The *Water Classification Regulation* –

Planning for Water Quality

In order for New Brunswick's existing surface and groundwater water resources to supply us with abundant clean water for the foreseeable future, they need to be protected and managed with care.

The *Water Classification Regulation* is a regulation under the *Clean Water Act*. The purpose of water classification is to set goals for surface water quality and promote management of water on a watershed basis. The *Water Classification Regulation* establishes water quality classes, and associated water quality standards, and outlines administrative processes and requirements related to the classification of water.

Water classification places the water of lakes and rivers or segments of rivers into categories or classes based on water quality goals. Each class is then managed according to the goal. The goals associated with a specific class are set according to the intended uses of the water, and the water quality and quantity required to protect the intended uses.

Public involvement is a cornerstone of the *Water Classification Regulation*. The Water Classification Program has been developed to help watershed and other multi-stakeholder community groups plan and set goals for surface water quality, and to help them achieve water quality goals through the establishment of water quality standards, action planning and watershed management.

This information sheet tells about the New Brunswick *Water Classification Regulation* and explains how the *Regulation* will be used to plan for water quality. It also explains how watershed and community groups can be involved in the process of setting water quality goals for their watersheds.

Water Classification – A Step-by-Step Process

The *Water Classification Regulation* outlines a step-by-step process for setting water quality goals, on a watershed basis. Water Classification places rivers or segments of rivers (including estuaries), tributaries and lakes into one of six possible categories, called classes. Each of these classes has its own set of water quality standards, designed to protect various uses of the water. Once waters are classified, they can be managed according to these standards.

The Classes:

	Outstanding Natural Waters
AP	Designated Drinking Water Supplies
AL	Lakes not classified as O or AP
A	Excellent Water Quality
B	Good Water Quality
C	Acceptable Water Quality

The Process of Water Classification has several important steps.

Water Classification – Step-by-Step

- identify and involve stakeholders
- gather water quality information
- assemble land and water use information
- set goals for water quality
- prepare and implement action plans

First, stakeholders are **identified and involved** early in the process, so that groups can build understanding and work to make decisions together.

Another important early step is **measurement and interpretation of existing water quality**. Historical information and newly collected data on water quality are used to build a picture of how the water quality may have changed in a watershed. Knowing the existing water quality helps a group make realistic decisions about the future of the watershed.

The next step is **mapping of land and water information**. Understanding the topography, geology, soils and vegetation cover in an area helps to explain water quality characteristics. Often ecological land classification can help to integrate the interpretation of these features. Land use and geology mapping helps to explain water quality changes from the natural system, and shows where sources of pollutants occur.

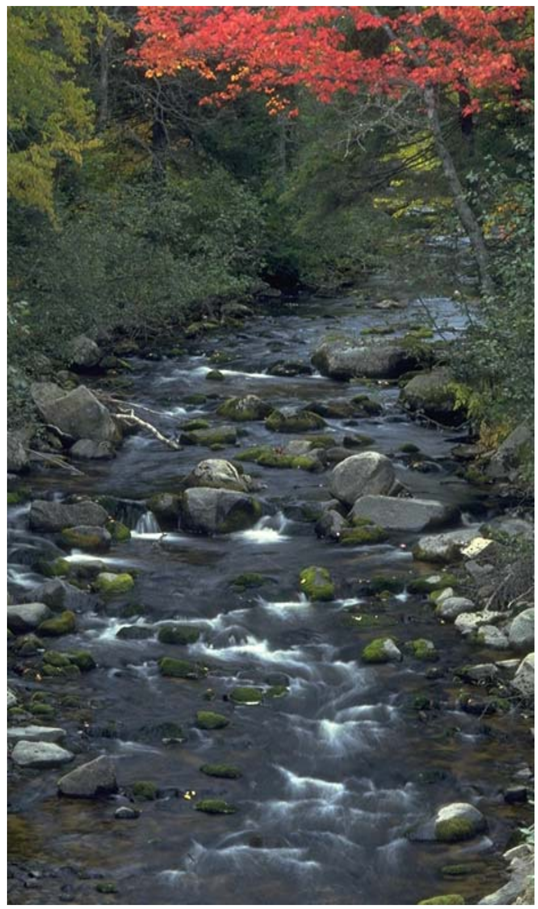
Once information is assembled, **stakeholders are involved in setting water quality goals** for waters in the watershed. The various stakeholders who have an interest in a watershed and its water are encouraged to work together to build consensus on water quality issues and goals.

Stakeholders include various landowners, residents and those who come from outside the watershed to use or enjoy the water. Stakeholders also include various groups of land users: farmers, foresters, industry (including those in the mining, pulp and paper, and aquaculture industries), anglers, canoeists, residential and recreational users, and others. Other stakeholders are the various levels of government: aboriginal, federal, provincial and municipal. Each of these groups has an interest in the water and, potentially, an influence on water quality.

By involving stakeholders early in the Water Classification process, everyone can understand why the water quality is the way it is, and what will result from actions to maintain, protect or restore that quality. This includes the economic, social and environmental consequences of decisions that are made and goals that are set.

The Classes

The Outstanding Natural Waters Class



The Outstanding Natural Waters Class is a special class for protecting the water of unique or representative lakes or rivers, which have essentially natural water quality and have had little disturbance from human activities. Groups or individuals are able to nominate lakes or rivers to this class, as long as the waters meet specific objective criteria. A Review Panel with representatives from various sectors will be established to consider nominations for inclusion in the Outstanding Natural Waters Class.

The AP Class

The AP Class is designed to further protect the surface watersheds which are designated as municipal drinking water supplies under the *Watershed Protected Area Designation Order*, *Clean Water Act.* There are 30 of these watersheds in the province. Waters in these watersheds are classified into the AP Class on the commencement date of the *Water Classification Regulation*.

The AL Class

Lakes are known to be very sensitive systems that must be managed differently from rivers and streams. For this reason, all lakes not classified in the Outstanding or AP Classes will automatically be placed into the AL Class on the commencement date of the *Water Classification Regulation*. Lakes will be managed on the basis of their trophic level, which is a measure of their productivity as related to nitrate and phosphate concentrations. Some impoundments will not be included in the AL Class.

The A, B and C Classes

Rivers and other watercourses not included in the above classes will be classified into one of three Classes, A, B or C. Each of these Classes will have their own water quality standards and management features. Waters will be classified into these classes watershed by watershed over the next few years.

Setting Goals for Water Quality

The six Classes represent goals for water quality. In most cases, the water will already meet the goal and actions taken will be to maintain the existing water quality. Sometimes, stakeholders will agree that a higher Class should be the goal and actions will be geared towards gradually improving water quality.

Implementation

Once the classification of a particular river system is accomplished, an implementation phase begins. One role of watershed groups, including stakeholders, will be to assist with action planning. An action plan lists and prioritizes achievable activities that will help to protect or restore a river system according to the goals set through Water Classification.

Other aspects of implementation will involve the design and promotion of voluntary Best Management Practices. Regulatory tools will include the standards

Best Management Practices (BMPs)

BMPs are methods of using land or water resources that minimize environmental impacts. BMPs are designed to be technically and economically feasible. BMPs can be designed for any sector of land and water use, including forestry, agriculture, urban development, and recreation.

under the *Water Classification Regulation*, as well as the existing approvals and permitting system that focuses on pollution sources and watercourse alterations.

The standards associated with the *Water Classification Regulation* include standards for microbiology, dissolved oxygen, aquatic life and (for the AL Class) trophic or nutrient status. There are also mixing zone standards to help industry achieve the in-stream standards. Some activities are prohibited or limited in certain classes of water. For specific information on the water quality and aquatic life standards, please see Table 1.

Water Classification is both a regulatory tool and a watershed management mechanism. The step-by-step achievement of water quality goals, accomplished by understanding the water and its watershed, and by involving stakeholders in establishing a vision for the water quality, makes Water Classification a means by which a watershed group can be focused, empowered and made action-ready.

The involvement of various stakeholders in the process of Classification helps to build stronger, more broadly based watershed management groups, which will benefit from new ideas and the understanding of various points of view long after the classification exercise is complete. Water Classification leaves a legacy of knowledge as well as concrete tools such as land and water mapping and water quality data. Action plans completed as a result of Classification can be used to prioritize activities and set objectives for maintenance or restoration initiatives. This provides the watershed group with focus and direction in the future.

Working with Watershed Groups

Water Classification is already a feature of watershed-based activities in New Brunswick. The Department of the Environment and Local Government is presently working in various parts of the province with watershed and community groups that have, or can develop, a watershed focus to begin the classification process in their area.

Examples of this partnership include the Eastern Charlotte Waterways ACAP (Atlantic Coastal Action Program) group that has undertaken the first steps of a Water Classification for the West Fundy Composite Watershed (the Magaguadavic and adjacent rivers). Working towards the eventual goal of classification, they have monitored the water quality, mapped the watershed, and begun the process of discussing a preliminary classification with stakeholders throughout the watershed. Eastern Charlotte Waterways Inc. has also produced a **Guidebook on Water Classification**, including six modules and a toolkit to take a watershed group step-by-step through the process of water classification and watershed management.

The Department of the Environment and Local Government has also begun to work toward water classification with established groups in other watersheds in the province. The Hammond River Angling Association, St. Croix International Waterway

Commission, and Tabusintac Watershed Association have also prepared preliminary water classifications for the associated watersheds.

Other groups working on the step-by-step process of classification include the following: Shediac Bay Watershed Association, Kennebecasis Watershed Restoration Committee, Chaleur Bay Watersheds, Friends of the Kouchibouguacis, Comité de gestion intégrée du basin versant de la baie de Caraquet, Société d'aménagement de la rivière Madawaska et du lac Témiscouata inc., Comité de gestion environnementale de la rivière Pokemouche, Nashwaak Watershed Association, Inc., Petitcodiac Watershed Monitoring Group, and Kent Watersheds Coalition.

As Water Classification progresses, watershed by watershed, groups like these will provide the focal point for community involvement, collection of new information, and determination of public vision in the goal setting process. Watershed groups will also be involved in implementing Water Classification through action planning and follow-up.

Watershed groups provide community-level input to water quality and water use management in New Brunswick. The Department of the Environment and Local Government applauds the hard work of these groups to facilitate the protection and improvement of New Brunswick's lakes and rivers. With their help, and with the help of all stakeholders, we look forward to implementing the *Water Classification Regulation* and long-term management of the province's lake and river systems.

Cette information est aussi disponible en français.

