# Prairie wetlands and carbon sequestration

## Assessing sinks under the Kyoto Protocol

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## Executive Summary

In 1992 nearly all countries of the world signed the United Nations Framework Convention on Climate Change (UNFCCC), establishing a long-term goal to stabilize atmospheric concentrations of greenhouse gases. Each party to the Convention is committed to limiting greenhouse gas emissions and protecting and enhancing greenhouse gas “sinks and reservoirs.”

In December of 1997, as part of efforts to fulfill the Convention, international negotiators signed the Kyoto Protocol in Japan. The Protocol directs developed countries to reduce their emissions of carbon dioxide ($CO_2$) and five other prominent greenhouse gases by at least 5 per cent below 1990 levels between 2008-2012. Canada is committed to reductions of 6 per cent and the U.S. to 7 per cent (see www.unfccc.de).

To help achieve these targets, the Protocol allows Annex 1 countries (developed nations) to credit removals of greenhouse gas emissions by natural sinks that store carbon. Carbon, a primary component of the most significant greenhouse gases, is sequestered (or stored) in forests, agricultural soils, and wetlands.

To date the Protocol allows credits for sequestration solely in forests. Wetlands do not qualify. Yet wetlands (including peatlands) have considerable potential for long-term carbon storage. Wetlands represent the largest component (14 per cent) of the global terrestrial biosphere carbon pool. In the course of human settlement, millions of wetlands have been drained for other uses, particularly agriculture. Draining and subsequent alteration have resulted in the release of a significant proportion of stored carbon in these former wetland sites. Many of these wetland areas could be restored.

Canada is now devising ways to meet its Kyoto Protocol commitments. As part of this emerging strategy, the federal government established several issues advisory tables, including a National Sinks Table. At the international level, Canadian negotiators are working to broaden the Protocol’s definition of sinks to include agricultural soils and wetlands. Including wetlands would present significant opportunities for Canada, which possesses nearly 25 per cent of the world’s wetland area, or over 127 million hectares. Canadian representatives will participate in upcoming seminars and workshops of the Subsidiary Body for Scientific and Technological Advice to the UNFCCC, as well as the upcoming Conventions of the Parties (COP5 and COP6) where the issue of sinks will be debated further.

In April 1999 Canadian scientists and policy-makers met at the Oak Hammock Conservation Centre in Manitoba to consider whether prairie and parkland wetlands are net sinks or sources of greenhouse gases and to provide recommendations regarding the recognition of wetlands as carbon sinks under the Kyoto Protocol. The Prairie Pothole Region is an area particularly endowed with wetlands and potential areas for wetland restoration. Workshop participants agreed that for wetlands to be accepted under the Kyoto Protocol, scientists must be able to provide confident projections of carbon sequestration potential in wetlands, and an acceptable methodology for determining verifiable changes in carbon stocks. Currently, no complete carbon balance studies exist on southern Canadian wetlands. Most urgently, scientists must devise a model that can accurately estimate wetland carbon flux. They must determine whether wetlands can be managed as net carbon sinks over time. As well, a lead agency must be assigned to direct this research and coordinate the wetlands agenda.

The Oak Hammock workshop recommended that the Sinks Table include consideration of wetlands in its pending Options Paper. In situating wetlands, the workshop advised that Canada's negotiators determine whether wetlands should be considered separate from, or part of, forests and agricultural lands. Both areas possess extensive wetlands. In fact, policy-makers attending the workshop debated the possibility of wetlands meriting inclusion in the Kyoto Protocol under the existing definition for forests. Wetlands may also be included as part of agricultural areas through future revisions of the Protocol's definition of land use.

Notwithstanding the outcome of the Kyoto negotiations, the Oak Hammock workshop participants felt the public, domestically and internationally, must be engaged in the wetlands issue. In addition to their potential as carbon sinks, wetlands are one of Earth's most biologically productive and diverse natural systems. They constitute a habitat base for exceptional levels of biodiversity, purify and moderate water resources, and provide food, fibre and water security for local communities. The federal government's wetlands policy describes wetlands as a key life support system, "in concert with agricultural lands and forests. Their importance goes beyond their status as the habitat of many endangered plant and animal species. They are a vital element of national and global ecosystems and economies." The ecological, economic, and social services wetlands provide warrant their ongoing restoration and conservation across the Canadian landscape and abroad.

## Introduction

This summary paper addresses the major issues concerning prairie and parkland wetlands as carbon sinks and presents the background to the Kyoto Protocol and the provisions for carbon sinks within the Protocol. It discusses the possible inclusion of wetlands as sinks and policy advancements since Kyoto. It includes descriptions of a recent workshop in Downsview, Ontario (January 18–19, 1999) that touched in part on wetlands, and the workshop at the Oak Hammock Conservation Centre in Manitoba (April 18–20, 1999), where scientists and policy-makers assessed whether prairie and parkland wetlands are sources or sinks of carbon. The Oak Hammock workshop focused on the Central Plains prairie and parklands because of their high densities of wetlands (historical and current), the rate of wetland degradation in the region, and the area's great potential for wetland restoration. Regional studies estimate that up to 70 per cent of prairie wetlands have been lost or severely degraded (Rubec, 1994).

The paper describes human settlement and activities that have an impact on prairie wetlands, and gives an overview of carbon sequestration potential in wetlands and related upland areas in the Central Plains, including techniques available for measuring carbon cycling. A final section describes scientific and policy issues that must be taken into account in any effort to see wetlands included in the Kyoto Protocol. This document does not propose policy options for achieving wetland creation and restoration, but it acknowledges that such policies are critical to wetland conservation initiatives. The Oak Hammock workshop participants reviewed an original draft of this paper. This version largely incorporates the ideas and recommendations that emerged from the workshop.

## 1. Background on UNFCC and the Kyoto Protocol

### The International Context

Over 160 nations have ratified the 1992 United Nations Framework Convention on Climate Change (www.unfccc.de). The agreement establishes a long-term goal to stabilize atmospheric concentrations of greenhouse gases at a level that would prevent dangerous anthropogenic interference with the climate system. The Convention states that "each party shall...limit its anthropogenic emissions of greenhouse gases and protect and enhance its greenhouse gas sinks and reservoirs" (National Sinks Table, 1998). The Convention defines a sink as "any process, activity or mechanism which removes a greenhouse gas, an aerosol, or a precursor of a greenhouse gas from the atmosphere."

Atmospheric concentrations of carbon dioxide can be reduced by photosynthesis, and then by sequestration in components of terrestrial, oceanic and freshwater ecosystems (Bruce et al., 1998). The Convention defines reservoirs as "a component or components of a climate system where a greenhouse gas or a precursor of a greenhouse gas is stored" (National Sinks Table, 1998). A source is defined as "any process or activity which releases a greenhouse gas, an aerosol, or a precursor of a greenhouse gas into the atmosphere." Article 4, paragraph 1 (a) of the Convention states that "all parties to the convention must develop, periodically update, publish and make available to the Conference of the Parties national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases."

### The Canadian Context

In April of 1998 Canada established a series of national advisory tables to provide the issue analysis, options development, and consensus-building required to develop Canada's strategy for international climate change negotiations. The National Sinks Table is mandated to identify the state of knowledge, gaps, and challenges surrounding the issue of biological sinks as they relate to forestry and agriculture "and any other biological sinks that may be identified" (National Sinks Table, 1998). The Sinks Table is undertaking a series of studies to move forward domestically and internationally on sinks, including forests, agricultural soils and wetlands.

### The Kyoto Protocol

#### Emissions Reductions

Canada and its major trading partners signed the Kyoto Protocol in December of 1997 to help fulfill the FCCC objectives. The Protocol defines varying targets for developed countries to reduce greenhouse gas emissions to 1990 levels over a five-year commitment period (2008–2012). Canada agreed to a 6 per cent reduction while average reductions for Annex 1 countries amount to about 5.2 per cent. The agreement does not include targets for commitment periods after 2012.

The Protocol calls for reductions in emissions of all significant greenhouse gases, particularly carbon dioxide ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$). Three other gases (hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride ($(SF)_6$) are also targeted for reductions. To come into force, the Protocol must be formally ratified by 55 Parties to the Convention, including enough Parties listed in Annex 1 (developed countries) to account for 55 per cent of worldwide carbon dioxide emissions in 1990 (www.unfccc.de). The implications of the Kyoto Protocol are that upon ratification, emission and removal estimates will become legally binding, and the verification process will be much more rigorous, particularly for sinks.

