provide for a framework for allocation of the resource, and must provide a means to fund costs associated with management of the resource.
c) Require the development of surface and groundwater monitoring and modeling systems that would provide for sufficient information to adequately protect, manage and allocate the water resource.

Within this integrated policy framework the province should:

2) Enhance Wetland Protection

Because the precise benefit of wetlands to water quality/quantity regimes can only be estimated although their potential could be significant, existing protection mechanisms of natural wetlands should be strengthened. The following specific actions are recommended:

a) Ensure that wetland evaluations using the latest version of the provincial evaluation system, are completed across southern Ontario.
b) Consider stringent wetland protection strategies in areas where wetlands are closely linked to drinking water sources and in areas where wetland cover as a percentage of the total watershed area is small.
c) Ensure that all new artificial manipulations of water resources are subjected to watershed-based impact analysis.
d) Encourage governments to protect non-provincially significant wetlands until watershed-modeling studies are completed and a more precise knowledge of the functions of wetlands and riparian areas within surface and groundwater systems are known.

3) Encourage and Enhance Wetland Restoration

The potential for enhancement of wetland areas could mean significant improvement in water quality. The need will be most extreme where wetland cover as a percentage of total watershed area is small and where drinking water sources are closely linked to wetlands. There exist many opportunities to enhance and restore natural wetlands. What is needed is commitment and resources. Where, through watershed modeling studies, restored wetlands can be shown to have a positive influence on surface and groundwater quality, the cost of wetland restoration should be supported as a water management business expense.

The creation of artificial wetlands as a means to mitigate potential impacts associated with land uses that can significantly impair water quality should also be investigated and utilized where appropriate.

4) Encourage the Adoption of Riparian Area Protection Programs

The significant public sector interest in water issues in rural watersheds must be better coordinated so that the effort does not result in overlap and duplication and provides for an effective program at the landowner level. Riparian area protection programs can improve water quality in rural areas and should be an integral part of water quality improvement programs; however, they must be integrated with other program measures. The Province should act as a leader in this regard creating the framework through which riparian area protection programs can be developed and implemented. In order to ensure uptake by rural landowners, one of the essential elements of program design must be acceptability at the landowner level.

5) Encourage and Improve Our Understanding of Watershed Management

Wetlands, riparian areas, and uplands are important components of watersheds. Further research on these landscape features and their roles in water quantity and quality functions in southern Ontario is required to ensure sustainable water resources for Ontario. Specific areas of research demanding attention at a watershed scale are as follows:

a) Hydrological Functions: There is a need to determine the role and ability of wetlands, riparian areas, and uplands to reduce and store surface water runoff. As well, an improved understanding of the groundwater recharge function of wetlands and uplands is required.
b) Water Quality Functions: There is a need to determine the role and long-term sustainability of wetlands, riparian areas, and uplands to retain nitrogen and phosphorus, attenuate microbial pathogens, and dissipate pesticides in agricultural landscapes. As well, there is a need to develop models of watershed function based on wetlands, riparian areas, and uplands for predicting water quality effects of different wetland protection and restoration scenarios.

IX. Final Thoughts

Immediate action is required to restore and sustain water supply and quality in Ontario. Sustainable water resource management requires focusing on individual watersheds and it is imperative that within those watersheds we move quickly to conserve existing landscape features (i.e., wetlands and riparian areas) that provide long-term benefits for securing the supply and quality of Ontario’s water. Watershed management programs and policy must move forward now using the best available information. Successful implementation of policies and programs to ensure long-term water supply and quality will require insightful leadership from all levels of government, agricultural producers, and private citizens groups.

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