For more information, please contact:

Water Classification Program
New Brunswick Department of Environment
P.O. Box 6000, Fredericton, New Brunswick
E3B 5H1
(506) 457-4846
email: water.classification@gnb.ca

NEW BRUNSWICK WETLANDS CONSERVATION POLICY

POLITIQUE DE CONSERVATION DES TERRES HUMIDES DU NOUVEAU-BRUNSWICK

Natural Resources
and Energy

Ressources naturelles
et Énergie

Environment and
Local Government

Environnement et
Gouvernements locaux

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POLICY STATEMENTS

The Government of New Brunswick will:

- Prevent the loss of Provincially Significant Wetland habitat and achieve the goal of no net loss of wetland function for all other wetlands. (Note: All coastal marshes are considered Provincially Significant under this policy, and will receive the highest degree of protection.);
- Promote and develop wetlands education and awareness programs and supporting materials;
- Promote stewardship and securement of wetlands through enhanced cooperation among local, municipal, provincial and federal governments and private sector stakeholders.

ÉNONCÉS DE PRINCIPES

Le gouvernement du Nouveau-Brunswick entend :

- prévenir la perte d'habitat de terres humides d'importance provinciale et la moindre altération des fonctions de toutes les autres terres humides (Remarque – En vertu de la présente politique, tous les marais côtiers sont considérés comme des terres humides d'importance provinciale et ils jouiront du degré le plus élevé de protection possible.);
- élaborer et soutenir des programmes d'éducation et de sensibilisation aux terres humides, ainsi que des documents à l'appui;
- faciliter l'intendance et la sécurisation des terres humides en améliorant la coopération entre les administrations locales, municipales, provinciales et fédérale et le secteur privé.

POLICY OBJECTIVES

The objectives of this policy are:

1. <u>Maintenance of Wetland Function.</u> To manage human activity on or near wetlands in a manner which will achieve no loss of Provincially Significant Wetland habitat and no net loss of wetland function for all other wetlands.
2. <u>Securement, Stewardship, Education and Awareness.</u> To promote and facilitate the development of wetland stewardship, awareness, and education through government initiatives and cooperative relationships with local citizens, private sector stakeholders, and municipal, provincial, and federal governments.

OBJECTIFS DE LA POLITIQUE

La présente politique vise les objectifs ci-après :

1. <u>Le maintien des fonctions des terres humides</u>. Gérer les activités humaines à l'intérieur ou à proximité des terres humides d'une manière qui n'occasionne aucune perte d'habitat de terres humides d'importance provinciale ni aucune altération des fonctions de toutes les autres terres humides.
2. <u>La sécurisation, l’intendance, l’éducation et la sensibilisation</u>. Encourager et faciliter l’éducation, la sensibilisation et l’intendance des terres humides en lançant des initiatives gouvernementales et en nouant des liens de collaboration avec des citoyens locaux, des intervenants du secteur privé et les administrations municipales, provinciales et fédérale.

BACKGROUND

Wetland Functions

Wetlands perform many important functions, including, but not limited to, the following :

- Protect human health by storing and purifying ground and surface water;
- Maintain ecosystem health and provide habitats, food and nutrients for many species, including humans;
- Provide habitat for Endangered Species and other species of special status;
- Provide important repositories for bio-diversity;
- Provide protection from flooding and storm surges;
- Stabilize shorelines of rivers and along the coast;
- Provide areas for natural food production and commercial products; and
- Provides recreational, scientific, aesthetic, spiritual and cultural opportunities.

Economic Consequences of Wetland Loss

Many wetlands play an integral part in purifying drinking water. Some jurisdictions, such as New York State, are recognizing the savings associated with conserving wetlands in comparison with the upgrading of expensive water treatment systems.

As more and more wetlands are degraded or lost, the natural capacity to buffer floods from spring runoff and tidal forces is lessened, increasing the threat of

CONTEXTE

Fonctions des terres humides

Les terres humides remplissent d'importantes fonctions, notamment, sans toutefois s'y limiter :

- elles protègent la santé humaine en emmagasinant et en purifiant les eaux souterraines et les eaux de surface;
- elles maintiennent la santé des écosystèmes et fournissent des habitats, de la nourriture et des éléments nutritifs à de nombreuses espèces, y compris aux humains;
- elles fournissent un habitat aux espèces en danger de disparition et aux autres espèces jouissant d'un statut spécial;
- elles servent de réserves importantes pour la biodiversité;
- elles assurent une protection contre les inondations et les ondes de tempête;
- elles stabilisent les rives des rivières et le littoral;
- elles fournissent des aires de production alimentaire et de production commerciale;
- elles fournissent des possibilités récréatives, scientifiques, esthétiques, spirituelles et culturelles.

Conséquences économiques de la perte des terres humides

De nombreuses terres humides jouent un rôle capital dans la purification de l'eau potable. Certaines administrations, comme l'État de New York, reconnaissent les économies pouvant découler de la conservation des terres humides comparativement au coût élevé de la réfection des systèmes de traitement de l'eau.

Au fur et à mesure que disparaissent ou se dégradent les terres humides, la nature devient moins en mesure d'absorber les inondations causées par les eaux de catastrophic flooding.

In the Moncton area, for example, tax dollars are now spent on flood control in areas where salt marsh has been converted to agricultural and urban land use. Coastal communities experienced severe flooding in January and October of 2000. Flood damage restitution as a result of such events has significant impacts on local and provincial economies.

The loss of wetlands through land reclamation was in large part responsible for the severe flooding that occurred in the Mississippi River Basin in 1993, resulting in $15 to $20 billion in damages.

Influence of Settlement Patterns

Historical settlement patterns have concentrated along the coastline and interior waterways creating pressure to infill or otherwise degrade wetlands. Today waterfront properties tend to carry higher real estate values. The economic and other benefits of wetlands are often not directly measurable or recognized until they are lost.

These factors have led to wetland conservation goals being in direct conflict with short-term individual economic goals. Only in cases of extreme wetland loss (such as our coastal marshes) or related environmental events (such as flooding related to storm surges), does the functional value of wetlands become apparent to the general public.

Status of New Brunswick's Wetlands

Only 4% of New Brunswick's land base is currently classed as wetland habitat. Of these 300,000 hectares, 3% is coastal marsh; 7% is Saint John River floodplain wetlands; 41% is freshwater inland wetland; and 49% is inland bog.

ruissellement du printemps et les forces des marées, ce qui accroît la menace d'inondations catastrophiques.

Dans la région de Moncton, par exemple, on a dépensé l'argent des contribuables pour lutter contre les inondations dans des secteurs où les marais salés ont été convertis à des fins agricoles ou urbaines. Des localités côtières ont subi de graves inondations en janvier et en octobre 2000. Les indemnités versées à la suite des dommages causés par les inondations ont d'importantes répercussions sur l'économie locale et provinciale.

La perte des terres humides due à la mise en valeur des terres est en grande partie responsable des graves inondations qui se sont produites dans le bassin versant du Mississippi en 1993 et qui ont entraîné des dommages de 15 à 20 milliards de dollars.

Influence des modes de peuplement

Le peuplement s'est historiquement concentré le long du littoral et des cours d'eau intérieurs, exerçant ainsi des pressions en vue du remplissage des terres humides ou de leur dégradation d'autres façons. Les avantages économiques et autres des terres humides ne sont souvent pas mesurables directement ni reconnus avant leur disparition.

Ces facteurs ont conduit à un conflit direct entre les objectifs de conservation des terres humides et les objectifs économiques à court terme. Ce n'est que dans les cas de perte extrême de terres humides (comme nos marais côtiers) ou de phénomènes environnementaux connexes (tels que les inondations causées par les ondes de tempête) que la valeur fonctionnelle des terres humides devient visible au grand public.

État des terres humides du Nouveau-Brunswick

Seulement 4 % du territoire néo-brunswickois sont actuellement classés comme habitat de terres humides. Sur ces 300 000 hectares, 3 % constituent des marais côtiers; 7 % correspondent aux terres humides de la plaine d'inondation du fleuve Saint-Jean; 41 % sont des terres humides intérieures d'eau douce; et 49 % sont des tourbières intérieures.

While the first two categories (coastal marsh and Saint John River floodplain wetlands) represent less than 0.4% of the total provincial land base, most of these areas are considered to be of international, national, or provincial significance.

Coastal marshes are one of the most productive wetland habitats, providing essential habitat and nutrient production for important marine species (among other functions). However, over 65% of New Brunswick's coastal marshes have been lost, mainly due to land conversion for agriculture.

The Saint John River floodplain wetlands are the most productive and extensive of our inland freshwater wetlands. They perform an essential function in storing floodwater during spring freshet. These wetlands are threatened by: urban, industrial and agricultural runoff; sedimentation; human encroachment; and recreational use.

Current Approach to Wetland Management

The responsibility for managing and protecting wetlands in New Brunswick rests primarily with the Department of Natural Resources and Energy (DNRE) and the Department of Environment and Local Government (DELG).

DNRE is responsible for the wetland habitat and biodiversity functions while DELG has responsibility for the functions related to ground and surface water quality, quantity and flood control.

The existing legislative tools were not designed specifically for managing wetlands. This has resulted in an inconsistent and ineffective approach to wetland conservation. The purpose of this policy is to clearly identify the Government's intent with respect to wetland management in New Brunswick.

Alors que les deux premières catégories (les marais salés et les terres humides de la plaine d'inondation du fleuve Saint-Jean) représentent moins de 0,4 % de l'ensemble du territoire provincial, la majeure partie de ces secteurs sont considérés comme des terres humides d'importance provinciale, nationale ou internationale.

Les marais côtiers figurent parmi les terres humides les plus productives : ils fournissent un habitat et des éléments nutritifs essentiels à des espèces marines importantes (entre autres fonctions). On a toutefois perdu plus de 65 % des marais côtiers du Nouveau-Brunswick, principalement par suite de la conversion des terres à l'agriculture.

Les terres humides de la plaine d'inondation du fleuve Saint-Jean constituent les plus productives et les plus vastes de nos terres humides intérieures d'eau douce. Elles jouent un rôle essentiel en emmagasinant l'eau des crues printanières. Or, elles sont menacées par les eaux de ruissellement urbaines, industrielles et agricoles, par la sédimentation, par l'empiètement humain et par les usages récréatifs.

Approche actuelle en matière de gestion des terres humides

Au Nouveau-Brunswick, la gestion et la protection des terres humides relèvent principalement du ministère des Ressources naturelles et de l'Énergie (MRNE) et du ministère de l'Environnement et des Gouvernements locaux (MEGL).

Le MRNE assume la responsabilité des fonctions liées à l'habitat humide et à la biodiversité, tandis que le MEGL assume la responsabilité des fonctions liées à la qualité et à la quantité des eaux souterraines et des eaux de surface, ainsi qu'à la lutte contre les inondations.