### Sinks

In addition to emission reductions, the Protocol calls for Annex 1 countries to quantify the removal of greenhouse gases in specified sinks. Article 3 states that the Parties will include the "net changes in greenhouse gas emissions from sources and removals by sinks resulting from direct human-induced land use change and forestry activities, limited to afforestation, reforestation, and deforestation since 1990, measured as verifiable changes in stocks in each commitment period" (Kyoto Protocol, 1997). These sinks will be added to or subtracted from Parties' gross emissions when assessing changes over 2008-2012. This Article has given rise to the informal term the "Kyoto Forest."

### Emissions Trading

Under the Protocol, Annex 1 nations such as Canada are permitted to gain recognition for emission reductions or greenhouse gas removals from other Annex 1 Parties. Specifically, Article 6 states that nations "may transfer to, or acquire from, any other such Party emission reduction units resulting from projects aimed at reducing anthropogenic emissions by sources or enhancing anthropogenic removals by sinks of greenhouse gases in any sector of the economy" (Kyoto Protocol, 1997). This provision creates significant emissions trading opportunities at the international level.

### Clean Development Mechanism

Article 12 of the Kyoto Protocol establishes a Clean Development Mechanism, whereby Annex 1 countries may collaborate with a nation not listed in Annex 1 on projects for achieving emission reductions in that other nation. The Annex 1 nation may apply any resulting certified emission reductions toward meeting its own commitments. Sink activities are not explicitly included in Article 12, although most countries seem to agree they should be included (National Sinks Table, 1998).

## A Case for Wetlands

The Kyoto Protocol does not currently recognize carbon sequestration in agricultural soils or wetlands. Article 3.4 specifies, however, that subsequent meetings would determine rules and guidelines for including additional human-induced activities in the "agricultural soil" and land-use change and forestry categories (Kyoto Protocol, 1997).

Securing the inclusion of agricultural soils in the Protocol could strengthen the case for recognizing wetlands. "The agricultural lands of Canada include localized wetlands. Those wetlands may also be included if agricultural soils sinks are included in the Protocol" (National Sinks Table, 1998).

The National Sinks Table has stated that the Protocol's failure to include wetlands at the outset "leaves an ecological information vacuum in the effects of wetlands on the atmosphere, and falls short of the FCCC goal: 'to protect and enhance sinks'" (National Sinks Table 1998). Wetlands cover 6 per cent of the world's land surface and contain 14 per cent of the terrestrial biosphere carbon pool (National Sinks Table, 1998). Aside from freshwater wetlands, coastal salt marshes and mangroves are considered the most important marine ecosystems for carbon sequestration.

Carbon dioxide is by far the most important greenhouse gas influenced directly by human activities (Bruce et al. 1998). The loss and degradation of carbon reservoirs (e.g., wetlands) can result in releases of large amounts of greenhouse gases into the atmosphere, negating gains made from emission reductions. In Canada, the federal government estimates that since 1800, about 20 million hectares, or one-seventh of Canada's total wetland base, have been drained or lost to other land uses. Millions more hectares have been seriously degraded or are at imminent risk (Government of Canada, 1991).

### Policy Advancements since Kyoto

Since 1997 international negotiators have been clarifying the definition of sinks. The June 1998 meeting of the Subsidiary Body for Scientific and Technological Advice to the FCCC (SBSTA-8) acknowledged that the land-use change and forestry categories are really three activities: land use, land-use change, and forestry. This recognition may signify that activities such as agriculture or those pertaining to wetlands could eventually be included under land use. As it is, agricultural and wetland areas may gain qualification under the category of land-use change (Rubec, pers. com., 1999). The SBSTA has asked the Intergovernmental Panel on Climate Change (IPCC) to prepare a special report on land use, land-use change, and forestry that will examine the implications of dealing with sinks.

An SBSTA workshop on sinks held in September 1998 clarified various definitions, particularly for those nations with slow-growing forests. It also opened the debate on defining land cover versus land use. At the Fourth Convention of the Parties (COP4) in Beunos Aires in November of 1998, negotiators decided that discussions on sinks will continue while the IPCC prepares its special report. At COP4, international negotiators recommended that following submission of the special report, a decision be made on the definition of sinks at the next possible Convention of the Parties (COP6).

### Canada’s Position on Sinks

Canada holds the position that all relevant sinks should be included in the Framework Convention on Climate Change and in the Kyoto Protocol. To make its case, Canada is tasked with developing good information on the potential contribution of sinks to meeting the national target; ensuring that future negotiations on sinks reflect Canada's interests and address inconsistencies in the Protocol; and developing strategies that capitalize on “sinks opportunities” to contribute to Canada's target. Before accepting an expanded definition of sinks, the international community must be satisfied that changes in sink size can be estimated in a transparent, reliable, practical and verifiable way at the landscape level. It must also be convinced that including sinks has advantages for Europe and for developing countries.

### Downsview Workshop

At a January 18-19, 1999 meeting in Downsview, Ontario, carbon-flux experts noted that wetlands are the largest terrestrial carbon reservoir in Canada, covering 14 per cent of the land surface but containing about 60 per cent of the carbon stock (approximately 150 Gt C). Very little information exists on the sensitivity of these carbon stocks to land-use changes, such as drainage, extraction, conversion, flooding, nutrient inputs, or restoration. Available research shows drainage reduces methane but increases carbon dioxide and nitrous oxide emissions, while flooding increases carbon dioxide and methane. In addition, climate change scenarios predict warming and changes in precipitation patterns which could affect the carbon cycle in wetlands.

Participants of the Downsview meeting proposed that a “Kyoto Wetland” be defined as wetland restoration (R, paralleling reforestation), wetland creation (C, paralleling afforestation), and wetland degradation (D, paralleling deforestation). They suggested that a carbon process and bookkeeping model be devised to simulate land-use changes and climate change impacts, and natural variability. Long-term monitoring sites representative of natural and degraded wetlands should be developed to enhance process-based research.

Participants’ felt that the links between wetlands and agricultural and forested lands must be better defined (e.g. wetland and agriculture, forested peatlands, upland and lowland, afforestation, and riparian zones). If forest soils are included in the “Kyoto Forest,” then peatlands are automatically included since many are forested. The impacts on wetlands of forestry and agriculture (hydrology, drainage, and biomass removal) must be taken into account. The workshop's wetlands working group recommended research into wetland restoration potential, and noted the lack of national coordination in wetland research. Valid models are needed to provide creditable and verifiable sinks in wetlands in general, but particularly in agricultural areas and in peatlands in forested areas.

### Oak Hammock Workshop

The workshop on carbon sequestration in prairie wetlands (April 1999) at the Oak Hammock March Conservation Centre in Manitoba addressed the question of whether prairie wetlands are sinks or sources of greenhouse gases. The science working group at this workshop concluded that restoring degraded or drained wetlands in Canada's prairies would likely result in net carbon storage over the long term compared with the land use (usually marginal agriculture) before restoration. This assessment is based on recent work in North Dakota on carbon storage in restored wetlands and on a general understanding of wetland carbon processes as compared with those processes in marginal tilled soils. The science group identified important information needs and the necessity to address those needs before detailed recommendations can be made regarding the potential of restored prairie wetlands as long-term carbon sinks. The science group emphasized the need to address wetlands in the context of restored prairie landscapes. Generally, restoration includes the wetland basin, the adjacent riparian zone, and associated uplands. The role of all these zones as carbon source and sinks must be addressed in detail.

The science working group at Oak Hammock reviewed the current knowledge related to carbon cycling in prairie wetlands, including all inputs, outputs, and storage processes. Considerable information is available on a wide range of topics associated with carbon cycling in these systems. A detailed modelling exercise was recommended to organize the available information appropriately and to identify specific research needs. In this regard, three critical information gaps were identified for immediate attention: prairie wetland gas exchange rates (including carbon dioxide, methane and nitrous oxide), wetland/riparian/upland interactions, specifically carbon budgets, and carbon accumulation rates in the soil and litter column of wetlands.

Workshop participants acknowledged the need for an ongoing carbon-working group for prairie and parkland wetlands to develop a working model, coordinate the ongoing research, and incorporate new information into the modelling exercise as it becomes available. Participants also noted that all information must be extrapolated to the landscape level to allow for regional and national inventories of carbon stores and changes in those stores. The need to scale up the wetland carbon storage data resulted in a discussion of a national inventory of wetlands on a scale sufficient to delineate and quantify wetland types and changes in land use over time (both regionally and nationally). The remote-sensing working group at the Oak Hammock workshop acknowledged that the technology is in place for such an inventory and work on this process could begin soon. A number of national agencies, both private and public, have expressed interest in participating in a national wetlands inventory.

