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Carbon sequestration potential of agroforestry practices in the L’Ormière River watershed in Quebec

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Abstract

The purpose of this study was to assess the economic and technical feasibility of implementing agroforestry practices on farmland for the purpose of Carbon sequestration. This exercise was carried out within the geographic context of an agricultural watershed, specifically the L'Ormière River watershed in Quebec. The specific objectives were to determine the potential for establishing windbreaks and riparian forest buffers within the watershed, to quantify the associated level of carbon sequestration and to determine whether the financial benefits generated by the resulting emission reduction credits would be sufficient incentive for the adoption of such agroforestry practices.

A spatial analysis of the L'Ormière River watershed suggested that riparian forest buffers could be established on an area of 144 ha (equivalent to 20 m wide X 2 sides X 36 km) and windbreaks on an area of 47.5 ha (equivalent to 9 m X 53 km). The total area available for these plantings, 191.5 ha, represents a 34% increase in the wooded area within the L'Ormière River watershed, itself an area of 3,000 ha (30 km^2). Over a period of 25 years, one hectare of land devoted to riparian forest buffers would be able to sequester 587 tonnes of CO_2 equivalent (12 odt biomass/ha-year), whereas the sequestration potential of one hectare of land planted to windbreaks would be 782 tonnes of CO_2 equivalent. At the watershed scale, over a 25-year-period, the total Carbon sequestration potential has been established at more than 120 thousand tonnes of CO_2 equivalent, which, at $5 per tonne CO_2, works out to potential revenue of approximately 600 thousand dollars from the sale of Carbon emission reduction credits.

The main goal of the study was to assess whether Carbon sequestration would provide sufficient incentive for agricultural producers to adopt agroforestry practices on their farms. Under current market conditions and based on the assumptions made in this study, it appears that sequestration potential does not provide sufficient incentive. This is because the annual revenue from the sale of Carbon emission reduction credits would be only about $435 per farm for the riparian forest buffer scenario and $235 per farm for the windbreak scenario. These modest earnings are unlikely to influence producers' decisions on whether to adopt the agroforestry practices studied.

Based on the typical farm analyzed for two types of farms, assuming 10 dairy farms and 11 grain farms in the watershed, and the 25-year horizon used, it was found that the riparian forest buffer systems would result in a loss of income of $59,200 for individual producers, if they receive government financial assistance, a cost-share of 70% for the purchase and establishment of the trees, or a loss of $87,600 without such assistance. Although the economics of these riparian buffers could be improved in various ways, the supplemental income from the sale of emission reduction credits would not help to make the systems profitable. By contrast, it was found that, over the same 25-year period, windbreaks would

generate supplemental income of $35,700 for individual producers with government financial assistance, or $22,000 without.

The findings show that the level of CO_2 sequestration associated with riparian forest buffers and windbreaks is too low to warrant the adoption of such practices. Carbon sequestration in itself is not a sufficient incentive for producers to establish windbreaks or riparian forest buffers. Based on the assumptions applied in the study, the sale of carbon credits is not an economic argument that carries weight in terms of the adoption of agroforestry practices. Instead, because of their multi-functionality, their adoption will rest on a combination of economic and environmental considerations.

The cost-benefit ratios were found to vary widely for the two agroforestry practices. For example, the establishment of riparian forest buffers appears to result in a net loss for agricultural producers, whereas the planting of windbreaks generates significant gains for producers because of the associated increase in crop productivity.

It follows that Carbon sequestration potential is not the sole attraction of agroforestry. The promise of agroforestry practices relates more to other ecological goods and services which were not taken into account in this study, but which can include reductions in non-point source pollution, erosion control, the opportunity to increase or maintain biodiversity and landscape enhancement. The only agroforestry benefits that were examined in the study were increases in agricultural yields (for windbreaks) and fibre production.

Nevertheless, agricultural producers can contribute to carbon sequestration through a variety of practices on their farms. Even if a given agroforestry practice does not generate enough carbon credits to justify participation in the emissions trading market, a broader set of such practices might generate a volume of credits that translates into significant supplementary income for producers. Research into a broader range of agroforestry practices would provide the opportunity to examine this possibility in greater depth. The fact remains that, on an individual basis, agricultural producers cannot generate enough Carbon emission reduction credits to participate in the emissions trading market because their transaction costs are too high in relation to the revenue that can be earned from the sale of carbon credits. Therefore, consideration should be given to cooperative approaches that would make it possible to aggregate producers' Carbon emission reduction credits and reapportion the proceeds of the sale of those credits among the participants.

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Introduction

The Kyoto Protocol of 1997 marked a turning point in efforts to tackle climate change at the international level. Under this protocol, a number of countries, including Canada, made a commitment to limit their greenhouse gas (GHG) emissions or to reduce them by a certain percentage relative to the 1990 level during the 2008–2012 period. Canada pledged to reduce its GHG emissions by 6% from the 1990 level, which translates into a real reduction of 30%, or 260 million tonnes of CO_2, from the 2005 level, taking into account changes in economic activities.

Furthermore, in order to attain their national reduction targets under Kyoto, various countries, including Canada, can implement certain mechanisms set out in the Kyoto Protocol, including emissions trading systems. In concrete terms, this involves imposing a cap on the emissions of large industrial emitters and creating an offset system that allows emission reduction credits to be exchanged within a given economic sector or between one sector and another sector in which emissions are below the cap.