Les outils législatifs existants n'ont pas été conçus expressément pour la gestion des terres humides. Cette carence a entraîné une approche incohérente et inefficace face à la conservation des terres humides. La présente politique vise à définir clairement l'intention du gouvernement en ce qui concerne la gestion des terres humides au Nouveau-Brunswick.

DNRE's Role in Wetland Management

DNRE manages wetlands through a variety of programs. The effectiveness of many of these programs is augmented by financial and other support through agreements with other conservation organizations.

One of DNRE's partnerships, the Eastern Habitat Joint Venture (EHJV), has been a major funding base for over ten years for projects that secure wetlands. American partners have funded 75% of the New Brunswick wetland securement program. To date, over 5300 hectares have been secured through acquisition and another 4000 through private stewardship arrangements.

DNRE is committed to exploring indirect methods of wetland securement, including legislative and policy initiatives. DNRE has developed a New Brunswick wetland classification system and is currently finalizing the provincial Wetlands Inventory as part of their commitment. The Inventory will be an important tool in the implementation of Provincial wetlands conservation efforts.

DNRE also manages the Crown peat resource through the *Crown Peat Resource Management Policy*. Other wetlands on Crown land are managed through the Crown Lands and Forests Act.

DNRE provides considerable technical expertise and advice, in the context of their habitat and bio-diversity mandate, to DELG in the administration of their applicable legislation.

DELG's Role in Wetland Management

DELG is responsible for the legislation that provides protection for wetlands. The *Environmental Impact Assessment Regulation*, under the Clean Environment

Rôle du MRNE dans la gestion des terres humides

Le MRNE assure la gestion des terres humides au moyen de divers programmes. Le soutien financier et autre obtenu grâce aux ententes avec d'autres organismes de conservation accentue l'efficacité d'un grand nombre de ces programmes.

L'un des partenariats établis par le MRNE, le Plan conjoint des habitats de l'Est (PCHE), constitue une source de financement précieuse depuis plus de dix ans aux fins des projets visant à sécuriser les terres humides. Des partenaires américains financent 75 % du programme de sécurisation des terres humides du Nouveau-Brunswick. On a jusqu'ici sécurisé plus de 5 300 hectares au moyen d'acquisitions de même que 4 000 hectares supplémentaires par le biais d'ententes d'intendance avec des organismes privés.

Le MRNE s'est engagé à explorer des méthodes indirectes de sécurisation des terres humides, notamment la prise de mesures législatives et l'élaboration de politiques. Le MRNE a établi un système de classification des terres humides et il est présentement en train de compléter l'inventaire provincial des terres humides en vertu de l'engagement qu'il a pris. Cet inventaire constituera un outil primordial face aux efforts déployés aux fins de la conservation des terres humides de la province.

Le MRNE gère en outre les ressources en tourbe des terres de la Couronne en vertu de la *Politique de gestion des tourbières de la Couronne*. Les autres terres humides situées sur les terres de la Couronne sont gérées en vertu de la *Loi sur les terres et forêts de la Couronne*.

Le MRNE fournit, dans le cadre de son mandat relatif aux terres humides et à la biodiversité, de nombreux renseignements et conseils techniques au MEGL afin de l'aider dans l'administration des lois pertinentes relevant de lui.

Rôle du MEGL dans la gestion des terres humides

Le MEGL assume la responsabilité des lois assurant la protection des terres humides. Le *Règlement sur les études d'impact sur l'environnement* de la *Loi sur*

Act, and the *Watercourse Alteration Regulation* under the Clean Water Act, provide the only specific regulatory mechanisms for managing development in or near wetlands. Regulatory reviews are a cooperative effort between the two departments.

The *protected area* designation under the Clean Water Act (Section 14) also offers opportunities for the protection of wetlands in the context of DELG's role in protecting drinking water quality.

Principles of Wetland Protection

Wetland protection is based on the following principles:

- Wetlands serve numerous valuable social, economic and ecological functions which should be maintained;
- In recognition of the historical and on-going wetland loss, the remaining wetlands require conservation, and, in some cases, protection;
- Some wetlands are of provincial, national and international significance and are deserving of protection;
- Securement of wetlands through acquisition, co-management and partnerships is a valuable conservation tool;
- Public support can be facilitated through public education and awareness regarding the functions and values of wetlands.

l'assainissement de l'environnement et le *Règlement sur la modification des cours d'eau* de la *Loi sur l'assainissement de l'eau* constituent les seuls mécanismes de réglementation prévus aux fins de la gestion du développement à l'intérieur ou à proximité des terres humides. Les examens réglementaires sont effectués conjointement par les deux ministères.

La désignation de *secteur protégé* en vertu de la *Loi sur l'assainissement de l'eau* (article 14) offre elle aussi des possibilités de protection des terres humides dans le contexte du rôle que le MEGL assume relativement à la protection de la qualité de l'eau potable.

Principes de protection des terres humides

La protection des terres humides repose sur les principes qui suivent.

- Les terres humides remplissent de nombreuses fonctions sociales, économiques et écologiques utiles qu'il faut maintenir.
- Compte tenu de la perte passée et continue de terres humides, il faut conserver et, dans certains cas, protéger les terres humides qui restent.
- Certaines terres humides constituent des terres d'importance provinciale, nationale et internationale et elles méritent d'être protégées.
- La sécurisation des terres humides au moyen des acquisitions, de la cogestion et des partenariats constitue un outil de conservation précieux.
- On peut stimuler le soutien du public au moyen de programmes d'éducation et de sensibilisation aux fonctions et aux valeurs des terres humides.

SCOPE AND APPLICATION

Provincially Significant Wetlands and Other Wetlands

This policy applies to all Provincially Significant Wetlands and to all other wetlands as defined by this policy, regardless of ownership.

CHAMP D'APPLICATION

Terres humides d'importance provinciale et autres terres humides

La présente politique s'applique à toutes les terres humides d'importance provinciale et à toutes les autres terres humides définies par la présente politique, peu importe leur propriétaire.

PROCEDURE

Objective 1:

Maintenance of Wetland Function

To achieve Objective 1, *Maintenance of Wetland Function*, in both Provincially Significant Wetlands and other wetlands, the following process will be followed:

Provincially Significant Wetlands

- All Provincially Significant Wetlands will be listed, mapped, and available to government and the public.

- Government will not support proposed activities in a Provincially Significant Wetland, within 30 meters of the perimeter of a Provincially Significant Wetland, or any activity that poses substantial risk to a Provincially Significant Wetland except:

    1. *Activities that rehabilitate, restore, or enhance a Provincially Significant Wetland, or*

    2. *Activities deemed to provide necessary public function, after completing an Environmental Impact Assessment with public review .*

- Wetlands can be added to the list of Provincially Significant Wetlands based on criteria *(see definitions), and deleted from the list should the wetland no longer meet the criteria*.

DÉMARCHE

Objectif 1

Maintien des fonctions des terres humides

On procédera comme suit pour réaliser l'objectif 1, soit *le maintien des fonctions des terres humides*, aussi bien dans le cas des terres humides d'importance provinciale que des autres terres humides.

Terres humides d'importance provinciale

- Toutes les terres humides d'importance provinciale seront inventoriées et cartographiées, et on mettra l'inventaire dressé à la disposition du gouvernement et du public.

- Le gouvernement n'appuiera aucune activité projetée à l'intérieur ou à moins de 30 mètres du périmètre d'une terre humide d'importance provinciale, ni aucune activité posant un risque substantiel à une terre humide, sauf :

    1. *les activités visant à remettre en état, restaurer ou améliorer une terre humide d'importance provinciale, ou*

    2. *les activités jugées essentielles pour le bien public, après la réalisation d'une évaluation environnementale publique avec examen public.*

- On pourra ajouter des terres humides à la liste des terres humides d'importance provinciale selon des critères établis (*voir les définitions*), *ainsi qu'en retrancher de la liste si elles ne satisfont désormais plus aux critères.*

- All coastal marshes are considered to be Provincially Significant Wetlands.

Other Wetlands

- The Policy applies to all other wetlands greater than one hectare in size.
- A provincial wetland inventory will assist in identifying wetlands and will be available to all stakeholders.
- Guidelines will be prepared for common activities that occur in and around wetlands that have the potential to negatively affect wetland functions.
- All activities in, or within 30 meters of a wetland, will be subject to a development review process that will assess wetland functions and the potential for negative effects. The development review process will require a three-step approach to reduce impacts that includes avoidance in the planning stage; activity minimization, and specific mitigation techniques during the construction phase.

Objective 2:

Securement, Stewardship, Education and Awareness

To achieve Objective 2, *Securement, Stewardship, Education and Awareness*, the following process will be followed:

DNRE's Role in Securement and Stewardship

DNRE will:

- Use a variety of strategies to conserve and protect wetlands, some which may include: restrictive covenants; conservation easements; stewardship agreements; ecologically sensitive land gifts; and acquisition.
- Retain ownership of all Provincially Significant

- Tous les marais côtiers sont considérés comme des terres humides d'importance provinciale.

Autres terres humides

- La politique s'applique à toutes les autres terres humides d'une superficie de plus d'un hectare.
- On mettra un inventaire provincial des terres humides facilitant le repérage des terres humides à la disposition de tous les intervenants.
- On préparera des lignes de conduite au sujet des activités courantes à l'intérieur et à proximité des terres humides qui pourraient affecter négativement les fonctions des terres humides.
- Toutes les activités à l'intérieur ou à moins de 30 mètres d'une terre humide feront l'objet d'un examen de la mise en valeur qui évaluera les fonctions des terres humides et la possibilité d'effets néfastes. Cet examen nécessitera une approche à trois étapes visant à réduire les effets du projet, notamment l'évitement pendant la phase de la planification, ainsi qu'une réduction des activités et des techniques d'atténuation particulières pendant la phase de la construction.

Objectif 2

Sécurisation, intendance, éducation et sensibilisation

On procédera comme suit pour réaliser l'objectif 2, soit *la sécurisation, l'intendance, l'éducation et la sensibilisation*.

Rôle du MRNE en matière de sécurisation et d'intendance

Le MRNE entend :

- recourir à diverses stratégies pour conserver et protéger les terres humides, notamment des clauses restrictives, des servitudes de conservation, des ententes d'intendance, des dons de terrains écosensibles et des acquisitions de terrains;
- conserver la propriété de toutes les terres humides

Wetlands or portions thereof, presently under Crown ownership.

- Participate in cooperative projects to manage wetland through agreements.