The Oak Hammock workshop acknowledged that wetlands are an integral component of the prairie agricultural landscape and should also be considered in any discussion of land use changes in the region, including carbon-storage opportunities in agricultural soils. Effects of land-use changes on overall carbon processes and storage within the wetland basin itself or the associated riparian and upland zones also require attention. Finally, the long-term impacts of climate change on the prairie environment and carbon storage in the prairie landscape (including wetlands) should be incorporated into the modelling efforts in these systems.

## 2. Wetland Overview

Wetland Protection in Canada

Canada possesses nearly 25 per cent of the world's wetland area, covering more than 127 million hectares (Government of Canada, 1991) (Fig. 1).

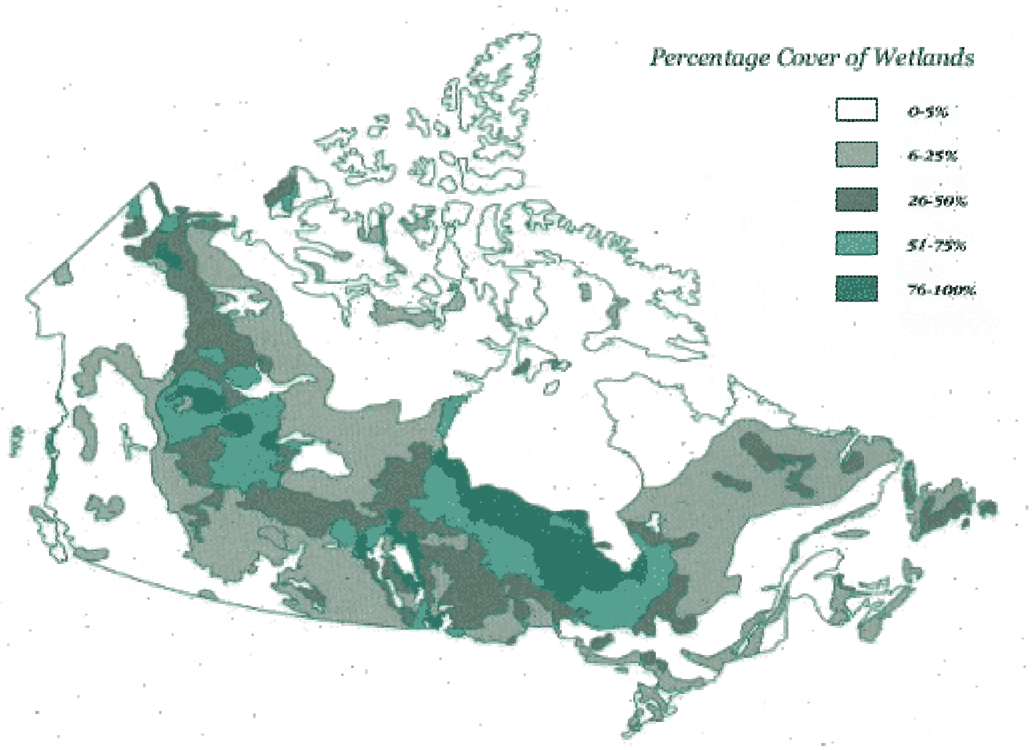


Figure 1: Distribution of wetlands in Canada.

The federal government defines wetlands as “land that is saturated with water long enough to promote wetland or aquatic processes as indicated by poorly drained soils, hydrophytic vegetation and various kinds of biological activity which are adapted to a wet environment” (Rubec and Lynch-Stewart, 1998). Wetlands are considered a key life support system, “in concert with agricultural lands and forests. Their importance goes beyond their status as the habitat of many endangered plant and animal species. They are a vital element of national and global ecosystems and economies” (Federal Policy, 1991). Wetlands include fens, bogs, swamps, marshes, and other shallow water bodies.

Several federal and provincial policies now exist which to some degree promote wetland conservation. The federal government’s objective with respect to wetland conservation is to “promote the conservation of Canada’s wetlands to sustain their ecological and socio-economic functions, now and in the future” (Government of Canada, 1991). The policy includes promoting research on the “impact of climate change” on Canada’s wetlands (Rubec and Lynch-Stewart, 1998).

All of Canada’s provinces have instituted non-regulatory wetland management programs. Four provinces have developed specific wetland conservation policies, including Ontario and the three Prairie Provinces of Alberta, Saskatchewan, and Manitoba. Quebec has instituted some regulatory measures through several pieces of legislation. New Brunswick and Nova Scotia are developing provincial policies, while Prince Edward Island protects wetlands through various legislative instruments (Rubec, pers. com, 1999).

In the past decade, voluntary, non-governmental initiatives have grown increasingly prominent. Partnerships are flourishing between government agencies, non-governmental organizations, the resource industry, private landowners, and local communities. These partnerships are often based on the integration of environmental concerns with social priorities and economic opportunity.

### Carbon Fluxes in Prairie Wetlands

There are five classes of prairie wetlands. These include (1) ephemeral ponds that are flooded for a few days in the spring; (2) temporary ponds that are flooded for a few weeks in the spring; (3) seasonal ponds flooded for a few months but normally drying up by late summer; (4) semi-permanent ponds that are flooded throughout most years but are dry during drought years; and (5) permanent ponds that are flooded continuously, except possibly during drought periods.

Wetlands do not have to be wet all year to be functional systems. Many wetlands dry up during the year (classes I-III), and in times of drought can remain dry for several years. While the wetland plants die during dry times, their seeds lie dormant in the soil, waiting to germinate when the moisture returns. All wetland classes are important for wildlife habitat, recreation and as possible sources of carbon sequestration.

## The Prairie Pothole Region of Canada

The Prairie Pothole region of Canada encompasses much of the land area of the southern Prairie provinces (Fig. 2). It covers the central and western portions of southern Manitoba, the lower half of Saskatchewan and southeastern Alberta. The total area is about 114.9 million hectares, or 12 per cent of Canada (State of Canada's Environment 1996). The region is divided into two zones: the Prairie ecozone to the south, composed mostly of agricultural cropland and grasslands; and a unique transition zone, consisting mostly of aspen parkland, where the southern prairie gradually gives way to the tree cover of the forested Boreal Plains ecozone to the north. The region was glaciated until 10,000–15,000 years ago, leaving glacial till soils overlain by organic deposits that formed under a grass and tree vegetative complex. Historically, retreating glaciers left about 10 million depressions, or prairie potholes, throughout the region. As runoff from precipitation occurred, complexes of wetlands developed with varying degrees of water permanence.

Human settlement of the pothole region began in the late 19th century, and while it was mostly completed by the mid-20th century, some areas (e.g., northwestern Alberta) were still being settled in the 1970s. Increasingly intensive agriculture occurred with settlement, and significant changes came about in land use and land cover. Land use in the region is mostly grain farming and cattle ranching. Since the advent of intensive agriculture, the construction of drainage systems has substantially reduced the number of depressions that retain water and increased the rate at which runoff reaches river systems. In many areas, most runoff flows through former wetlands with short retention time and limited groundwater recharge. This drainage system has resulted in the loss of up to 50 per cent of pristine wetlands (Ducks Unlimited, 1990). Yet much wetland area remains, interspersed with extensive grasslands.

### The Prairie Ecozone

The Prairie ecozone, comprising the southern portion of the pothole region, consists of flat to gently rolling landscape underlain by deep glacial deposits. Before European settlement, the ecozone consisted largely of dry mixed grasslands in southeastern Alberta and southwestern Saskatchewan, and tallgrass prairie in southeastern Manitoba. Since settlement, the ecozone has become one of the most extensive agricultural regions in the world. Of its total land area of 47 million hectares, 70 per cent is classified as cropland and 27 per cent as rangeland and pasture (State of Canada's Environment, 1996).

Depending on weather conditions, the prairie ecozone can contain between 2 and 7 million wetlands. The greatest number of wetlands occurs along the subhumid northern grasslands and adjacent aspen parkland, where wetlands occur on 25–50 per cent of the land surface. Many former wetland areas have been converted to agricultural production. For example, in the mixed-grass prairie of southwestern Manitoba, wetland degradation and grassland conversion have been extensive. According to Zittlau (1979), almost 900,000 hectares of this area were affected by drainage between 1890 and 1935. Kiel et al. (1972) suggest that further drainage continued through the 1960s. Drainage was also prevalent during the dry 1980s, and Caswell and Shuster (1992) note that 10–45 per cent of the remaining basins are affected annually, primarily by agriculture. Current threats include continued agricultural and urbanization expansion (Ducks Unlimited, 1990).