The agriculture sector or the forestry sector, for instance, might find it advantageous to develop Carbon sequestration projects and sell the resulting emission reduction credits to large industrial emitters. Emitters would be willing to purchase credits from these sectors when the price of those credits is lower than the cost of implementing the requisite measures to reduce their own emissions.

In view of this possibility, it is conceivable that individual agricultural producers would be interested in implementing agricultural practices, particularly agroforestry practices, that can help to remove greenhouse gases from the atmosphere. The Carbon reduction credits earned from such practices could be sold to large emitters that have reached their allowable emission limits.

The Canadian government set up the Greenhouse Gas Mitigation Program for Canadian Agriculture (GHGMP) with the aim of beginning the process of reducing GHG emissions (and enhancing carbon sequestration) from agriculture through soil, nutrient and livestock management measures. The program was a starting point for attaining the objective of reducing GHG emissions from agriculture—5.8 million tonnes of CO_2 equivalent per year[1]—during the Kyoto commitment period from 2008 to 2012. It had several thrusts: identifying best management practices that reduce GHG emissions; increasing public awareness; and encouraging producers to adopt suitable soil, nutrient and livestock management practices.

[1] This value represents the estimated sector potential; range could be anywhere from 3 to 10 Mt depending on practice adoption

Under the program, studies were undertaken to assess the effect of given practices in relation to GHG mitigation and the results were harnessed to enhance existing practices.

The present study was undertaken to assess the economic, technical and environmental feasibility of implementing agroforestry practices with a view to Carbon sequestration. Specifically, the objective was to determine whether the financial benefits generated by the resulting emission reduction credits would provide sufficient incentive for agricultural producers to adopt such agroforestry practices. The analysis was carried out in the geographic context of the L'Ormière River watershed, which is located within the Maskinongé River watershed. The study also provides an estimate of the Carbon sequestration potential at the watershed scale and the associated economic impacts.

The study stared through a review of existing incentives for the adoption of agroforestry practices that contribute to Carbon sequestration. These agroforestry practices are described, and the technical and environmental potential associated with those practices was assessed in relation to the L'Ormière River watershed. This information was used to calculate the Carbon sequestration potential at the watershed level which fed into a cost-benefit analysis for the adoption of the selected agroforestry practices. This analysis was completed by an economic evaluation of the Carbon sequestration potential of those practices at the watershed level.

1. Measures for promoting agroforestry practices that support Carbon sequestration

Canada and other countries can implement a variety of direct or indirect measures to encourage the adoption of agroforestry practices that sequester or remove GHGs from the atmosphere.

1.1. Kyoto Protocol

The Kyoto Protocol of 1997 sets out a time frame for the reduction of anthropogenic GHG emissions, considered to be the main cause of global warming. In ratifying the Protocol, 39 industrialized countries, including Canada, made a commitment to reduce their CO_2 emissions by an average of 5.2% annually relative to the 1990 baseline during the 2008–2012 commitment period.

The Kyoto Protocol also presents several mechanisms intended to assist participating countries achieve their reduction targets. For example, under an *Emissions Trading System*, industrialized countries that ratified the Kyoto Protocol and pledged to reduce their GHG emissions can purchase emission reduction credits from other countries that have not yet reached their emissions quota. Another Kyoto mechanism, *Joint Implementation*, allows these countries to trade the credits they earn from carrying out emission reduction projects. Finally, under the *Clean Development Mechanism*, industrialized countries can earn reduction credits by carrying out GHG emission reduction projects in developing countries.

In addition, every country that has an emission cap can try to meet its reduction target by implementing various measures such as a system of tradable offset carbon credits. This approach involves setting emission limits for major industrial emitters and allowing GHG emission reduction credits to be traded within a given sector. An offset system could also be put in place for the benefit of sectors whose emissions are below the allowable limit.

Once an offset system is in place, agricultural producers could implement Carbon sequestration projects and sell their reduction credits to large industrial emitters. Emitters would be willing to buy credits from the agriculture sector when the price of those credits is lower than the cost of implementing measures to reduce their own emissions.

Canada has explored the possibility of setting up an offset cabon credit trading system but it has not yet done so. The European Union already has an operational emissions trading scheme; some U.S. states have also set up systems of this type (Chicago, Illinois and California), but these U.S. carbon markets are operating outside the Kyoto Protocol.[2]

Finally, other possible approaches include taxation measures, greenhouse gas emission standards and awareness projects supporting voluntary efforts to cut GHG emissions.

1.2. Examples of programs in other countries

In the United States, the Environmental Quality Incentives Program (EQIP) provides producers in certain watersheds with financial assistance for adopting environmentally beneficial agricultural practices. The assistance covers 75% of eligible costs and up to 90% for beginning producers, with payments limited to an total of $450,000 per farm during the period of the program. These financial incentives are intended to encourage producers to implement conservation practices that they would not otherwise adopt. The program objectives include reducing greenhouse gas emissions, particularly N_2O. Another initiative, the Agricultural Management Assistance (AMA), was designed to help producers who voluntarily adopt management methods to achieve various goals such as sequestering or removing GHGs (e.g., through the establishment of windbreaks). The maximum amount of assistance provided is $50,000 per fiscal year.