DNRE's Role in Education and Awareness

DNRE will:

- Promote and assist in the development of wetland education programs that target the general public, public schools, landowners and other private sector stakeholders.
- Support and encourage the development of cooperative educational programs with private sector stakeholders.
- Encourage the exchange of information and expertise among government departments regarding wetland issues.
- Encourage all other government departments, municipalities, planning commissions, and local service districts to ensure that all policies and programs are consistent with and, where appropriate, supportive of the wetland conservation objectives of this policy.

d'importance provinciale ou parties de ces dernières qui sont actuellement la propriété de la Couronne;

- participer à des projets de coopération visant la gestion des terres humides en vertu d'ententes.

Rôle du MRNE en matière d'éducation et de sensibilisation

Le MRNE entend :

- promouvoir et seconder l'élaboration de programmes d'éducation sur les terres humides à l'intention du grand public, des écoles publiques, des propriétaires fonciers et d'autres intervenants;
- appuyer et encourager l'élaboration de programmes d'éducation conjoints avec des intervenants du secteur privé;
- encourager l'échange de renseignements et d'expertise entre les ministères en ce qui concerne les questions touchant les terres humides;
- encourager tous les autres ministères, les municipalités, les commissions d'urbanisme et les districts de services locaux à s'assurer que toutes leurs politiques et programmes sont compatibles avec les objectifs de conservation des terres humides de la présente politique et, lorsqu'il y a lieu, qu'ils les appuient.

DEFINITIONS

Wetland [1]

Land that has the water table at, near, or above the land's surface, or which is saturated, for a long enough period to promote wetland or aquatic processes as indicated by hydric soils, hydrophytic vegetation, and various kinds of biological activities adapted to the wet environment.

Wetland Function

The biological, hydrological, physical, social, cultural, and economic roles that wetlands play.

Provincially Significant Wetland

Wetlands having provincial, national or international importance for one or more of the following reasons are considered Provincially Significant:

1. Wetlands, such as coastal marshes, which represent a remnant of a formerly more widespread wetland type where, historically, impacts to this habitat type have been severe.
2. Wetlands that are within a designated Ramsar[2] site, National Wildlife Area, Provincial Wildlife Management Area, Migratory Bird Sanctuary, Western Hemisphere Shorebird Reserve Network site, Ecological reserve, Protected Natural Areas.
3. Wetlands that are project sites under the North

[1] Lands currently being used for agricultural purposes that are periodically 'wet' are not considered to be wetlands by this definition. Where these lands were previously wetland, they are considered to have been converted to alternate uses.

[2] Ramsar is the first of the modern global intergovernmental treaties on conservation and wise use of natural resources. Designated Ramsar sites meet the Ramsar criteria for inclusion in the "List of Wetlands of International Importance". Signatories are challenged to maintain the ecological character of each Ramsar site.

DÉFINITIONS

Terre humide [1]

Terre où la nappe phréatique se trouve au niveau de la surface, près de la surface ou au-dessus de celle-ci, ou qui est saturée pendant une période suffisamment longue pour soutenir les processus humides ou aquatiques caractérisés par la présence de sols hydriques, d'une végétation hydrophyte et de divers genres d'activités biologiques adaptées au milieu humide.

Fonctions des terres humides

Rôle biologique, hydrologique, physique, socioculturel et économique que jouent les terres humides.

Terre humide d'importance provinciale

Les terres humides ayant une importance provinciale, nationale ou internationale pour une ou plusieurs des raisons ci-après sont considérées comme des terres d'importance provinciale :

1. Terres humides, telles que les marais côtiers, qui représentent des vestiges d'un type de milieu humide auparavant plus répandu et ayant par le passé été soumis à une incidence marquée.
2. Terres humides qui se trouvent dans un site Ramsar [2], une réserve nationale de faune, une zone d'aménagement pour la faune provinciale, un refuge d'oiseaux migrateurs, un site du Réseau des réserves pour les oiseaux de rivage dans l'hémisphère occidental, ou des aires naturelles protégées.
3. Terres humides constituant des sites de projets dans

[1] Les terres actuellement utilisées à des fins agricoles qui sont périodiquement « humides » ne sont pas considérées comme des terres humides en vertu de cette définition. Les terres de ce type antérieurement humides sont considérées comme des terres converties à des utilisations de rechange.

[2] Ramsar constitue la première des conventions intergouvernementales modernes à l'échelle planétaire visant la conservation et l'utilisation rationnelle des ressources naturelles. Les sites Ramsar désignés satisfont aux critères établis dans la Convention aux fins de l'inclusion dans la « Liste des zones humides d'importance internationale ». Les pays signataires ont la responsabilité de maintenir le caractère écologique de chaque site Ramsar.

American Waterfowl Management Plan and secured for conservation through the Eastern Habitat Joint Venture.

4. Wetlands that contain: one or more Endangered and/or Regionally Endangered Species as designated under the New Brunswick Endangered Species Act; or, other species of special status.

5. Wetlands that represent a significant species assemblage and/or have a high value for wildlife on the basis of size, location, vegetation, diversity or interspersion.

6. Wetlands that have a significant hydrologic value including flood control, water quality protection, recharge or discharge of groundwater.

7. Wetlands that have, or are managed for, social and/or cultural values, including, but not limited to, community, spiritual, archaeological, scientific, educational, and recreational importance.

le cadre du Plan nord-américain de gestion de la sauvagine et dont on an assuré la conservation en vertu du Plan conjoint des habitats de l'Est.

4. Terres humides qui abritent une ou plusieurs *espèces menacées* ou *espèces régionales menacées* d'après les désignations de la *Loi sur les espèces menacées d'extinction* du Nouveau-Brunswick, ou d'autres espèces jouissant d'un statut spécial.

5. Terres humides qui représentent un assemblage d'espèces importantes ou qui ont une grande valeur pour la faune en raison de leur superficie, leur emplacement, leur végétation, leur diversité ou leur répartition.

6. Terres humides qui ont une valeur hydrologique importante, notamment pour la lutte contre les inondations, la protection de la qualité de l'eau ou la reconstitution ou l'évacuation des eaux souterraines.

7. Terres humides qui ont une valeur sociale ou culturelle ou aménagées à cette fin et qui ont de ce fait notamment, sans toutefois s'y limiter, une importance communautaire, spirituelle, archéologique, scientifique, éducative et récréative.

Necessary Public Function
Activities that provide public function on a provincial scale such as public transportation projects, public infrastructure, linear pipeline or transmission corridors, and projects necessary for public safety.

Activities
Actions that have the potential to affect wetland function and habitat. Actions may include, but are not limited to, cutting or disturbing vegetation, ditching, draining, infilling, grubbing, water diversion, water flow changes, drilling, structure placement, soil disturbance, vehicular use in, or within 30 meters of any wetland.

Private Sector Stakeholders
Includes, but not limited to, individuals, non-government

Activités essentielles pour le bien public
Activités jouant un rôle public essentiel à l'échelle provinciale, comme les projets de transport public, l'infrastructure publique, les corridors linéaires pour pipelines ou lignes de transport d'énergie, et les projets essentiels à la sécurité publique.

Activités
Interventions pouvant affecter le rôle et l'habitat des terres publiques. Ces interventions peuvent comprendre, sans toutefois s'y limiter, la coupe ou la perturbation de la végétation, l'excavation de fossés, le drainage, le remblayage, le défrichage, le détournement de cours d'eau, les modifications du débit d'eau, la mise en place d'ouvrages, la perturbation du sol et la circulation de véhicules à l'intérieur ou à proximité d'une terre humide.

Intervenants du secteur privé
L'expression englobe, sans toutefois s'y limiter, les

organizations, groups, associations, educational institutions, researchers, businesses, not for profit organizations, landowners.

Rehabilitate
To repair a degraded or damaged Provincially Significant Wetland

Restore
To re-establish a Provincially Significant Wetland to a previous state or function.

organisations non gouvernementales, les groupes, les associations, les établissements d'enseignement, les chercheurs, les entreprises, les organismes sans but lucratif et les propriétaires fonciers.

Remettre en état
Réparer une terre humide d'importance provinciale dégradée ou endommagée.

Restaurer
Ramener une terre humide d'importance provinciale à un état ou un rôle antérieurs.

iv wetlands

a) Overview of Wetlands

There are five classes of wetlands recognized in Canada: 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).

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). As such, the U.S. Army Corps of Engineers has promoted the hydrogeomorphic (HGM) approach to wetland classification and assessment (Brinson 1993, 1995, 1996 in Cole et al. 2002). This classification focuses on position in the landscape and hydrology (e.g., slope, headwater floodplain, mainstem floodplain, etc.); however, because regional differences in soils, climate, etc. can affect wetland functions, caution is advised when attempting to apply models of classification between regions (Cole et al. 2002).

Many wetlands 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 2-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 2-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 2-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 2-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 2-e).

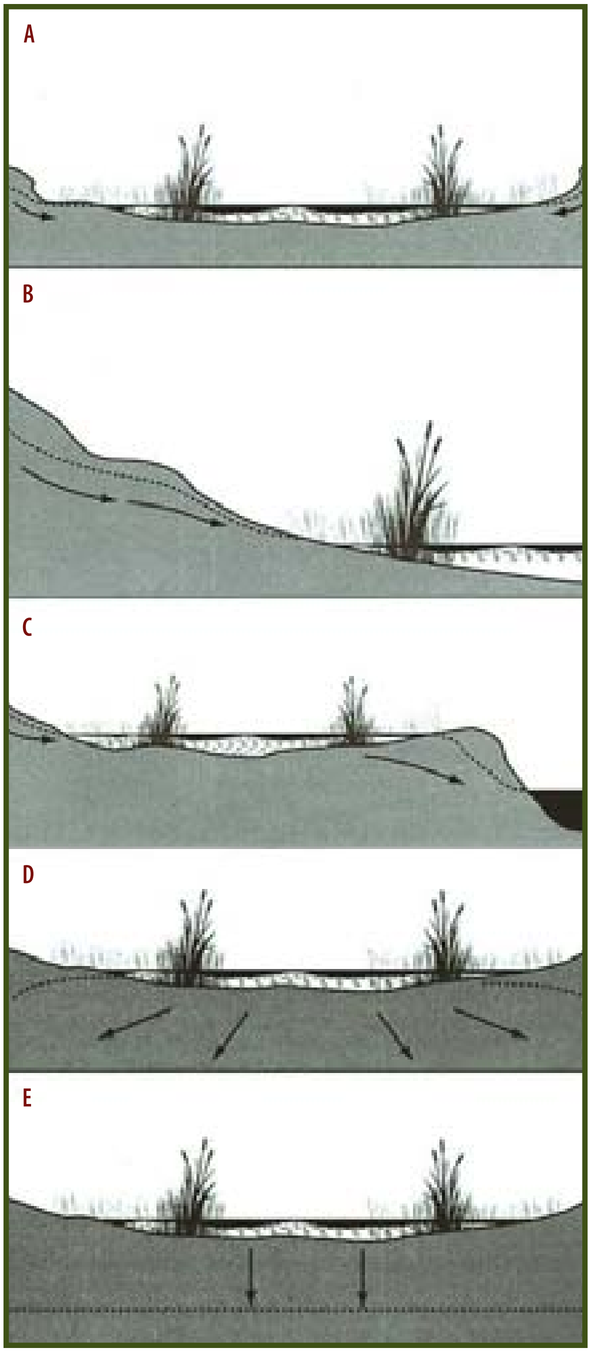


FIGURE 2 – **Possible discharge – recharge interchanges between wetlands and groundwater systems including: (A) marsh as a depression receiving groundwater flow; (B) groundwater spring or seep wetland or groundwater slope wetland at base of a steep slope; (C) floodplain wetland fed by groundwater; (D) 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, Meyer et al. 2003). Each situation is unique and dependent on local topography, climate, geology, and watershed characteristics (e.g., LaBaugh et al. 2000). Land use is also a key factor influencing wetland hydrology. For example, the conversion of cultivated land to brome grass surrounding a prairie wetland resulted in enhanced trapping of snow and infiltration into frozen soil (van der Kamp et al. 2003). In a review of hydrological processes in temperate headwater wetlands in the glaciated regions of northeast North America, Taylor (1997) concluded that wetland hydrology is complex, depending on wetland type, catchment characterisitics, and climatic conditions.