### The Parkland Region

In the more northern transition zone that divides the Prairies and Boreal Plains ecozones, prairie grasslands give way gradually to a more forested terrain. The southern portion of this zone is called the Parklands, where the natural vegetation is grassland interspersed with aspen and oak bluffs. Only portions of this prairie and forest mosaic remain, since much of the landscape has been converted to agriculture.

Though thousands of shallow ponds, or sloughs, still dot the parkland landscape, grain farming has caused significant wetland loss and degradation. In efforts to maximize production, the agricultural industry (via individual actions and government policies) drained and filled millions of wetlands in the region. The North American Waterfowl Management Plan (NAWMP) estimates the loss of pristine wetlands at 40 per cent while Lynch-Stewart et al. (1993) estimate a number closer to 50 per cent. Turner et al. (1987) report that in the prairie pothole region many, if not most, of the remaining wetlands are now affected in some manner by haying, burning, brushing, filling and grazing.

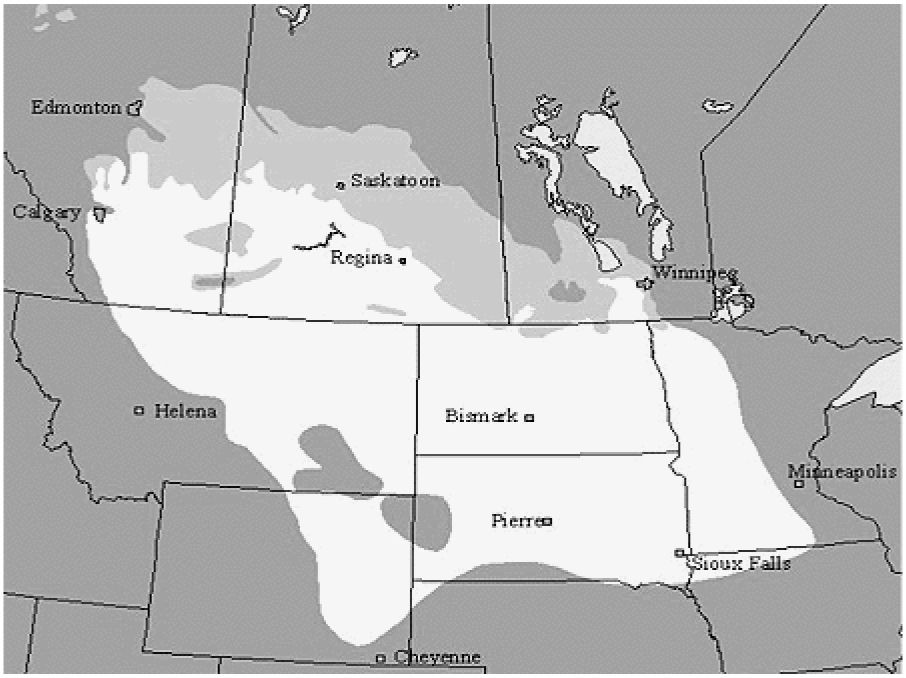


Figure 2: Prairie pothole region of Canada.

## 3. Carbon Sequestration in Wetlands

### Prairie Wetlands

The major factors affecting carbon cycling in prairie wetlands are inputs, outputs, and storage capability. Inputs can occur as gas (photosynthesis, algae and macrophytes), solids (dust, water and soil erosion, and animal biomass), and dissolved substances (dissolved organic carbon, dissolved inorganic carbon). Outputs also occur in these three states: as gas through respiration (carbon dioxide, methane and nitrous oxide); as solids (e.g., harvesting of vegetation such as hay cropping); and as dissolved substances in water through surface and ground water flow (dissolved organic carbon and dissolved inorganic carbon).

Carbon is stored in wetland sediments over the long term. Short-term stores are in existing biomass (plants, animals, bacteria and fungi) and dissolved components in the surface and groundwater. Modifiers of carbon storage are numerous and include factors such as wetland class, vegetative zone, depth into sediment, north–south latitudinal gradient, salinity, climate cycles, temperature, hydrology and surrounding land use. The magnitude of wetland carbon storage capacity is unknown. While some carbon cycling data are available on a small scale, it remains unknown whether these data represent all situations or can be extrapolated to the landscape level.

Scientists in the U.S. undertook a recent wetland restoration study in northern states of the Central Plains. In 1996 they sampled 204 wetlands of varying wetland classes and found that undisturbed, pristine wetlands hold twice as much carbon as drained wetland areas converted to agriculture. The study indicates that carbon sequestration in wetlands could be achieved through wetland restoration, but it would likely take 10 years before carbon storage levels returned to those associated with pristine wetlands. The analysis also stressed that dried wetland basins continue to emit carbon even after draining.

In terms of the Kyoto Protocol, 1990 is the measuring baseline for changes in carbon storage. An inventory is necessary of potential areas for wetland restoration and creation. Storage values must be defined and extrapolated to a five-year period, to discern changes in stock during the Kyoto commitment period 2008–2012. While there are many gaps, sufficient information exists to facilitate a trial modelling exercise of carbon cycling in wetlands. Scientists working in carbon cycling on prairie wetlands are confident that net carbon storage and gains made through restoration of prairie and parkland wetlands are possible at both the site and landscape level.

Climatic warming, UV radiation, and agricultural activity can all have extreme effects on the biogeochemistry and food chains of prairie wetlands. It is therefore imperative to obtain an understanding of the major biogeochemical processes and how these processes may be affected by external influences such as atmospheric change and agriculture. Construction of a carbon model for a prairie wetland would be an important initial step in this process.

Riparian Zones

Riparian zones are situated on the wetland fringe, where the vegetation is affected by the presence of the wetland. The cover type in riparian zones is varied. In the prairies, riparian cover includes trees, shrubs, sedges, rushes or forbs that lead into the upland grasslands. Though data exist on the carbon cycling in riparian zones, the numbers are dispersed among information pertaining to agricultural soils and forested lands. It may prove difficult to bring this information into a focused wetland riparian context. The components of carbon cycling in riparian areas, including inputs, outputs and turnover rates, have not been determined. Measurement and verification of carbon cycling in riparian zones are also significant challenges.

Native tree and shrub cover occurs to some extent in all parts of the prairie and parkland region. In some of the drier parts, this type of cover is found exclusively in riparian or wetland areas. In much of the prairie region, the typical woody cover type around wetlands is a ring of willows or other shrub species such as alder and dogwood. Biomass equations have been developed for these shrub species. These equations are applicable to the entire region, and the results are easily converted to above-ground carbon values (Connolly and Grigal, 1983). What must be developed is a sampling protocol, using these equations, which will provide overall carbon storage values (tonnes per hectare) for these species. Biomass equations and carbon contents have also been developed for 12 woody species including chokecherry and buffaloberry (Kort and Turnock, 1996) (Table 1).

In the dark gray and black soils of the parkland and northern plains, trembling aspen and balsam poplar are the dominant tree species associated with riparian and wetland areas. Freedman and Keith (1995) provide carbon contents for these stands for the Manitoba Aspen Parkland Region. Above-ground values of 25.6 tonnes of carbon per ha and total values of 34.5 tonnes of carbon per ha are described for 60-year-old stands. Kort and Turnock (1997) give total carbon values for the woody component of riparian areas in the agricultural soil zones of Saskatchewan. They use a carbon value of 34.0 tonnes of carbon per ha for the black soil zone, 22.3 tonnes of carbon per ha for the dark brown soil zone and 20.6 tonnes of carbon per ha for the brown soil zone. The carbon contents of other native tree species associated with riparian areas have also been determined (Freedman and Keith, 1995) (Table 2), and can be applied to similar sites throughout the region.

The impacts on carbon cycling of land management practices in riparian zones are unclear. While cultivation likely lessens carbon storage potential, the effects of grazing is open to question. Good grazing management should increase carbon-holding potential. The effects of burning are unknown. The condition of riparian zones may also influence the carbon cycling of adjacent wetlands, since riparian areas have various effects, such as protecting wetlands from chemical and nutrient inputs.

Scientists need to determine how much carbon is stored in riparian zones in different eco-regions, and what management practices within riparian zones will affect their sink or source potential. Various factors may impede this research. Riparian zones are a low priority and may be neglected if not included as part of the wetland landscape in Kyoto negotiations. The short timeframe provided by the Kyoto Protocol is also a concern, since it may take years to develop a good understanding of natural carbon cycling processes in riparian areas. Scientists do not yet possess a conceptual carbon cycling model that links the riparian zones and adjacent wetlands or uplands. It is also unclear which organization (wetland, agricultural, or other) would take the lead on this research.