In France, individual agricultural producers can enter into sustainable agriculture contracts (Contrats d'Agriculture Durable, CAD) with the government that entail a voluntary five-year commitment to implement environmentally beneficial agricultural practices in return for financial compensation. Although this is a national program, the measures to be implemented are defined on a regional basis. They include certain agroforestry practices that contribute to Carbon sequestration, such as the establishment of windbreaks or riparian forest buffers. An average of 27,000 euros is awarded over the term of each contract.

In Europe, the Luxembourg Agreement, signed by the Agriculture Ministers of the European Union in June 2003, integrates the principle of cross-compliance into the Common Agricultural Policy (CAP), which governs the EU single farm payments made to producers for implementing nationally defined environmentally beneficial practices, some of which help to mitigate GHG emissions.

1.3. Canadian programs

In Canada, the federal government's Agricultural Policy Framework (APF) has a strong environmental focus and seeks to promote environmentally sustainable agriculture. Quebec's Prime-Vert program is

[2] The United States did not ratify the Kyoto Protocol.

administered by the Quebec Department of Agriculture, Fisheries and Food (MAPAQ) and receives funding from the APF. Prime-Vert promotes the adoption of beneficial management practices on farms, including practices that help to mitigate GHG emissions, and provides support, enabling farms to comply with environment-related acts and policies. The program has three main thrusts: management of manure and pesticides; conservation of soil, water and air; and development and extension of agri-environmental knowledge. Both technical and financial assistance are provided.

Among the beneficial management practices eligible for financial assistance are agroforestry practices that can contribute, either directly or indirectly, to a reduction in GHG emissions or to carbon sequestration.

The Prime-Vert program includes some measures intended to reduce non-point source pollution with the primary goal of improving water and air quality. Assistance is available to enable farms located in specific watersheds to implement practices that can support Carbon sequestration: riparian zone management, windbreak establishment and winter cover crop establishment. The financial assistance covers up to 70% of the eligible costs, with a cap of $30,000 per farm over the term of the program.

Prime-Vert also covers cooperative projects aimed at reducing non-point source pollution. Although the main objective of these projects is to improve water quality, some of the measures included in this program component can play a role in Carbon sequestration. The financial assistance covers up to 20% of the eligible costs of implementing practices related to riparian zone management (creation of riparian buffers by planting shrubs and trees) or windbreak establishment. Eligible farms are those participating in the Greencover Canada program.

Greencover Canada, another program funded under the Agricultural Policy Framework, is aimed at promoting the implementation of environmentally beneficial management practices in exchange for financial compensation. One of the program objectives is to increase carbon sequestration in the soil. The program also promotes practices to improve water quality that also contribute to greenhouse gas mitigation.

Greencover Canada encompasses practices such as the planting of forage crops, trees and shrubs in the riparian strip in order to create buffer zones, and the establishment of shelterbelts. In the Equivalent Agri-Environmental Planning (or group planning) component, every project must be submitted by at least two producers located in the same watershed, and the applicants must have an environmental farm plan (EFP) (in Quebec, an agri-environmental support plan). Financial assistance provided under Greencover Canada covers up to 50% of the eligible expenses, with a total payment of up to $20,000 per farm for the establishment of riparian buffer strips and up to $10,000 per farm for the establishment of shelterbelts.

Changes to the program made in April 2006 meant that farms participating in a joint project under Greencover Canada became eligible to receive the 20% supplementary financial assistance from the Prime-Vert program. The total amount of assistance available under the two programs for cooperative projects thus covers up to 70% of eligible expenses.

The Greenhouse Gas Mitigation Program for Canadian Agriculture (GHGMP), originally established under the Government of Canada 2000 Action Plan on Climate Change, also sought to promote awareness and knowledge transfer, focussing on the economic and technical aspects of agricultural practices that help to mitigate GHG emissions.

In Quebec, GHGMP funding was administered by the Centre pour le développement de l'agriculture au Québec (CDAQ). The funding was earmarked for on-farm activities and trials that promote agricultural practices contributing to greenhouse gas mitigation, as well as for extension activities. In 2004, trials were carried out at 260 sites in Quebec on various themes: direct seeding, conservation practices, types of nitrogen fertilizer and application rates for corn crops; testing of manure spreading periods (for corn); management of solid and liquid manure; tillage methods; green manure projects; and manure spreading sites.

Finally, the Financière agricole du Québec (FAQ), the result of a 2001 merger between the Régie des assurances agricoles du Québec (RAAQ) and the Société de financement agricole (SFA), offers a range of financial tools designed to support the financial and economic stability of farms. Some of these financial assistance arrangements are contingent on the implementation of environmentally beneficial practices, in keeping with ecoconditionality (i.e., cross-compliance) strategies. Aside from certain mandatory standards pertaining to the type of seed to be used and seeding schedules, ecoconditionality often translates into a set of recommendations for environmentally sound practices that producers are expected to implement; however, if they fail to do so, they do not lose their financial assistance.