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). Water source to wetlands is highly variable, ranging from almost completely precipitation-derived to groundwater-sourced (Winter et al. 2001). Although significant advances have been made in our understanding of wetland hydrology in recent years (Hill and Devito 1997; Winter 1999; van der Kamp et al. 2003) 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. Observation and measurement of runoff and other components of the water budget typically are difficult, further complicating study of wetland hydrology.

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 damage to homes and businesses. The ability of wetlands 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, vegetation disperses incoming water, reduces 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).

Prior to drainage of productive land on the Prairies, the numerous small depressions in morainal areas (i.e., that are not part of an integrated drainage system) only rarely contributed to stream flow (Winter 1989). Typically the water would run into depressions and infiltrate during the frost-free period. Hubbard and Linder (1986) suggested that numerous small wetlands in the prairie pothole region cumulatively store a large amount of spring runoff, based on the extrapolation of data collected from 213 wetlands on 648 ha. Hayashi et al. (2003) studied small (<1000 m^2) depressions (i.e. wetlands) and found that they stored a large portion, or all, of the snowmelt runoff generated in their respective watersheds. Although each wetland has a small storage, they collectively provide a significant storage capacity.

Wetlands may play a key role in controlling stormwater runoff; however, the flood reduction benefits of wetlands are often seasonal. Wetland water storage occurs underground in saturated soils or in surface depressions (Winter and Woo 1990). When water tables are low during the dry season, considerable storage capacity is available in unsaturated peat and wetlands are effective in retarding or preventing runoff. 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). For example, Taylor (1982) showed that small wetlands near Peterborough, Ontario held back runoff in the summer months, when water levels were low. However, in the spring and fall, storage capacity was exceeded and runoff was released downstream.

Hydrological models, spatial analysis, and computer simulations have been used to demonstrate the ability of wetlands to store surface runoff. 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. 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. Spring runoff retention in boreal forest peatlands in northern Manitoba is influenced by frost-table dynamics and surface storage conditions (i.e., water levels), and therefore interannual variation is common (Metcalfe and Buttle 2001).

Positive benefits of maintaining wetlands in the landscape are well known. 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). Miller and Nudds (1996) linked the large 1993 and 1995 floods in the Mississippi River Valley to wetland drainage, and 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 excess river flows associated with the 1993 flooding in the U.S. midwest. They concluded that restoration of an estimated 7% of the watershed would be sufficient to deal with even extreme event floods on a large scale.

Wetland modification may be equally detrimental as wetland loss to a watershed's runoff-holding capacity. For example, wetland channelization, which often occurs in urban areas, leads to increased runoff and loading from a basin. Whiteley and Irwin (1986) found that, of two creeks flowing into the Beverly Swamp in Ontario, the unchannelized stream delayed flood peaks by 20 to 30 hours and reduced peak flows compared to the stream with a well-defined channel. 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 x 106 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 x 106 m^3/km^2).

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. Recent efforts to model groundwater and surface water mixing during storm events have been used to attempt to explain this phenomenon (e.g., Brassard et al. 2001).

2. Groundwater Recharge

Recharge of groundwater is an extremely important function of some wetlands and occurs when water percolates slowly from wetlands to underground aquifers. 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 between wetlands and groundwater is 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 be a site of groundwater discharge (Carter 1986; Hill 1990; LaBaugh et al. 1998) (Figure 3).

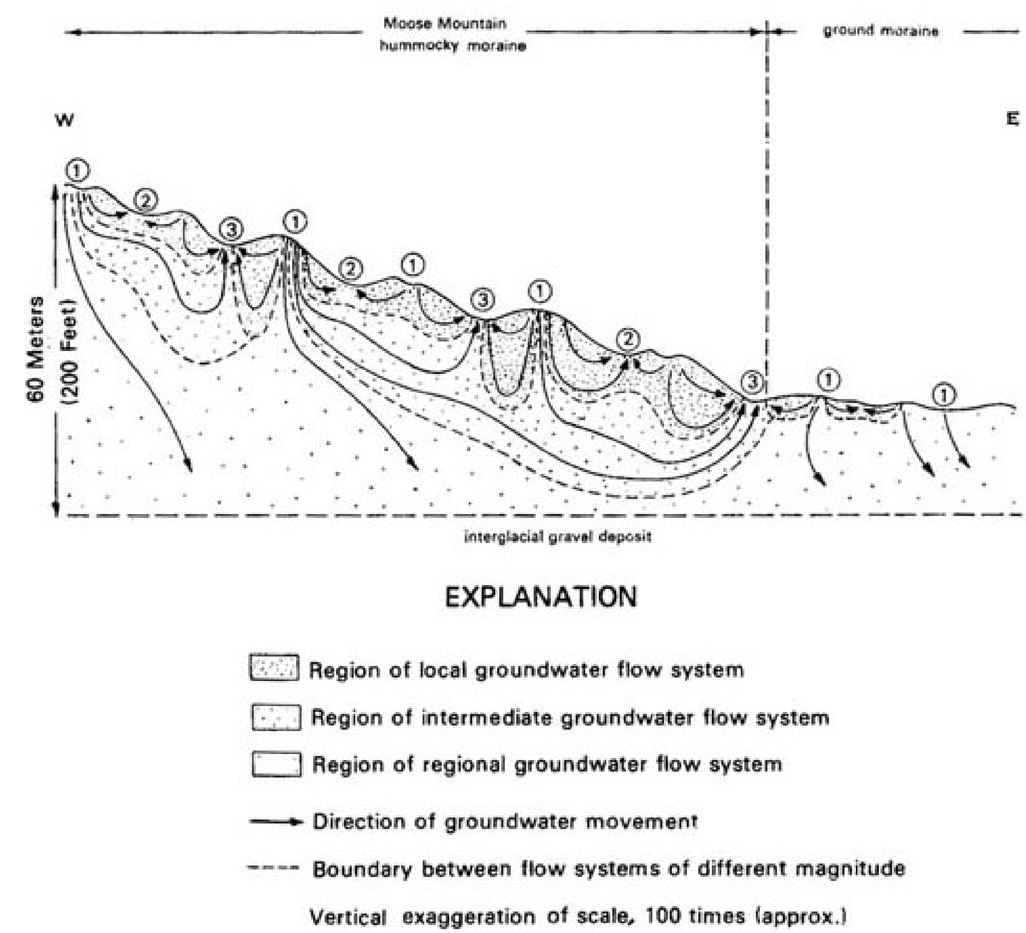


FIGURE 3 – Diagrammatic section of the flow systems of Moose Mountain, Saskatchewan (1) recharge areas, (2) discharge area of local flow system, (3) discharge area of local and intermediate flow systems (Winter 1989).

Groundwater recharge occurs from many areas in the landscape, including wetlands (from seasonal to permanent) and uplands (Winter 1988; van der Kamp and Hayashi 1998). 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 materials overlying aquifers may determine the rate of aquifer recharge. In general, glacial drift in eastern North America is permeable because the bedrock from which the drift is derived is more permeable than in other areas (Winter and Woo 1990).

Prairie potholes in the semi-arid portion of the northern prairies are known to be important for groundwater recharge, despite low hydraulic conductivity of clay-rich glacial deposits (van der Kamp and Hayashi 1998). The ponded water in wetlands is generally connected to and continuous with the water table in the surrounding area (Figure 3) and therefore all seepage of water from the ponds into the subsurface can be regarded as groundwater recharge. Recharge to the aquifers depends on the availability of water in wetlands and other depressions in the overlying landscape, as well as the hydraulic conductivity of overlying aquitards. van der Kamp and Hayashi (1998) found that estimates of recharge from prairie potholes (2-45 mm/yr) were similar to published rates of aquifer recharge in other areas (5-40 mm/yr), suggesting that these wetlands are the main source of recharge to regional aquifers. Since then, other studies have shown that small wetland depressions are important in both groundwater recharge and water storage in many physiographic settings, including the northern glaciated prairies (Hayashi et al. 2003) and Appalachian Ridge and Valley province (Moorhead 2001). Hayashi et al. (2003) used piezometers and infiltrometers to study infiltration of snowmelt water under small depressions in Saskatchewan. Water table wells and piezometers were used to study seasonal patterns of the water table in an Appalachian mountain fen, and indicated that the fen is an aquifer recharge area (Moorhead 2001).

Hydrology studies in eastern Canada 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. 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).

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 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). This makes them ideal for processing wastewater, and as a result, constructed wetlands have become common for primary, secondary, and tertiary treatment of sewage. Information on the design and performance of constructed wetlands for improving water quality is readily available for the U.S. (e.g., Kadlec and Knight 1996), and to some degree for Canada (see Kennedy and Mayer 2002). Constructed wetlands efficiently remove total nitrogen and phosphorus (Kirby 2002), BOD (Knowlton et al. 2002), and fecal coliform (Knowlton et al. 2002, Hill and Sobsey 2001, Kern et al. 2000) from municipal and animal production facility wastewaters (Table 2). Constructed wetlands are also used to treat a wide range of surface waters, nonpoint source pollutants in runoff, and domestic and industrial effluents. Examples in the recent literature include treatment of lake water from Lake Apopka, FL (Coveney et al. 2002) and septic tank effluents in Ohio (Steer et al. 2002). Although there is evidence of significant improvement of effluent quality by constructed wetlands (Table 2), site-specific conditions may prevent some parameters from meeting applicable guidelines for receiving waters (e.g., Hench et al. 2003, Steer et al. 2002).