To overcome these impediments, scientists must firstly develop a specific model to illustrate what is known and what information is missing. Benchmark sites and values must be located and established, and protocols in monitoring must be developed. A unifying group must be put in charge of this process that will encourage short- and long-term research programs. This group must increase public awareness of the importance of wetlands and riparian zones and pursue policies that enhance and protect riparian areas.

### Upland Areas *(See Appendix II for tables).*

Any investigation of carbon cycling in wetlands must incorporate the associated upland areas. Vegetative cover types in upland areas can vary greatly, from grasslands to forests or some combination between these types. The extent of the carbon reservoir represented by this cover depends on the size, location, and type of cover in the area. The potential of each cover type to increase carbon sequestration will depend on the land base available for improvement or enhancement.

Grasslands are the most common upland cover type in the prairie and parkland region. The carbon-holding potential of native and tame grasslands varies greatly depending on soil type, soil texture, condition, and climate (Table 3). The size of the carbon reservoir varies depending on species, soil zone, stand age and other factors (Kirychuk and Tremblay, 1995) (Table 4). Above-ground carbon values from 0.4 tonnes of carbon per ha to 2.6 tonnes of carbon per ha are possible. The below-ground component of a reservoir may increase the amount of carbon by an additional two to four times (Rochette and Jaques, 1995).

Upland areas can be planted with non-native tree and shrub species (Table 5). This practice has been common on the Canadian prairies, where a tree-planting program has been in existence for almost 100 years. Planted species are often used for field and farmyard shelterbelts, wildlife enhancement plantings, snow traps, watershed stabilization, or to otherwise enhance the prairie environment. Trees and shrubs often thrive in low areas around wetlands and are capable of sequestering large amounts of atmospheric carbon in their biomass. These plantings can be designed to maximize their carbon holding potential and still function as an integral component of the wetland-based landscape.

## 4. Techniques for Measuring Carbon Cycling

### Prairie Wetlands

### Modelling

Various model types have been devised for modelling carbon sequestration in wetlands. The Century Model, the most widely accepted model focusing on soil carbon dynamics, has not been applied to wetlands. Scientists in the U.S. developed the model with input from soil scientists at the University of Saskatchewan. It simulates soil organic carbon in a range of cropping systems, rotations and tillage practices in the Great Plains. It has been used to simulate grasslands, forest and savannas. The model would need considerable modifications to be applied to wetlands. Wetland models must include the carbon inputs and outputs to the wetland, the riparian zone, and the associated uplands and the interaction of these areas in the overall carbon budget.

Forester diagrams, which are used to develop models, have been developed for carbon stocks and fluxes in prairie wetlands in a collaborative effort involving scientists at the National Water Research Institute, Saskatoon, Saskatchewan, and the University of Saskatchewan (Figs. 3 and 4). In these models, the carbon dynamics of the low prairie, wet meadow, shallow marsh, deep marsh and open water zones of wetlands are simulated. This structure has been adopted to account for spatial variability and the difference in scale of processes in these areas.

The models for each wetland zone represent biomass flows for vegetative species typical of the areas, and changes in carbon stocks in the various biophysical components. Biological activity is a function of environmental factors such as precipitation, water volume and solar energy input. The model incorporates linkages to surrounding land uses, which influence wetland functions, to ensure that the model simulates wetland functions within the context of the larger system. The conceptual model can be altered to account for more detailed cycling of organic carbon. In addition, sectors can be constructed that can be linked to the carbon model to simulate nitrogen dynamics. This system of models can be used to evaluate the balance of carbon dioxide, methane and nitrous oxide in prairie wetlands. The models were developed in the STELLA graphical programming language. Stocks are shown as boxes within the forester diagram. Stocks integrate the differences between inputs and outputs to simulate temporal changes in variables. Flows are represented by sets of arrows stemming from, or going into, stocks. Flows reflect the temporal changes to the stock. Clouds at the beginning of flow and stock sequences represent atmospheric sources. Input parameters are represented by circles and provide information on processes, relationships and constants used in the calculation of the flows. Feedback is simulated with this combination of stocks, flows and input parameters (Figs. 3 and 4).

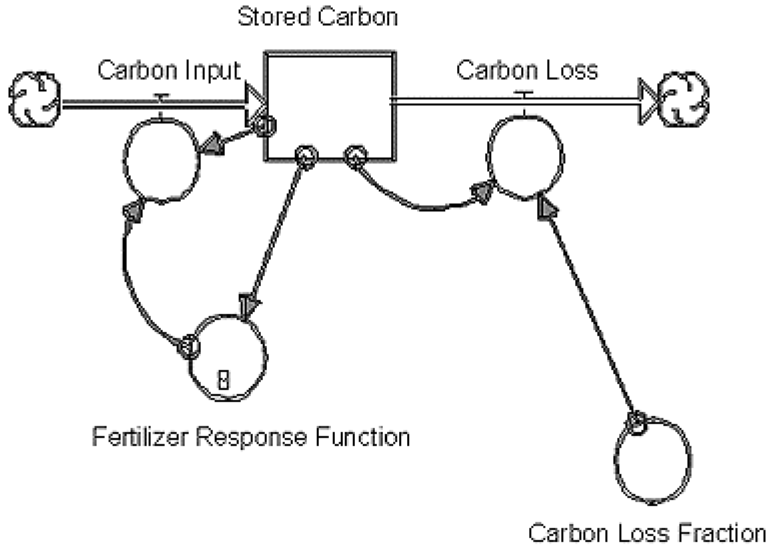
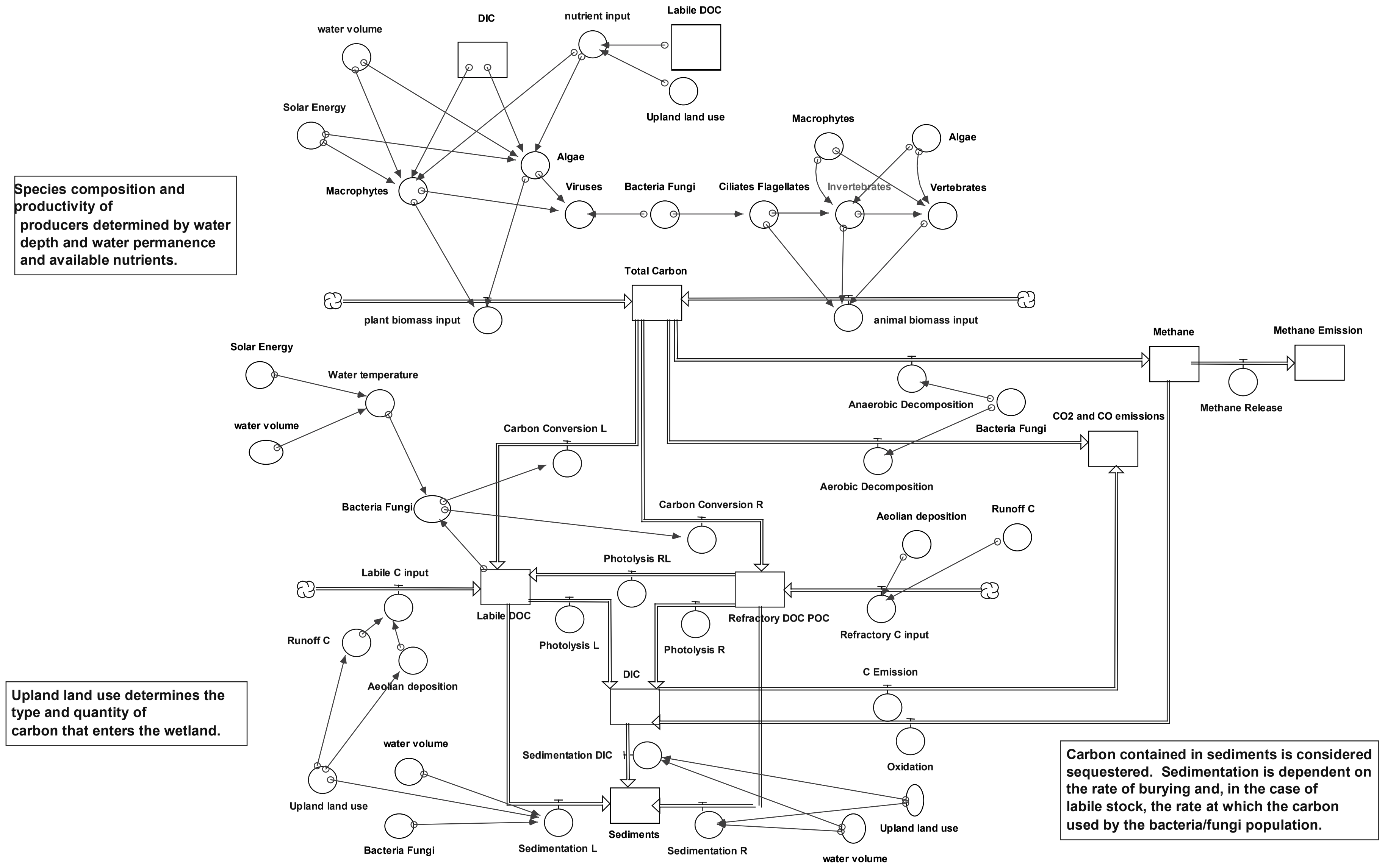


Figure 3: Basic wetland carbon model.