1.4. Main findings

This review of existing measures demonstrates that in Canada at present, neither the federal nor provincial government offers assistance intended specifically to promote the adoption of agroforestry practices with the primary aim of sequestering Carbon. Many of the existing measures centre on practices that help improve water quality or soil quality; Carbon sequestration is viewed as a collateral, or secondary, benefit of these approaches. Financial assistance under the Prime-Vert program, for example, is intended for watersheds with degraded water quality. Air quality issues are difficult to address as they reach beyond watershed boundaries and effects from GHG emissions can be felt at great distance from their source.

At present, there are no programs that provide compensation specifically for the adoption of agroforestry practices that sequester Carbon. However, some programs provide funding for measures that can contribute to carbon sequestration. This is also true for the existing programs at the international level. Carbon sequestration is one of many environmental benefits generated by agricultural and agroforestry practices aimed primarily at improving water quality in specific watersheds. Water quality is the main focus of the U.S. programs described above.

Regarding initiatives carried out in other countries, the French program is contractual in nature whereas the U.S. program is voluntary, and both are based on a set of practices designed to support the attainment of a number of environmental objectives simultaneously. In Canada, the applicable measures tend to be implemented separately, instead of being integrated into an overarching approach for individual farms. By contrast, France and the United States apply what is essentially a comprehensive approach by encouraging agricultural producers to implement a set of applicable measures on their farms during a given time period.

Programs more specifically related to practices that contribute to Carbon sequestration, such as GHGMP, were limited to the investigation and promotion of these practices through on-farm trials and extension activities. Extension activities are very important given the gaps in current approaches for measuring Carbon sequestration achieved through agricultural and forestry practices. The uncertainty surrounding carbon sequestration measurement and mitigation can hinder the adoption of appropriate methods on farms and increase project costs.

The most attractive financial incentive for encouraging adoption of Carbon sequestration practices by agricultural producers might be an offset system that would enable them to sell emission reduction credits to major industrial emitters.

2. Implementation of agroforestry practices for Carbon sequestration in the L'Ormière River watershed

The main purpose of this study was to assess the economic, technical and environmental feasibility of encouraging producers to implement agroforestry practices that contribute to greenhouse gas sequestration. The analysis uses hypothetical representative farms (average farm for region) and takes into account the soil characteristics, agricultural activities and other conditions existing in the upstream and downstream regions of the targeted watershed. Specifically, the goal was to determine whether carbon offset credits earned from agroforestry practices would provide sufficient incentive for producers to implement these practices. The geographic setting of the study is the L'Ormière River watershed which is located within the Maskinongé River watershed. Watershed management is the appropriate level for a comprehensive analysis of the agroforestry practices to be implemented and for the use of a cooperative approach. In this section the procedure followed in describing the representatiave farm and selecting the agroforestry practices is explained.

Our decision to analyze the economic impacts of agroforestry practices using representative farms is tied to the economic evaluation method that was adopted: the partial budget approach. This decision is also justified by the fact that the adoption of agroforestry practices generates costs and benefits that cannot be dissociated from the characteristics of the farm where those practices are to be applied.

2.1. Description of representative farm and selection of agroforestry practices

The L'Ormière River watershed encompasses two zones that can be readily differentiated in terms of their geomorphology, soil characteristics and agricultural activities; these two zones are separated by Saint-Barthélemy terrace. The upstream zone is characterized by clay soils (Rideau clay) and the river is bordered by steep banks which are typically unvegetated, making them prone to water erosion. The agriculture sector in this part of the watershed is characterized primarily by livestock production, particularly dairy farms, along with forage crops. Downstream, extending to the river mouth near the town of Maskinongé, the river flows through land characterized by fairly recent, loamy and fertile soil (Chaloupe and Berthier alluvion series), used primarily for grain corn and soybean production. In this part of the watershed, the riverbanks are not steep. These differences show the importance of taking into account the characteristics of the targeted area when selecting suitable agroforestry practices.

Agricultural and agroforestry practices that contribute to Carbon sequestration include the following: (1) increase in perennial herbaceous crops (e.g. hay and pasture) in the rotation; (2) establishment of woody crops such as Christmas trees, fast-growing willows or hybrid poplars; (3) inclusion of legume crops in the rotation, (4) planting of windbreaks and riparian forest buffers; and (5) environmentally sound livestock waste and fertilizer management.

In this study, the agroforestry practices contributing to carbon sequestration were selected using the following criteria:

- The technical feasibility of implementing such practices in the L'Ormière River watershed, taking into account the existing environmental conditions (soil characteristics, agricultural activities, etc.);
- Recognition of the real Carbon sequestration capacity of agroforestry practices as reported in the scientific literature and ease of quantifying sequestration capacity;
- The existence of scientific methods permitting quantification of Carbon sequestration associated with agroforestry practices;
- The ease of implementing and monitoring the proposed practices;
- The possibility of conducting an economic analysis of the cost and benefits for individual farms.

Based on the above criteria, two hypothetical representative farms were identified. The first representative farm, found in the upstream portion of the watershed, is a typical dairy farm, as described by the Centre de référence en agriculture et agroalimentaire du Québec (CRAAQ).[3] Such a farm has 61 cows and covers 114 ha, with 30% of the acreage devoted to field crops and 70% to forage crops. The second representative farm, in downstream portion of the watershed, is a field crop (grain corn and soybeans) farm, according to the description developed by the Financière agricole du Québec for calculating provincial farm income stabilization insurance (ASRA). This field crop farm covers 286 ha.