Natural wetlands have been the subject of much investigation with respect to water quality functions. Early studies 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). Debate about whether wetlands located further upstream within a watershed relative to others have a greater impact on water quality and flood protection is ongoing (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 produce site-specific biogeochemical functions (Hill and Devito 1997).

TABLE 2 – Percent reduction in total nitrogen (TN), nitrate-N (NO_3), ammonia-N (NH_4), total phosphorus (TP), phosphate (SRP), sediment (TSS) and pathogens in constructed wetlands.

Author	Location	TN	NO_3	NH_4	TP	SRP	TSS	Pathogens
Coveney et al. (2002)	Florida; constructed wetland treating lake water	30-52	++	++	30-67	++	89-99	
Falabi et al. (2002)	constructed Lemna pond							61-62[a] 89-98[b]
Hill and Sobsey (2001)	North Carolina; constructed wetland receiving swine effluent							>96[c]
Kern et al. (2000)	Germany; constructed wetland receiving swine effluent							95[d]
Kirby (2002)	Nova Scotia; 2 constructed wetland receiving municipal effluent	77, 87			83, 90		45, 48	98, 99.8[d]
Knowlton et al. (2002)	Missouri; constructed cattail wetland	36		17	4			97[d]

++ *soluble nutrients increased* **a** *Total and fecal coliform* **b** *Cryptosporidium and Giardia* **c** *Fecal coliform, Salmonella, E. coli* **d** *Fecal coliform*

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 desirable; however, rates of flux and turnover times are difficult to measure in situ (but see Fisher and Reddy (2001) for a description of phosphorus flux from wetland soils in the Everglades). 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 and outputs should be measured in terms of mass per unit area of wetland per year. Although most studies of wetland water quality measure removal efficiencies based on concentrations, recent work has focused on mass balances per unit area of wetland per year (e.g., Craft and Casey 2000, White et al. 2000; see Mitsch et al. 2000, Saunders and Kalff 2001 for reviews). Mass balances are often calculated for the growing season only, ignoring fall and winter inputs and outputs and leading to incomplete mass balances. Hydrology has a direct influence on the retention or export of nutrients and sediments (e.g., Devito and Dillon 1993a); thus, it is necessary to first understand a wetland's water mass balance before calculating nutrient mass balances (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 may exhibit different biogeochemical behaviour because of how they are linked to their watersheds (Hill and Devito 1997; Bedford 1999). Several characteristics contribute to wetlands' 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 litter (Mitsch et al.1989). Other factors that influence nutrient assimilation by wetlands include: nutrient loading rate, water quality and depth, soil type and chemistry, vegetation, algal and microbial communities, primary production and decomposition rates, and hydraulic retention time (Moustafa 2000). A detailed examination of all of these factors will not be attempted here, but several examples of research conducted in these areas can be found in the primary scientific literature and are cited below.

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 forms 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).

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.

Nitrogen

Nitrogen is the focus of water quality concerns where large amounts of fertilizers are used on high input crops (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.

In agricultural areas without excess water such as Saskatchewan, water contamination by nitrogen under current management practices is associated with specific events such as storms and in areas with intensive livestock or crop operations (MacDonald 2000). In a survey of drinking water wells in Alberta, 13% of 376 shallow wells sampled had nitrate-plus-nitrite levels above the guideline for human drinking. Thus, prairie groundwater resources are not only at risk, but are already showing signs of nitrate contamination.

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; Environment Canada 2001). Seventeen percent of Ontario farmland is at high risk for nitrogen contamination of waterways, 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.

Nitrogen (N) in wetland soils and biota is primarily organic (Kadlec and Knight 1996). A wetland N cycle typically consists of interconversion between organic N, ammonium, and nitrate (Figure 4). The form of nitrogen most readily available for uptake by wetland microorganisms and plants is ammonium (NH_4+), produced by microbes during organic matter decomposition. Ammonium is absorbed by plants or microorganisms and the nitrogen incorporated into organic matter. As a positively-charged ion, ammonium can also be immobilized onto negative soil particles (Mitsch and Gosselink 2000b). 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 (NO_3-). Nitrate must be reduced to ammonium by plants or microbes before it can be used in their growth (Mitsch and Gosselink 2000b).

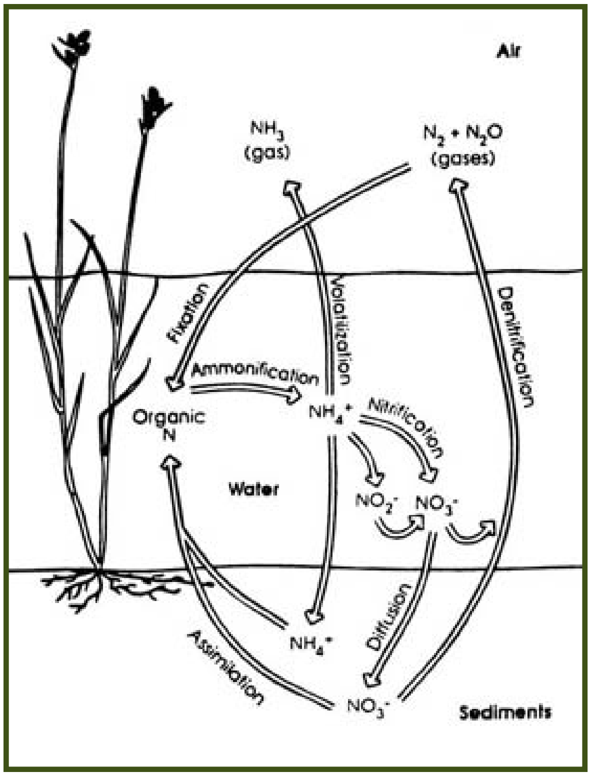


FIGURE 4

Simplified wetland nitrogen cycle. *(Knight and Kadlec 1996)*

Nitrogen is assimilated by wetlands primarily by one of three processes: (i) denitrification of nitrate to nitrogen gas (N_2) that is lost to the atmosphere, (ii) sedimentation of particulate N, or (iii) assimilation by plants and microbes (Saunders and Kalff 2001, Braskerud 2002, Janzen et al. 2003). Although N is retained in wetland plants, biota, and sediments, it may be permanently removed by denitrification and harvest of wetland plants (Matheson et al. 2002). Denitrification is typically the primary mechanism of N attenuation in wetlands and riparian buffers (see Section V), and is especially efficient for reducing nitrate contamination of shallow groundwater (Vellidis et al. 2003, Matheson et al. 2002, Flite III et al. 2001, Hanson et al. 1994).

Prairie wetlands are rarely unimpacted systems and can be expected to receive significant external nitrate loading from surrounding agricultural lands (Crumpton and Goldsborough 1998). However, 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.

The effectiveness of prairie wetlands as sinks for non-point source nitrogen loads is likely to depend on the magnitude of nitrate loads and the capacity of the wetlands to remove nitrate by dissimilatory processes (Crumpton and Goldsborough 1998). Increased nitrate loading in agricultural watersheds can be expected to stimulate denitrification (Isenhart 1992; Moraghan 1993). Recent studies suggest that the ability of natural, restored, and constructed wetlands to attenuate N loading from wastewater and surface water runoff from various land uses is high (Tables 2, 3), although there is some variability due to seasonal and landscape influences (e.g., White and Bayley 2001).

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.

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/m2/yr and are sustainable for the treatment of non-point source (NPS) pollution. Saunders and Kalff (2001) reviewed several North American and European nitrogen mass balance studies, and found that, on average, N retention in wetlands was 64% of TN loading, 34% in lakes, and 2% in rivers.

Phosphorus

Phosphorus (P) enrichment of surface waters, whether by agricultural runoff or by wastewater effluent, and the resultant increase in primary production may 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. Phosphorus retention is considered one of the most important attributes of natural and constructed wetlands (Mitsch and Gosselink 2000b), and 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). Total P is the sum of phosphorus dissolved in the water plus particulate phosphorus, including organic phosphorus, algal and bacterial phosphorus, and phosphorus sorbed to suspended solids (Kadlec and Knight 1996). All forms of organic P and insoluble inorganic P must first be transformed to ortho-phosphorus before they can be used by primary producers (Mitsch and Gosselink 2000b).

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). The clay-phosphorus complex is particularly important because much of the phosphorus brought into wetlands is sorbed to clay particles. Phosphorus retention over the long term has been shown to be greater in floodplain wetlands than depressional wetlands in Georgia, due to the co-deposition of P with fine-textured clays in the floodplain wetland (Craft and Casey 2000). The primary means of net long-term storage of phosphorus is through wetland soil/sediment accretion (Kadlec and Knight 1996). For example, over 60% of P inputs from a beef processing facility were found to be stored in the sediments of a restored northern prairie marsh over a 5-year period (White et al. 2000). Most wetland macrophytes obtain phosphorus from soil; therefore, sedimentation of phosphorus sorbed onto clay particles is an indirect way in which phosphorus is made available to biotic components of the wetland (Mitsch and Gosselink 2000b). Plants transform inorganic phosphorus to organic forms that are stored in organic peat, mineralized by microbial activity, or exported from the wetland.

Johnston (1991) reviewed the retention of phosphorus of several wetlands in the US with no direct anthropogenic inputs and found that percent retention ranged from 9 to 80%. A similar range of percent retention of P can be found in the recent literature (Table 3). 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, translating to a 46% reduction in potential phosphorus loads to the Eramosa River.

Phosphorus retention by wetlands in Ontario is variable, depending on season, stream flow, and other variables. The Hidden Valley wetland in Kitchener retained total phosphorus (inputs exceeded outputs by 100%), but exported plant-available ortho-phosphorus (Gehrels and Mulamoottil 1989). 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. In contrast, beaver ponds and conifer swamps in central Ontario's Precambrian Shield retained plant-available soluble phosphorus during summer, but overall retention of total phosphorus was low on an annual basis (Devito and Dillon 1993a, 1993b; Devito et al. 1989).

TABLE 3 – Percent reduction in total nitrogen (TN), nitrate (NO_3), ammonia (NH_4), total phosphorus (TP), phosphate (SRP), sediment (TSS) and pathogens in natural wetlands.