Species composition and productivity of producers determined by water depth and water permanence and available nutrients.

Upland land use determines the type and quantity of carbon that enters the wetland.

Carbon contained in sediments is considered sequestered. Sedimentation is dependent on the rate of burying and, in the case of labile stock, the rate at which the carbon used by the bacteria/fungi population.

Figure 4: Wetland carbon model.

Remote Sensing

Remote sensing has become an important tool in wetland management, particularly for inventories of wetland resources. A wide variety of sensing devices are available, from airborne devices to earth-observation satellites. The information gathered from these devices can be used in many ways for ecological studies, hydrologic studies, and in monitoring changes in these systems over time. These tools are important sources of timely and repetitive information, especially for wetlands because their hydrological parameters change regularly.

The main remote sensing data sets in use are based on LANDSAT Thematic Mapper (TM) satellite imagery of the prairie and parkland regions. As baseline data, Ducks Unlimited Canada has developed a thorough wetlands database for prairie Canada, from the period 1985–96. Ducks Unlimited has also generated local wetland habitat inventories from LANDSAT-TM imagery.

A debate is ongoing as to whether the present methods for classifying wetlands at a regional level can also be used for monitoring changes over time. Ducks Unlimited has indicated that 80 per cent of the wetlands on the prairie and aspen parkland region are less than one hectare, and many are only seasonally or temporarily inundated with water. Some researchers feel that the spatial resolution of LANDSAT may be insufficient to monitor changes at this fine level. Sources of high-resolution satellite imagery do exist, however, and need to be examined for their utility in this regard. As remote sensing technology continues to improve, the launching of additional satellites will soon enable scientists to enhance their classifications and inventory of prairie wetlands.

## Carbon Storage

A variety of techniques are available to monitor and verify carbon fluxes and stores in wetlands. Determination of carbon inputs and outputs in association with water flows can be determined by volume determinations of the flows involved (surface and ground water, precipitation) and the concentration of carbon (dissolved and particulate, organic and inorganic) in those flows. Atmospheric uptake of carbon can be determined by biomass accumulation (above and below ground) of the primary producers in the system. Carbon inputs and outputs can be integrated by using stable isotopes to determine carbon pathways and allochthonous (exterior) versus autochthonous (within the wetland) carbon inputs. Decomposition studies can follow the movement of carbon from the death of plants and algae through to burial of material in the sediments. While requiring complicated techniques and analyses, gas-exchange studies can monitor gas losses (carbon dioxide, methane and nitrous oxide) from the system through respiration and decomposition processes. Sampling of the soil profile can provide information on carbon stored in wetland sediments.

While there are techniques available for detailed carbon studies, future efforts must address the need for simple and rapid assessment of the carbon stores in wetlands and the changes in those stores over time. This is an important challenge for the wetlands scientific community.

Various techniques are available for measuring carbon storage and cycling in trees and native cover. Above-ground biomass (dry weight) values for native grasslands are available from rangeland management information. Above-ground carbon contents for native prairie grasslands are adapted from Abouguendia (1990) (Table 1). Above-ground carbon content for select tame or seeded grasslands that represent a significant short-term carbon reservoir are adapted from Kirychuk and Tremblay (1995) (Table 4). Connolly and Grigal (1983) and Kort and Turnock (1996) have developed biomass equations for certain shrub species (Table 1). Freedman and Keith (1995) provide carbon content for dominant tree species in the Manitoba Aspen Parkland Region (Table 2). Unfortunately, on-the-ground verification information is lacking.

Researchers at the Shelterbelt Centre of the Prairie Farm Rehabilitation Administration (PRFA) in Saskatchewan possess distribution records of the types of trees and shrubs that have been planted and their carbon-holding potential, but verification is required of the condition and survival rates of these plants (Turnock, pers. com., 1999).

## 5. Acceptance of Wetlands and the Kyoto Protocol

### Science Issues

Canadian scientists face several significant questions regarding the potential for carbon sequestration in wetlands. The fundamental question is whether wetlands can be managed as net carbon sinks over time. Participants of the carbon flux workshop in Downsview expressed the concern that the short-term framework of the Kyoto commitment period makes it difficult to account for carbon sequestration in wetlands, which may occur over hundreds or possibly thousands of years. In their paper on agricultural soils, Bruce et. al (1998) state that "[t]he key phrase in the Kyoto Protocol for international acceptance is 'verifiable changes in stock'." Currently, no complete carbon balance studies that include net ecosystem production and respiration exist on southern Canadian wetlands (National Sinks Table, 1998). Carbon inventories (with a 1990 baseline) are sorely needed, as are ongoing carbon-flux monitoring and verification.

Scientific evidence must be forthcoming soon that shows carbon-storage potential of wetlands. A model is urgently needed that will verify carbon change, as well as provide estimates of potential change in the two major gases, methane and nitrous oxide. The impacts of climate change must be considered in any modelling exercise. Priority techniques for measurements must be identified. Wetlands are known to store carbon, but it is unknown how much they store or over what sort of timeframe. Baseline measurements and a wetland inventory are required as soon as possible. The rate of drainage and rate of restoration and creation must be inventoried.

Other research needs include studies of gas exchanges, wetland and riparian interaction, and total carbon stores in the soil and litter column. Natural peat-forming wetlands store carbon but at the same time release small quantities of nitrous oxide and larger amounts of methane. When wetlands are drained and converted to other uses, large quantities of carbon dioxide and nitrous oxide are released, while methane emissions drop (National Sinks Table, 1998). Although carbon dioxide is much more abundant in the atmosphere, molecule for molecule nitrous oxide and methane are more potent greenhouse gases (Bruce et al., 1998). According to the Intergovernmental Panel on Climate Change, in terms of its ability to trap the sun's heat over 100 years, 1 kg of nitrous oxide is equivalent to about 310 kg of carbon dioxide, and 1 kg of methane is equivalent to about 21 kg of carbon dioxide (Bruce et al., 1998). Researchers are currently addressing this issue throughout Canada as it pertains to agricultural lands (National Sinks Table, 1998) and must begin similar work in wetland systems.

### Policy Issues

#### Wetlands Under Kyoto

At the Oak Hammock workshop, participants favoured including wetlands as part of agricultural and forested lands, which are well inventoried and include extensive wetland area. Carbon fluxes in wetlands are far less understood than they are in forests and agricultural areas. The forestry and agricultural sectors are globally competitive, market-driven industries supported by substantial public, private, and academic research and development infrastructures (National Sinks Table 1998). Each sector has a long and extensive research history on carbon dynamics as they relate to site and crop productivity. As it is, the National Sinks Table notes that significant knowledge gaps remain even for forests and agricultural areas. Considerable research is yet required to provide "internationally credible estimates" of verifiable changes in carbon stocks in forests, and that "large uncertainties" remain as to how much carbon can be sequestered in agricultural areas (National Sinks Table, 1998) and especially wetlands.

Central Coordinator

Progress in advocating the potential of wetlands as sinks has been sluggish because no single agency has championed the cause. No government agencies have given high priority to wetlands. A national program and a lead agency to steer research efforts and funding is urgently needed. A national coordinating body can facilitate many pressing needs. Chief impediments to ascertaining the total carbon budget include shortfalls in funding and the difficulty of international collaboration. These impediments can be overcome by raising the public and political profile of prairie wetlands and emphasizing the broad range of values inherent in wetland research and conservation. High-level political lobbying, international scientific cooperation, and interagency cooperation are all essential. Partnerships among government, non-governmental organizations, and private landowners must be fostered if efforts to create and restore wetlands are to succeed. Science and policy linkages must be established and maintained. The lead agency would focus ongoing research and refine carbon sequestration analysis, and maintain a presence in the ongoing policy debate. Ducks Unlimited Canada possesses the infrastructure, knowledge and experienced personnel that might prove suitable in such a role.