For each representative farm, the adoption of agroforestry practices that contribute to Carbon sequestration was evaluated. Based on the environmental characteristics (steep banks, major water erosion problems, etc.) of the upstream portion of the watershed, our assessment focussed on the establishment of riparian forest buffers (planting of trees or shrubs in the riparian strip to support the production of ecological goods and services). In the downstream section, characterized by lowlands and grain corn production, windbreak establishment was determined to be the most appropriate agroforestry option. Note that both of the proposed agroforestry systems are simple ones that do not involve the production of understory crops, small fruits, nuts, etc.

[3] CRAAQ, 2006. Références économiques. Entreprise laitière. Analyse comparative provinciale 2004.

The table below shows the proposed agroforestry practices and the corresponding model farms.

TABLE 1. REPRESENTATIVE FARMS AND PROPOSED AGROFORESTRY PRACTICES

RepresentativeFarm	**Agroforestry Practices that Contribute to Carbon Sequestration**
Dairy farm	Riparian forest buffer*
Field crop production (grain corn and soybeans)	Windbreaks

Source: ÉcoRessources Consultants

* A riparian forest buffer system entails the planting of trees or shrubs in the riparian zone based on a specific design with the aim of producing various ecological goods and services.

2.1.1. Establishment of riparian forest buffers for Carbon sequestration on a typical dairy farm in the upstream portion of the watershed

Besides helping to improve water quality, control erosion and maintain the biodiversity associated with the trees planted in the riparian strip, riparian forest buffers support carbon fixation in plant tissues. The contribution that forests make to Carbon sequestration is widely recognized in the scientific literature, providing justification for the selection of this agroforestry practice in the present study.

In Quebec, the Protection Policy for Lakeshores, Riverbanks, Littoral Zones and Floodplains (PPRLPI) defines a riverbank as "a strip of land bordering a lake or watercourse and extending inland from the high-water mark." The manadatory width of shore or bank to be protected (on both sides of the stream) is measured horizontally and generally is,

- At least 10 m wide,
  - ⇒ where the slope is less than 30%, or
  - ⇒ the slope is greater than 30% with a bank less than 5 m high.
- At least 15 m wide,
  - ⇒ where the slope is continuous and greater than 30%, or
  - ⇒ the slope is greater than 30% with a bank over 5 m high.

In agricultural areas, the width of the buffer strip is defined in the municipal by-laws. Where no such definition exists, the default definition for the buffer strip is a zone of vegetation at least three metres wide measured from the high-water mark. In addition, under Quebec's Agricultural Operations Regulation, restrictions are imposed on the agricultural practices permitted within the buffer strip, such as a prohibition on spreading fertilizer. In terms of accounting for the gains and losses associated with the trees planted in the riparian strip, it was assumed that this three-metre-wide protective strip is currently maintained as prescribed and that producers do not earn income from it.

Planting trees in the riparian zone is intended to promote Carbon sequestration. The resulting woodland must therefore comply with the definition set out under the Kyoto Protocol, which states that a forest (minimum unit for Carbon sequestration) is an area of land of 0.5 to 1.0 ha with tree crown cover (or equivalent stocking area) of more than 10–30% with trees that have the potential to reach a mean height of 2 m to 5 m at maturity. According to the Quebec Department of Natural Resources (MRNF), the recommended width of a riparian forest buffer for the purposes of CO_2 sequestration is 20 m or more.

In practice, the width of the riparian forest buffer will depend largely on the characteristics of the environment (slope, soil type, cultural practices, etc.). However, in order to assess the economic feasibility of establishing a riparian forest buffer on a farm, it is necessary to define an average width (or typical width) of such a system.

If the PPRLPI definitions and the steep banks characterizing the upstream portion of the L'Ormière River watershed (> 30%) are considered, the proposed riparian forest buffer should be at least 15 m wide. Taking into account the riparian strip's contribution to Carbon sequestration under the Kyoto Protocol, the typical riparian forest buffer will have a width of 20 m in this analysis.

The life expectancy of a plantation is equal to the lifespan of the slowest-growing species. Here, we propose a riparian planting composed of hybrid poplar (*Populus*) and red ash (*Fraxinus pennsylvanica*). The life expectance of this tree combination, then, is determined by red ash which is greater than 25 years. Carbon credits can therefore be earned over the long term,[4] generating higher prices than would be the case for short-term credits.[5]

Table 2 shows the relative value of non-permanent carbon credits (such as those associated with forestry projects) depending on the lifespan of the project. The value of the short-term credits (5 years) is equal to 14% of the value of permanent credits, based on a discount rate of 3%; however, their value would be equal to as much as 35% of the value of permanent credits, given a discount rate of 9%. Over a 25-year

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4 Carbon reduction credits earned in forestry or agroforestry projects are considered to be non-permanent credits, because sequestration is reversible (the sink can turn into a source).