Author	Location	TN	NO_3	NH_4	TP	SRP	TSS	Pathogens
Casey and Klaine (2001)	South Carolina; riparian wetland receiving golf course runoff		80			74		
Comin et al. (2001)	Spain; restored wetland receiving rice field runoff	50-98				<50		
Jordan et al. (2003)	Maryland; restored wetland in agricultural watershed (two year average)		35	25			0	
Kao and Wu (2001)	North Carolina; natural wetland receiving stormwater runoff from agricultural land	>80			59		91	
Nõges and Järvet (2002)	Estonia; natural riparian wetland receiving municipal wastewater (mass balances)	65			17	++	96	99[a]
Shan et al. (2002)	China; natural multi-depression wetland system receiving continuous surface runoff				93.9	90.0	94.9	
Velledis et al. (2003)	Georgia; restored riparian wetland adjacent to manure application area		78	52	66	66		
White and Bayley (2001)	Alberta; restored marsh receiving wastewater; summer		87	76	64			
White and Bayley (2001)	Alberta; restored marsh receiving wastewater; winter		-26	46		26		
Woltemade (2000)	Maryland; restored wetland receiving agricultural runoff		68		43			
Woltemade (2000)	Illinois; restored wetland receiving agricultural runoff		36-45		20			

++ *soluble phosphorus increased* **a** *coliform bacteria*

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); other estimates of phosphorus retention by wetlands in the Laurentian Great Lakes suggest that 15% of watershed area should be maintained as wetlands (Wang and Mitsch 1998). 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.

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 from 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 major 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; Meyer et al. 2003). 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, vegetation disperses the water and reduces flow velocity, and therefore increases the retention time of 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), and in turn on the removal of sediment-associated pollutants such as nitrogen, phosphorus, pathogens, and pesticides. 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.

Natural and constructed wetland systems are effective for sediment removal, typically measured by percent retention of total suspended solids (Tables 2, 3). Sediment retention can range between 49 and 98% in surface-flow and subsurface-flow constructed wastewater wetlands (Mitsch and Gosselink 2000b). Kadlec and Knight (1996, 331) found that reduction of suspended solids in wastewater and stormwater ponds ranged from 66-92%. Depressional wetlands (i.e., closed basin with no outlet) may retain all incoming sediment (Novitzki 1979; Gleason and Euliss 1998). Slope wetlands also retain sediment if water velocities decrease substantially within the wetland area (Novitzki 1979). Small riparian wetlands are also known to act as net sediment storage sites (Heimann and Roell 2000).

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 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).

The ability of wetlands to remove and retain sediments is a basic concept of improved water quality, but excessive sediment loads can be harmful to natural wetlands. Many prairie wetlands are closed systems that can totally fill with sediments and hence lose their capacity to function properly (Gleason and Euliss 1998). Wetlands in agricultural watersheds in the Great Lakes region exhibit high turbidity, suspended solids, and nutrient levels (Crosbie and Chow-Fraser 1999). 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 land-scapes 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).

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). Factors influencing removal of pathogens include: natural die-off, sedimentation, predation, and adsorption, which are in turn influenced by retention time and seasonal variability (Falabi et al. 2002). 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).

Treatment wetland removal efficiencies are nearly always greater than 90% for coliforms and greater than 80% for fecal streptococcus (Kadlec and Knight 1996). *Giardia, Cryptosporidium* and *Salmonella* are also reduced effectively by wetlands (Table 2). Few studies of pathogen removal by natural wetlands are found in the literature, thus additional information is necessary to confirm that natural wetlands are as effective as constructed wetlands.

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, Golds-borough 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. Wetlands have been shown to attenuate landfill leachate near Pembroke ON (Fernandes et al. 1996), dissolved chlorinated volatile organic compounds in groundwater near a former manufacturing site in Minnesota (Richard and Connell 2001), and heavy metals from urban stormwater runoff and a former lead-acid manufacturing plant (Sriyaraj and Shutes 2001, Gallardo-Williams et al. 2002).

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, regardless of surrounding land use(Frankforter 1995; also see Donald et al. 2001). 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. 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. For example, Kao et al. (2001, 2002) found that a natural wetland in North Carolina completely removed atrazine from diffuse agricultural runoff after several storm events.

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. 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 4) 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 4). 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.

TABLE 4 – Range of percent retention for nitrogen, phosphorus, sediment, coliforms and pesticides in natural wetlands.

	Retention (%)
Nitrogen – Nitrate	up to 87
– Ammonium	up to 76
Phosphorus	up to 94
Sediment	up to 98
Coliforms (constructed wetlands)	up to 99
Pesticides	<1 day - several months[1]

1 *Time for residues to decrease by 50%*

Wetlands can reduce the impacts of sedimentation on water quality within watersheds (Table 4). 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 4). Natural wetlands are dominated by microbes (bacteria, fungi and algae) and plant life that are important for reducing pathogens.

High levels of biological productivity in wetlands result in dissipation of pesticides due to 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 groundwater disappear rapidly from wetlands (Table 4), primarily due to adsorption to organic matter in sediments and decomposing litter.

V

riparian area management

Riparian areas are transitional landscape features occurring between uplands and wetlands, streams, or lakes; it is this position in the landscape that allows them to act as natural "filters" of both surface and groundwater. Riparian zones are typically characterized by soils vegetation and biota that are considered transitional between upland and wetted habitats. Natural riparian areas have been altered by activities that have modified the landscape, including industry, agriculture, and urban development; however, restoration and conservation of remaining riparian zones have accelerated as our understanding of their critical role in watershed functioning expands.

Buffers are areas of native or replanted perennial vegetation that lie between lands subject to human alteration and naturally occurring waterways, and may be referred to as buffer strips, riparian buffers, or grass/vegetated filter strips (VFS) (Castelle et al. 1994; Dosskey et al. 2002). Buffers are critical for abatement of non-point source (NPS) pollutants in both surface and groundwater; in fact, the USDA has developed two national standards, in the form of filter strips and riparian forest buffers, toward reducing agricultural NPS pollution (Lee et al. 2003). Because buffers typically are components of agricultural BMPs, agriculture will be the focus of the following discussion; however, other industries and land use classes also find applications in which natural and restored riparian buffers are useful for NPS pollution prevention in nearby waterways.

Buffers reduce surface water runoff, thereby increasing sedimentation and retention of sediment-associated pollutants (nutrients, pesticides, bacteria, etc.). 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). A decrease in runoff volume and velocity as water moves through the buffer allows for sediment and associated pollutants to deposit in the buffer and increases the time of contact for adsorption onto soil and vegetation (Fajardo et al. 2001; Rankinen et al. 2001). This results in a reduction in surface runoff and associated pollutants to down-slope riparian systems (Hayes et al. 1979; Foster 1982; Rankinen et al. 2001). Retention of sediment by buffers in literature reviewed here typically is high, whereas percent retention of nitrogen, phosphorus, pesticides, and fecal coliform bacteria is variable (Table 5).

Because nitrate is primarily exported from watersheds via groundwater, the ability of riparian areas to reduce nitrate concentrations has been of great interest. Although the species composition of riparian vegetation community is important, nitrate removal capacity is dependent on the interaction of groundwater with "biologically active zones" - riparian zone components that support removal processes such as plant/microbial uptake and denitrification (Gold et al. 2001). Site attributes such as hydric status and geomorphology affect this interaction (Rosenblatt et al. 2001), and therefore should be incorporated into efforts to integrate riparian zones into watershed scale nitrate management schemes.

In addition to their importance in water quality, 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). 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 (Castelle et al. 1994).

Buffers may be positioned in the landscape depending on local physiographic and hydrological features, ranging from within- and edge-of-field to streamside. Although the methods of determining appropriate, efficient, yet cost-effective buffer dimensions and biological components are beyond the scope of this document, there is still considerable research required to ease planning and application of buffers to reduce agricultural NPS pollution (Dosskey 2002). Lyons et al. (2000) reviewed the positive and negative implications of grassed, treed, or mixed riparian buffers. Site-specific studies of optimal buffer width and vegetation type are available (e.g., Dukes et al. 2002, Sparovek et al. 2002) as are discussions related to management and restoration of riparian buffers (Simpkins et al. 2002, Quinn et al. 2001, Hession et al. 2000, Jorgensen et al. 2000, Lowrance et al. 2000a).

TABLE 5 – Percent reduction in groundwater and surface water total nitrogen (TN), nitrate-N, TKN, total phosphorus (TP), phosphate (PO_4) and sediment (TSS) in buffer strips.

Study	Parameter	Reduction (%)	Notes
Surface Water			
Ontario (Abu-Zreig et al. 2003)	TP	31-89	VFS vs. bare soil controls.
Iowa (Lee et al. 2003)	TN	80, 94	In grass and grass/woody buffers respectively.
	Nitrate-N	62, 85	
	TP	78, 91	
	PO_4	58, 80	
	TSS	95, 97	
Norway (Syverson 2002)	TP	76, 89	In 5m and 10m buffer, respectively. Avg. 1992-99.
	TN	62, 81	
	TSS	81, 91	
	Organic M	83, 90	
Connecticut (Clausen et al. 2000)	Nitrate-N	83	Restored riparian buffer vs. row crop.
	TKN	70	
	TP	73	
	TSS	92	
Groundwater			
Estonia (Kuusemets et al. 2001)	TN	40, 85	In 31m and 51m buffers, respectively.
	TP	78, 84	
Neuse R. Basin, North Carolina (Spruill 2000)	Nitrate-N	65-70	Riparian buffers vs. non-buffer areas.
Connecticut (Clausen et al. 2000)	Nitrate-N	35	Restored riparian buffer vs. row crop
Virginia (Snyder et al. 1998)	Nitrate-N	45	Riparian buffer vs. upland agricultural field.

The efficiency of riparian buffers determined in laboratory- and field- level experiments is not always demonstrated at the watershed scale, and may be partially due to spatial heterogeneity in hydrology and landforms (Montas et al. 2000). For example, Schiff et al. (2002) found that two adjacent forested catchments in Ontario had annual nitrate export that differed by a factor of ten, although soils, forest cover, and microbial nitrification were similar in each watershed. The difference was attributed to slope stratigraphy and hydraulic conductivity, which influenced groundwater flow in relation to the biologically active zone. Research at this scale is lacking, as most of the quantitative studies of the ability of buffers to abate water pollution focus on within-field processes, instead of examining the response of streams or lakes to buffer placement (Dosskey 2001).

Mathematical models are an alternative way to develop estimates of water quality improvement in response to buffers. The Riparian Ecosystem Management Model (REMM) was designed to simulate biological, chemical, and physical processes that occur in riparian buffer zones, and allows for comparisons of management scenarios and the incorporation of site-specific conditions into buffer zone design (Lowrance et al. 2000a). When used along with pollutant loading models such as GLEAMS (Groundwater Loading Effects of Agricultural Management Systems), REMM may be used to estimate nutrient loading from agricultural fields through riparian buffer zones (e.g., Stone et al. 2001).