Benefits Abroad

Including wetlands in the Protocol will prove helpful well beyond Canada's borders, extending benefits of wetland creation and restoration to Third World countries. Placing wetlands in the Protocol will allow Canada to employ the Clean Development Mechanism and produce far-reaching global benefits. Promoting the conservation of wetlands in other countries has political implications internationally. It will dispel any suggestion that by pushing to broaden the definition of sinks in the Protocol, Canada is simply trying to use its vast wetlands and agricultural lands to offset industrial emission reductions. Canada's substantial holding of global wetland areas could be viewed internationally as an unfair advantage in meeting its Kyoto commitments, a perception that could potentially jeopardize the inclusion of wetland sinks in the Protocol (Lindwall, pers. com. 1999). A similar concern faces those advocating inclusion of agricultural soils. "The issue is sometimes viewed as one of North America vs. the rest of the world. Many perceive carbon soil sinks as a North American licence to avoid confronting anthropogenic emissions from energy use" (Bruce et al., 1998). Indeed, one of the objectives of the Sinks Table is to recommend additional sinks activities for inclusion in the Protocol that do not put Canada itself at an unfair “disadvantage” (National Sinks Table,1998). Integrating wetlands into the Protocol also positions Canada well for future world trade negotiations focused on the environment.

### Funding Support

The value of carbon-flux research must be made clear to obtain funding. In the private sector, many industries have adopted a “wait-and-see” attitude to the international climate change negotiations. Though some companies embrace a future where the burning of fossil fuels is vastly reduced, many are waiting to see whether Canada and other nations ratify the Kyoto Protocol before taking action. Over time, policy-makers suspect that industry will take a more definitive position. Retrofitting and corresponding emission reductions are likely to occur, making offsets like carbon sequestration a short-term solution. But in that short term, some companies are willing to support research into the offset alternatives. To secure funding, scientists must submit clear proposals with well-defined objectives, plans of action, timelines and expected results. Demonstrating to industry credible expertise, and the need for the research, will improve the likelihood of obtaining corporate support. Public-sector funding of research in agricultural and forested lands, in contrast to wetland areas, has been considerable because of the economically productive natural resource industries inherent to these areas.

### Future Negotiations

The Oak Hammock workshop reached a consensus that the National Sinks Table should include wetlands in its Options Paper. Internationally, Canada will push forward in negotiations on Article 3.4, which states: “Parties to this Protocol shall...decide upon modalities, rules and guidelines as to how, and which additional human-induced activities ...in the agricultural soils and the land-use change and forestry categories, shall be added to, or subtracted from the assigned amounts for Parties included in Annex 1.…” Canada will continue to point out that the Protocol must provide incentives to ensure the sustainability of existing forests, agricultural lands, and wetlands. Canada will continue to lobby for the inclusion of additional activities that can act as sinks and participate in seminars and workshops at SBSTA and COP5 and COP6. Through future international negotiations, Canada will also continue its strategy of publicizing the environmental benefits of including additional sinks in the Kyoto Protocol

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## Conclusion

The essential first step in efforts to gain inclusion of wetlands in the Kyoto Protocol is the development of a sound model for measuring and verifying wetland carbon cycles. The next priority is to determine ways to measure and verify 1990 benchmark levels of carbon sinks and sources and subsequent human-induced changes. If wetlands gain acceptance to the Kyoto Protocol, the Sinks Table advises that all public, private, and non-governmental interests would then need to undertake management activities that produce verifiable increases in wetland carbon stocks. The result will be a translation of science into strategic options and recommendations for strengthening or adopting stronger wetland policies.

The Kyoto Protocol could enhance wetland conservation. But wetland restoration must continue regardless. The Protocol is incidental to the need for wetlands. In the past decade, the functions, or ecological services, provided by wetlands have become increasingly recognized as important environmental and economic components of the landscape. Wetland conservation, restoration and watershed protection are becoming more prominent features of sustainable land-use planning and practice. Wetlands perform many essential ecological services, and Canada must continue to create and restore wetlands throughout the country for the benefit of all natural and human communities.

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## Appendix I: Key Dates

- The Sinks Table is working toward preparing an options paper that outlines the best way to move forward on sinks and which will be used in providing overall advice to Ministers in 1999;
- The Intergovernmental Panel on Climate Change has been instructed to prepare a Special Report on Land-Use, Land-Use Change, and Forestry that will examine the implications of dealing with sinks in a limited fashion, and any additional activities including agricultural soils, for completion by May, 2000;
- The question of whether to include more sinks in the Kyoto Protocol, and if so which sinks to include and how, will likely be finalized at COP6 in December, 2001.

## Appendix II: Measurements of Carbon Storage in Trees and Native Cover in Upland Areas Associated with Prairie and Parkland Wetlands

Table 1. Carbon contents for 12 important prairie shelterbelt species.

| | Above ground carbon | | | | Total carbon | | | |
|---|---|---|---|---|---|---|---|---|
| Species | kg/tree | t/km | t/1.6km | t/ha | kg/tree | t/km | t/1.6km | t/ha |
| Green ash | 63.2 | 25.3 | 40.5 | 50.6 | 88.5 | 35.4 | 56.6 | 70.8 |
| Manitoba maple | 85.7 | 34.3 | 54.9 | 68.6 | 120 | 48 | 76.8 | 96.0 |
| Poplar | 266.6 | 106.7 | 170.7 | 213.4 | 373.3 | 149 | 238.4 | 298.0 |
| Siberian Elm | 99.9 | 39.9 | 63.9 | 79.8 | 139.8 | 55.9 | 89.4 | 111.8 |
| White spruce | 143.4 | 41.0 | 65.6 | 82.0 | 186.4 | 53.3 | 85.3 | 106.6 |
| Colorado spruce | 101.2 | 29.9 | 46.3 | 59.8 | 131.5 | 37.6 | 60.2 | 75.2 |
| Scots pine | 80.5 | 23.0 | 36.8 | 46.6 | 104.6 | 29.9 | 47.8 | 59.8 |
| Caragana | NA | 25.9 | 41.4 | 51.8 | NA | 38.9 | 61.8 | 77.8 |
| Chokecherry | NA | 20.1 | 32.2 | 40.2 | NA | 30.2 | 48.3 | 60.4 |
| Villosa lilac | NA | 16.7 | 26.7 | 33.4 | NA | 25.1 | 40.2 | 50.2 |
| Buffaloberry | NA | 15.6 | 25 | 31.2 | NA | 23.4 | 37.4 | 46.8 |
| Sea-buckthorn | NA | 11.0 | 17.6 | 22.0 | NA | 16.1 | 25.8 | 32.2 |

Assumptions:
1) Carbon contents are provincial averages derived from values obtained from trees sampled in the brown, dark brown and black soil zones of Saskatchewan.
2) Total carbon content values assume a root to top ratio of 0.4:1 for deciduous trees, 0.3:1 for conifers and 0.5:1 for shrub species.
3) Carbon values for t/km and t/1.6 km are based on recommended spacing between trees (2.5 m for deciduous trees and 3.5 m for conifers).
4) Tonnes per hectare. Assumes a 5 metre wide shelterbelt 2.0 km long.

Table 2. Carbon contents for three native tree species (from Freedman and Keith, 1995).

| Species | Site Type | Age | Above-ground carbon (t/ha) | Total carbon (t/ha) |
|---|---|---|---|---|
| White Birch (*Betula papyfera*) | Good | 60 | 41.8 | 56.5 |
| Ash (*Fraxinus* spp.) | Medium | 60 | 21.4 | 28.9 |
| Oak(*Quercus* spp.) | Medium | 60 | 26.6 | 35.9 |

Table 3. Above-ground carbon contents for native prairie grasslands (adapted from Abouguendia, 1990).