5 According to Olschewski and Benítez (2005), the price of temporary credits is calculated from the price of permanent credits using the formula:

$$P_{\text{temporary credits}} = P_{\text{permanent credits}} (1 - 1/(1+\text{discount rate})^{\text{Time}})$$

period, the value of temporary credits ranges from 52% to 88% of the value of permanent reduction credits, depending on the discount rate applied. In the analyses for this report, a discount rate of 8.48% was used

TABLE 2. VALUE OF NON-PERMANENT CARBON CREDITS RELATIVE TO PERMANENT CREDITS

Discount Rate	Relative Value of Carbon Credits Depending on the Expiry Date (%)				
	5 Years	10 Years	15 Years	20 Years	25 Years
3	14	26	36	45	52
5	22	39	52	62	70
7	29	49	64	74	82
9	35	58	73	82	88

Source: Olschewski and Benitez, 2005

2.1.2. Establishment of windbreaks for Carbon sequestration on a typical grain farm in the downstream part of the watershed

In the downstream portion of the watershed, on the lowlands, a typical farm specializes in field crop production (grain corn and soybeans), according to the characterization used by the Financière agricole du Québec for calculating farm income stabilization insurance. Specifically, the average farm has 202.6 ha of grain corn and 83.3 ha of soybeans.

The yields used by the Financière agricole to calculate compensation are as follows:

- Grain corn: 7.2 mt/ha
- Soybeans: 3.0 mt/ha

In order to assess the economic feasibility of planting windbreaks on a farm, the typical windbreak system must be defined in relation to several characteristics. First, in order for a windbreak to be considered a carbon sink, it must meet the Kyoto Protocol definition of a forest. In addition, although single-row windbreaks can be effective, multiple-row ones provide better habitat for wildlife and they can trap larger amounts of snow, which leads to less of a delay for field operations in the spring.

For effective field protection (control of wind erosion, uniform distribution of snow, more effective water use and reduction in crop damage), the windbreak system will be composed of a series of windbreak rows separated by a distance equal to about 15 times the expected height of the trees. Given an expected mean height of 20 m (as is the case for some tree species potentially suitable for the L’Ormière River watershed, such as hybrid poplar and red ash), the distance between the rows should be 300 m. However, based on the cadastral data available on the parcelling of land within the L'Ormière River watershed, we calculated a distance of 150 m between each windbreak row. The density of the windbreak planting is estimated to be 1,200 stems/ha.

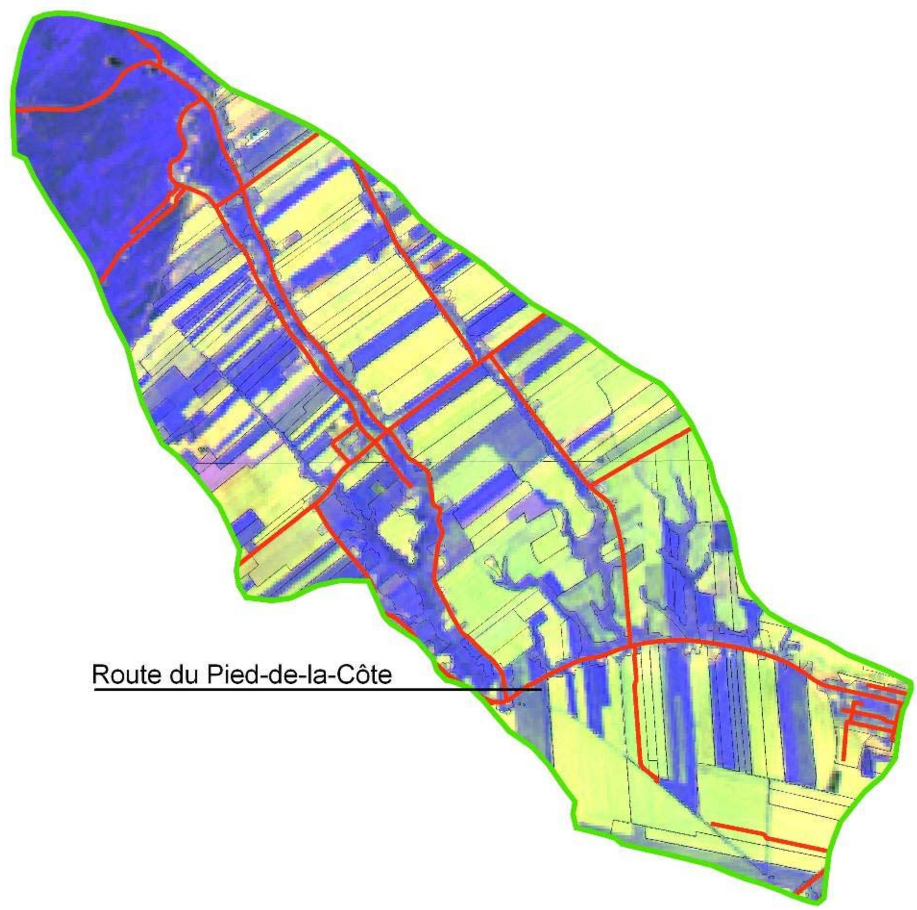
The choice of site for the windbreaks should take into account such factors as prevailing wind direction and the characteristics of the farmland in the downstream part of the watershed, particularly the drainage system.

Therefore, for the economic analysis, the selected technical configuration is a windbreak composed of three rows of trees spaced 9 m apart and a distance of 150 m between windbreaks. Given that under the Kyoto Protocol, a forest must cover an area of at least 0.05 ha, each windbreak must be at least 55.5 m long. Finally, considering that on the representative farm 70% of the land area is planted to grain corn and 30% to soybeans, a total of 10 windbreaks will be required and, on the whole, 7 will be on land devoted to grain corn and the other 3 on land devoted to soybean production.