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). Bharati et al. (2002) found that cumulative infiltration of surface runoff was 5x greater under riparian buffers than within cultivated fields or pastures in Iowa. Buffers 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. Simulated VFS experiments in laboratory flumes also suggest that density, slope, and sediment particle size are major factors determining sediment deposition in buffers (Jin and Romkens 2001). Sediments and NPS pollutants are trapped by buffers most efficiently when field runoff is dispersed uniformly (i.e., when concentrated flows do not occur) (Dosskey et al. 2002).

The buffer width required for efficient nutrient/sediment removal has been debated (Fennessey and Cronk 1997). Subsurface flows may be 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. Tate et al. (2000) reported that a buffer area excluding livestock from irrigated pasture in the Sierra Nevadas of California significantly reduced TSS concentrations and loads compared to an unbuffered control. Other recent studies have demonstrated sediment removal between 81 and 97% in various buffer types and sizes (Table 5).

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 led 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 two 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; Hill et al. 2000). Significant denitrification of subsurface groundwater nitrate has been observed in many studies, but generally is limited by differences in soil saturation and organic carbon content of riparian soils (Shannon et al. 2000, Flite III et al. 2001). Localized denitrification may occur in deeper groundwater where there are available organic carbon supplies (e.g., in a deep riparian aquifer in Ontario; Hill et al. 2000). Riparian zone hydrology also plays a role in the degree of denitrification of nitrate (Angier et al. 2001). Wigington, Jr. et al. (2003) found that, although nitrate was reduced in shallow groundwater moving from commercial grass fields through the herbaceous riparian zone, the overall potential for denitrification was limited because very little runoff actually contacted the riparian zone. The majority of overland flow moved to streams via saturated swales. They concluded that, in poorly drained landscapes, nitrate loading to streams may be reduced more effectively by correct fertilizer application rates and timing. Similar results in an urban riparian zone in Japan were reported by Kinohira et al. (2001).

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. Recent studies indicate that 62-94% of total nitrogen and 62-85% of nitrate in surface runoff are retained by buffers (Table 5). Removal of nitrate from groundwater ranged from 35 to 70% (Table 5).

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, Environment Canada 2001). Efforts to reduce phosphorus losses from agricultural systems need 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. Recent work (Table 5) suggests that up to 91% of phosphorus in surface runoff may be retained by buffers. Although Dosskey et al. (2001) suggest that groundwater phosphorus tends to increase through buffers, very few studies of groundwater phosphorus dynamics have been completed (but see Carlyle and Hill 2001 for phosphate dynamics in a forested floodplain connected to a large sand aquifer in Ontario).

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). Early 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. For example, although tall fescue VFS reduced coliform bacteria by up to 87% in runoff from livestock confinement areas, numbers remained high and were in excess of 1000 CFU/100 mL (Fajardo et al. 2001). 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. (2000a,b) studied 30 m mix of grass and forested buffer strips applied with swine wastewater in Georgia. Total and fecal coliform numbers in the wastewater pulse did not decline as runoff moved downslope. 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 substantially 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.

Mersie et al. (1999) found that atrazine and metolachlor were reduced in switch grass filter strips by 52 and 59%, respectively. Bare soil "controls" retained 41-44% of these pesticides. In a Nebraska study by Schmitt et al. (1999), sediment-associated permethrin was reduced by 27-83% in vegetated filterstrips, whereas dissolved constituents such as atrazine, alachlor, and bromide were not noticeably attenuated.

e) Summary

Sustaining both agriculture and the integrity of aquatic ecosystems requires the improvement of surface and groundwater quality while maintaining farm productivity. 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 6).

TABLE 6 – Range of percent retention for sediment, nitrogen, phosphorus, pesticides and coliforms in buffer strips.

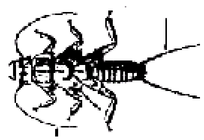
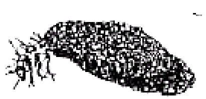
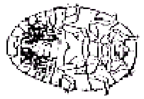
	Retention (%)
Sediment	66-97
Nitrogen	35-96
Phosphorus	27-97
Pesticides	8-100
Coliforms [1]	70-74

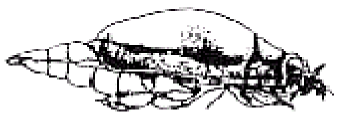
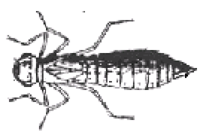
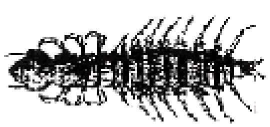
1 *fecal coliform*

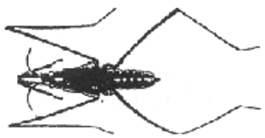
Buffer strips can effectively remove nutrients from surface water flow. The main mechanisms of nitrate removal are by vegetation uptake in the roots and anaerobic microbial denitrification in the saturated zone of the soil. Relatively narrow buffers seem to be very effective in reducing nitrogen (Table 6). Phosphorus retention can be effective (Table 6) in buffer strips that contain both woody and herbaceous vegetation, grasses and cropped buffer systems. Buffer strips can trap a significant proportion of pathogens (Table 6); however, remaining levels often exceed minimum drinking water standards. Low soil moisture and high soil temperature substantially 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 6).

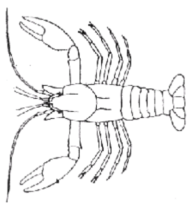
Buffer strips are an essential practice in watershed protection; however, they should be viewed as a secondary best management practice. In-field management practices such as conservation tillage and upland conservation are important for pollution control because they prevent pollution at its source.

QUICK REFERENCE GUIDE TO AQUATIC INVERTEBRATES

Name	Distinguishing Characteristics	Where Found	How Oxygen is Obtained	Food Gathering	Things To Look For
Stonefly Nymph 	2 tails, 2 sets wing pads, (wing pads not always noticeable)	Cold running water	Through body surface; some small gills; does "pushups to increase oxygen flow	Predator or herbivore	Streamlined body for crawling on rocks; requires high oxygen levels
Mayfly Nymph 	3 tails (sometimes 2); 1 set wing pads.	Cool or cold running water	Through gills along abdomen; may wave gills in water to increase oxygen flow	Herbivore or scavenger	Requires high to medium oxygen levels
Caddisfly Larva 	Most species build cases or nets soft body, some free living	Cool or cold running water; ponds	Through body surface; some finger-like gills	Filter feeder, herbivore, predator	Builds cases of heavy material (rocks) to avoid being swept away by fast-flowing streams; uses grass and plants to make cases as well
Water Penny Larva 	Round, flat, segmented, disk-like body	Cold running water	Usually through gills on underside	Herbivore—grazes on algae	Flattened body resists pull of current
Predaceous Diving Beetle Larva 	Up to 6 cm long; robust jaws	Most still and moving water habitats	Through body surface	Voracious predator	Special channels in jaws to suck body fluids of prey

Name	Distinguishing Characteristics	Where Found	How Oxygen is Obtained	Food Gathering	Things To Look For
Whirligig Beetle 	Black; congregates in schools	Surface of quiet water	From atmosphere	Predator or scavenger	Has two pairs of eyes to see above and below water's surface; has type of "radar" to locate object in water; secretes white odorous substance to deter predators
Black Fly Larva 	Small body; small hooks at end of abdomen attach to rocks	Cold running water	Through body surface; small gills	Filter feeder	Anchors to rocks with silk; only needs medium to high oxygen levels
Dragonfly Nymph 	Stout body; arm-like grabbing mouthpart	Cool still water	Dissolved oxygen, through gills in internal body chamber	Active predator	Clings to vegetation or hides in clumps of dead leaves or sediment
Damselfly Nymph 	3 leaf-like gills at end; arm-like grabbing mouthpart	Cool still water	Through gills at end of abdomen	Active predator	Clings to vegetation or hides in clumps of dead leaves or sediment
Hellgrammite (Dobsonfly, Alderfly or fishfly Larva 	Up to 9 cm. Long	Cool or cold, slow to fast moving water	Through gills along side of abdomen; some fish flies have breathing tubes	Active predator	Can swallow prey without chewing

Name	Distinguishing Characteristics	Where Found	How Oxygen is Obtained	Food Gathering	Things to Look For
Water Strider Adult 	Skates on water's surface	Ponds or still pools of stream	From atmosphere	Active predator	Can stay on water's surface because feet have small surface area and are water repellant
Water Boatman Adult 	Long swimming hairs on legs	Ponds or still pools of stream	From atmosphere, by carrying air bubble from water's surface on body	Omnivore, herbivore, or scavenger	Has swimming hairs on legs that act as oars
Backswimmer Adult 	Light-colored underside; swims on back	Ponds or still pools of streams	From atmosphere, by carrying air bubble from water's surface on body	Predator	Swim on back, sleek body shape
Cranefly Larva 	Cylindrical body; often has lobes at hind end, may have small soft legs	Bottoms of streams and ponds in sediment and algae	From atmosphere through spiracles (openings) at hind end	Active predator, herbivore, or omnivore	Species that eat woody decaying matter have gut bacteria to digest cellulose
Mosquito Larva 	Small body; floats at surface	Cool to warm still water	From atmosphere through breathing tube, on hind end as a larva and front end as pupa	Scavenger —feeds on micro-organisms	Swims or dives when disturbed

Name	Distinguishing Characteristics	Where Found	How Oxygen is Obtained	Food Gathering	Things to Look For
Aquatic Sowbug 	Flattened body, top to bottom; 7 pairs legs	Shallow freshwater, among rocks and dead leaves	Through body surface on legs	Scavenger —eats decaying matter---or omnivore	Male clasps female under it during mating; female then sheds half of exoskeleton, which becomes case into which fertilized eggs are placed
Crayfish 	5 pairs of legs, first pair often robust; looks like small lobster	Under rocks or in burrows in shallow freshwater	Through gills under body	Scavenger or omnivore	Crawls backwards when disturbed; males display some courtship behavior to reduce female aggressiveness
Scud 	Flattened body, side to side swims on side	Bottom of lakes, streams or ponds, or streams	Through gills under body	Scavenger or omnivore	Male carries female on its back during mating; female then sheds half of exoskeleton, which becomes case into which fertilized eggs are placed
Midge Larva 	Small thin body with a hard head and small legs on the hind end	Most still and moving water habitats	Through body surface, small gills	Predator, herbivore, or omnivore	Extremely common; sometimes red because they have hemoglobin in their blood to help transport oxygen; wiggle actively
Rat-Tailed Maggot Larva 	Cylindrical body; tail-like breathing tube	Cool to warm water with low oxygen levels	From atmosphere through breathing tube	Scavenger —eats decaying matter and sewage	Can survive low oxygen levels fatal to most invertebrates

Reviewed: 7/29/2021