Table 3.1. Above-ground carbon contents (t/ha) for the dry areas in the brown soil zone.

|  | Range Condition | | | |
|---|---|---|---|---|
| Range Sites | Excellent | Good | Fair | Poor |
| Clayey | 0.25 | 0.20 | 0.16 | 0.13 |
| Loamy | 0.25 | 0.20 | 0.16 | 0.13 |
| Sandy | 0.20 | 0.16 | 0.13 | 0.10 |
| Dune sand | 0.15 | 0.12 | 0.10 | 0.08 |
| Thin | 0.15 | 0.12 | 0.10 | 0.08 |
| Badland | 0.08 | 0.06 | 0.05 | 0.04 |
| Gravelly | 0.15 | 0.12 | 0.10 | 0.08 |
| Saline lowland | 0.25 | 0.20 | 0.16 | 0.13 |
| Wetland | 0.60 | 0.48 | 0.38 | 0.30 |

Table 3.2. Above-ground carbon contents (t/ha) for the moist areas in the brown soil zone.

| | Range Condition | | | |
|---|---|---|---|---|
| Range Sites | Excellent | Good | Fair | Poor |
| Clayey | 0.35 | 0.28 | 0.22 | 0.17 |
| Loamy | 0.35 | 0.28 | 0.22 | 0.17 |
| Sandy | 0.30 | 0.24 | 0.19 | 0.15 |
| Dune sand | 0.20 | 0.16 | 0.13 | 0.10 |
| Thin | 0.20 | 0.16 | 0.13 | 0.10 |
| Badland | 0.10 | 0.08 | 0.06 | 0.04 |
| Gravelly | 0.20 | 0.16 | 0.13 | 0.10 |
| Saline lowland | 0.35 | 0.28 | 0.22 | 0.17 |
| Wetland | 0.70 | 0.56 | 0.45 | 0.36 |

Table 3.3. Above-ground carbon contents (t/ha) for the nonwooded areas in the dark brown soil zone.

| | Range Condition | | | |
|---|---|---|---|---|
| Range Sites | Excellent | Good | Fair | Poor |
| Clayey | 0.45 | 0.36 | 0.29 | 0.23 |
| Loamy | 0.45 | 0.36 | 0.29 | 0.23 |
| Sandy | 0.40 | 0.32 | 0.26 | 0.21 |
| Dune sand | 0.30 | 0.24 | 0.19 | 0.15 |
| Thin | 0.25 | 0.16 | 0.13 | 0.10 |
| Badland | 0.20 | 0.08 | 0.06 | 0.04 |
| Gravelly | 0.25 | 0.20 | 0.16 | 0.13 |
| Saline lowland | 0.45 | 0.36 | 0.29 | 0.23 |
| Wetland | 0.80 | 0.64 | 0.51 | 0.41 |

Table 3.4. Above-ground carbon contents (t/ha) for nonwooded areas in the black soil zone.

| | Range Condition | | | |
|---|---|---|---|---|
| Range Sites | Excellent | Good | Fair | Poor |
| Clayey | 0.55 | 0.44 | 0.35 | 0.28 |
| Loamy | 0.55 | 0.44 | 0.35 | 0.28 |
| Sandy | 0.45 | 0.36 | 0.29 | 0.23 |
| Dune sand | 0.30 | 0.24 | 0.19 | 0.15 |
| Thin | 0.30 | 0.24 | 0.19 | 0.15 |
| Gravelly | 0.30 | 0.24 | 0.19 | 0.15 |
| Saline lowland | 0.55 | 0.44 | 0.35 | 0.28 |
| Wetland | 0.90 | 0.72 | 0.58 | 0.46 |

Table 3.5. Above-ground carbon contents (t/ha) for wooded areas.

| | Soil Zone | | | |
|---|---|---|---|---|
| Vegetation or Site | Dark Brown | Black | Dark Gray | Gray |
| ASPEN | | | | |
| Normal upland | 0.10 | 0.10 | 0.15 | 0.15 |
| Dune sand | 0.10 | 0.20 | 0.15 | 0.15 |
| Thin | n/a | 0.10 | 0.10 | 0.10 |
| CLEARED | | | | |
| Nonseeded | n/a | --- | 0.40 | 0.40 |
| OTHERS | | | | |
| Wetland | n/a | n/a | 0.40 | 0.40 |

Table 4. Above-ground carbon contents (tonnes of carbon per ha) for eight forage species in three soil zones. *

| Species | Soil Zone | AGE : 1-3 | 4-6 | 7+ |
|---|---|---|---|---|
| Alfalfa-creeping rooted | Brown | 1.2 | 0.9 | 0.7 |
| | Dark Brown | 2.5 | 1.9 | 1.3 |
| | Black | 1.8 | 1.4 | 1.0 |
| Alfalfa- taprooted | Brown | 1.3 | 1.0 | 0.7 |
| | Dark Brown | 2.6 | 2.0 | 1.3 |
| | Black | 1.9 | 1.4 | 1.0 |
| Altai wildrye | Brown | 0.8 | 0.6 | 0.4 |
| | Dark Brown | 1.6 | 1.2 | 0.8 |
| | Black | 1.5 | 1.0 | 0.7 |
| Crested wheatgrass – diploid | Brown | 1.0 | 0.8 | 0.6 |
| | Dark Brown | 1.7 | 1.3 | 0.9 |
| | Black | 2.4 | 1.8 | 1.2 |
| Crested wheatgrass – tetraploid | Brown | 0.9 | 0.7 | 0.5 |
| | Dark Brown | 1.7 | 1.3 | 0.9 |
| | Black | 2.6 | 1.9 | 1.3 |
| Meadow bromegrass | Brown | 0.8 | 0.6 | 0.4 |
| | Dark Brown | 1.3 | 1.0 | 0.7 |
| | Black | 1.9 | 1.4 | 1.0 |
| Russian wildrye | Brown | 0.9 | 0.7 | 0.5 |
| | Dark Brown | 1.1 | 0.8 | 0.6 |
| | Black | 1.1 | 0.8 | 0.6 |
| Smooth bromegrass | Brown | 0.8 | 0.6 | 0.4 |
| | Dark Brown | 1.7 | 1.3 | 0.9 |
| | Black | 2.3 | 1.7 | 1.2 |

* adapted from Kirychuk and Tremblay (1995).

Table 5. Predicted above-ground carbon content ranges for four cover types.

| Cover type | From | To |
|---|---|---|
| Native grassland | 0.04 t/ha | 0.9 t/ha |
| Tame grassland | 0.4 t/ha | 2.6 t/ha |
| Native tree | 31.2 t/ha* | 41.8 t/ha |
| Planted tree | 22.0 t/ha | 213.0 t/ha |

* carbon values for some small native shrubs not yet available.

## Appendix III: Oak Hammock Workshop Agenda

Final Agenda and Speakers

**April 18, 1999** **International Inn - Winnipeg**

I. 7:00 - 9:00 p.m. Icebreaker Reception

**April 19, 1999** **Oak Hammock Marsh**

7:30 a.m. Bus leaves International Inn for Oak Hammock Marsh

II. 8:30 - Noon Plenary Session
Chair – Ed Tyrchniewicz
International Institute for Sustainable Development

1. Carbon Sinks Issues – Wayne Lindwall, Agriculture and Agrifood Canada
2. Overview of Wetlands and Climate Change – Doug Chekay, Ducks Unlimited, and Allen Tyrchniewicz, International Institute for Sustainable Development
3. Report on Downsview Meeting on Carbon Flux Process – Rick Bourbonniere, National Water Research Institute
4. Carbon Fluxes in Wetlands – Henry Murkin, Institute for Wetland and Waterfowl Research, and Richard Robarts, WHO-UNEP Collaborating Centre for GEMS/Water
5. Conceptual Framework for Research into Wetlands and Carbon Sequestration – Al Moulin, AAFC, and Lawrence Townley-Smith, PFRA
6. Charge to the Workshop Groups

III. 1:30 - 5:00 p.m. Individual Workshop Groups

A. Physical and Biotic processes affecting carbon cycling in wetlands.
Facilitator: Henry Murkin. Rapporteurs: Lisette Ross and Rhonda McDougal.
B. Physical and biotic processes affecting carbon cycling in riparian zones.
Facilitator: Jeff Schoenau. Rapporteur: Bob Turnock.
C. Remote sensing and modelling for inventory of carbon related to wetlands.
Facilitator: Al Moulin. Rapporteur: Ken Belcher.
D. Information needs for policy development in wetlands and carbon sequestration.
Facilitator: Bernie Ward. Rapporteur: Jonathon Scarth.

IV. 5:30 - 8:30 p.m. Reception, banquet, and light entertainment

**April 20, 1999** **Oak Hammock Marsh**

7:30 a.m. Bus leaves International Inn for Oak Hammock Marsh

V. 8:30 - 10:00 a.m. Plenary Session

1. Group Reports from Previous Day and discussion
2. New Charge to the Workshop Groups

VI. 10:00 - Noon Individual Workshop Groups (same groups, facilitator and rapporteur as previously)

VII. 1:00 - 3:30 p.m. Plenary Session

1. Group Reports from Morning
2. Reaction Panel: What Have We Learned and Where Do We Go From Here?
    - John Hastie, Valdrew Consulting
    - Clayton Rubec, Environment Canada
    - Barry Warner, Waterloo University
    - Hague Vaughan, Environment Canada
    - Jim McCuaig, CIDA and Wetlands International
    - Robert Stedwill, SaskPower
    - Wayne Lindwall, Agriculture and Agrifood Canada

3:30 p.m. Bus leaves Oak Hammock Marsh for International Inn

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