3. Technical and environmental potential of agroforestry in the L'Ormière River watershed

A spatial analysis was conducted for identifying the agroforestry potential of the L'Ormière River watershed. It consisted in assessing the area of the plantings resulting from the implementation of the two proposed agroforestry systems, that is, windbreaks and riparian forest buffers. Figure 1 shows the L'Ormière River watershed, an area of 30 km^2 and an agricultural zone that can be divided into two sectors separated by Pied-de-la-Côte range.

FIGURE 1. THE L'ORMIÈRE RIVER WATERSHED, LANDSAT 7TM IMAGE (BAND PAIRS 7-3-4)



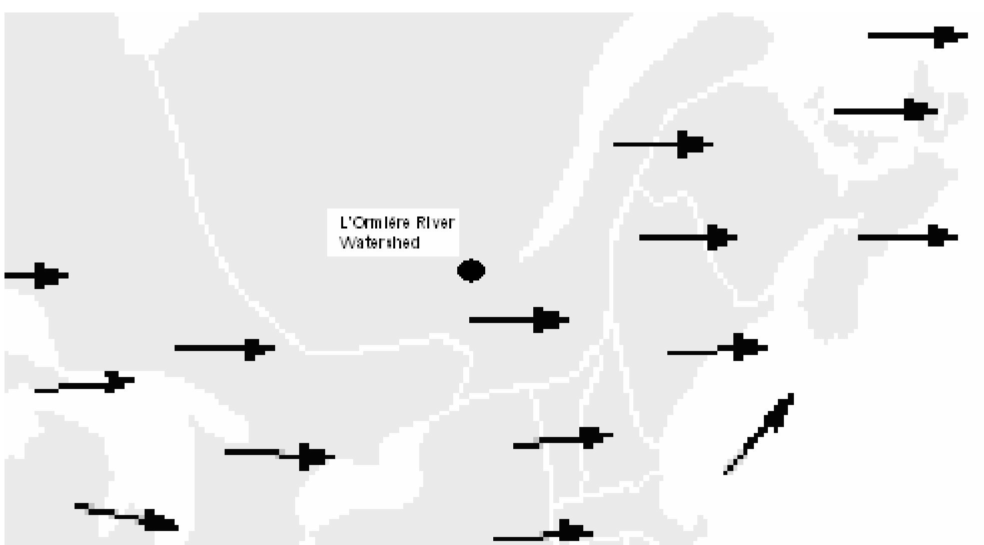
Source: Base de données des cultures généralisées (BDCG), Financière agricole, 2006

3.1. Methodology used for the spatial analysis

In order to assess the potential for implementing the selected agroforestry practices according to the proposed planting designs, it was necessary to define the existing geographic objects constraining the choice of sites available for those practices.

- In the case of riparian forest buffers, natural and generalized streams were used as a basis for site selection.
- In the case of windbreaks, the cadastral map for agricultural land provided by the Financière Agricole du Québec was used, specifically for grain corn and soybean crop production areas. The prevailing wind direction was considered in the selection of sites for windbreaks in order to orient them perpendicular to wind direction. For actual windbreak establishment, a more precise investigation would be required to account for wind orientation at the local scale.

FIGURE 2. MAP OF PREVAILING WINDS



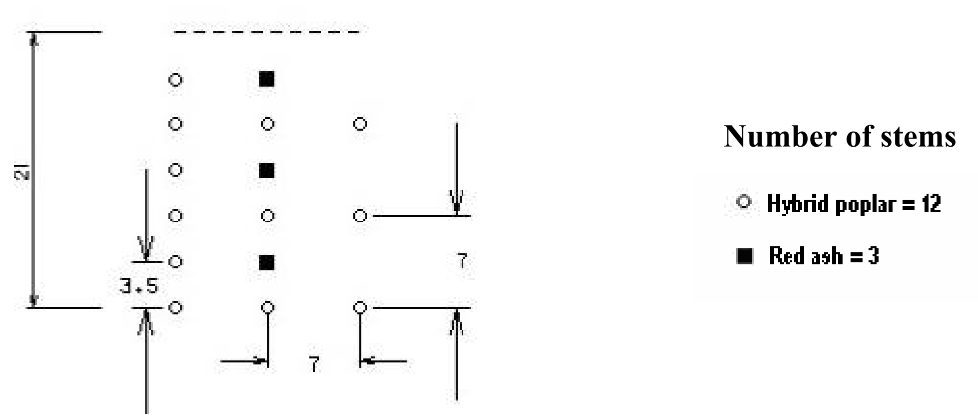
Source: Environment Canada

Once the geographic objects were identified, areas with planting constraints were identified. These parcels were subtracted from the areas generated for the windbreaks and the riparian forest buffers. Figure 3 shows the various vegetation-related constraints, such as woodlands and existing plantings, as well as the buildings and roads.

FIGURE 3. PLANTING CONSTRAINTS

Source: Charland, P., 2007 for Econova

The planting design is based on a model developed during experimental work carried out at the Portageur Enr. tree farm (2003), which is located in the L'Ormière River watershed, and on the approach adopted for the economic analysis. To simplify the study, two candidate species were selected for the riparian forest buffers and the windbreaks: hybrid poplar and red ash. The strips making up the riparian forest buffer are arranged on both sides of the stream. Each strip is composed of three tree rows with a first row of poplars to facilitate harvesting. Similarly, the windbreaks are composed of three rows of trees, in keeping with the proposed planting models.



To identify potential planting areas for the selected agroforestry practices, buffer zones were created around the linear objects representing the windbreak rows and the streams. However, applying a buffer to streams without taking sinuosity into consideration can result in a suboptimal configuration for the actual plantings. Consequently, the streams were generalized to smooth the shape of the riparian forest buffers. In addition, as illustrated in Figure 4, the different sets of riparian strips were merged in order to calculate the potential surface areas. Whereas the original strips accounted for 135 ha, the merged strips cover a total area of 144 ha, an increase of 6%.

FIGURE 4. GENERALIZATION OF STREAMS TO CREATE RIPARIAN FOREST BUFFER SYSTEMS

Source: Charland, P., 2007 for Econova

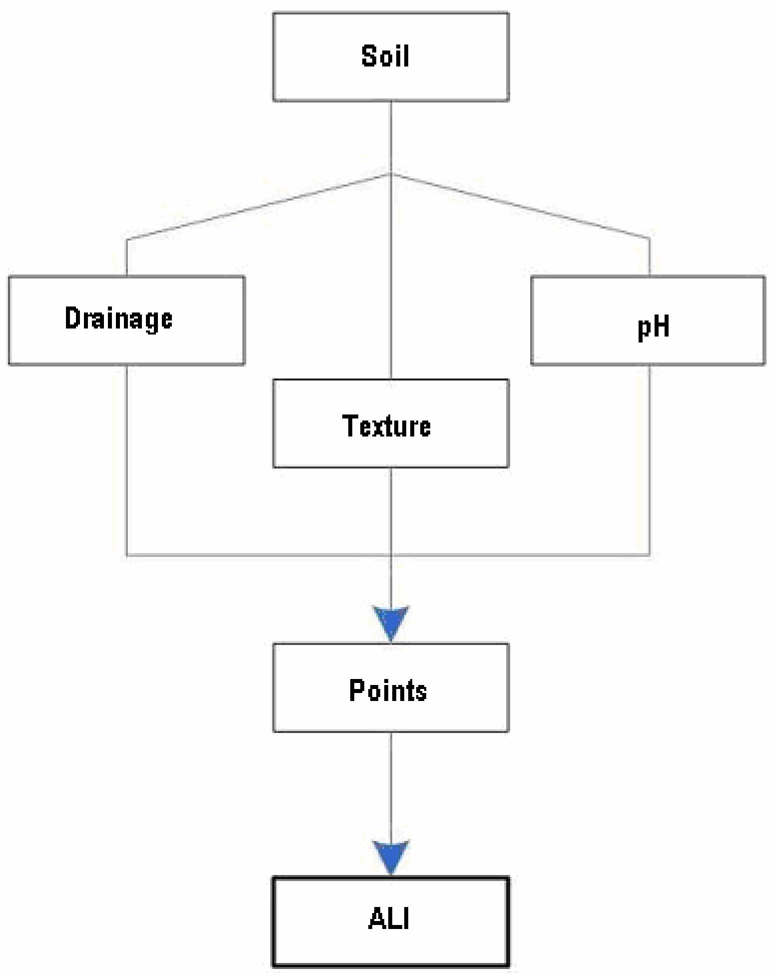
Furthermore, the soil suitability for the recommended tree species was evaluated where an abandoned land index (ALI) was derived for hybrid poplar (HPop) and red ash (FPen). Figure 5 shows the process involved in calculating the index. Three parameters were used to determine the ALI: soil pH, soil texture and drainage quality. A rating is assigned to each of these criteria according to the species' ability to grow in soil with those characteristics (Tables 4, 5 and 6).

The ALI equation is as follows:

ALI_species = (rating_pH_species + rating_texture_species + rating_drainage_species) / 3

Finally, by carrying out a matrix analysis of superimposed layers, the three parameters were combined for hybrid poplar and for red ash. Figure 6 illustrates the ALI calculation for both target species. The results obtained show that the ALI for hybrid poplar is quite low for the windbreak scenario, but average for the riparian forest buffer. The ALI for red ash is fairly high for both the windbreaks and the riparian forest buffers.

FIGURE 5. DIAGRAM ILLUSTRATING THE CALCULATION OF THE ALI



Source: Charland, P, 2007 for Econova

TABLE 3. PH CLASSES BASED ON IRDA'S SOIL CLASSIFICATION

Species	Code	pH Class					
		pH < = 4.8	4.8 > pH < = 5.5	5.5 > pH < = 6.0	6.0 > pH < = 6.8	6.8 > pH < = 7.5	pH > 7.5
Hybrid poplar	HPop	0.2	0.7	1	0.9	0.7	0.5
Red ash	FPen	0	0.5	0.7	1	0.9	0.8
Classes		**Acid**				**Neutral**	**Alkaline**
Hybrid poplar	HPop	0.88				0.7	0.5
Red ash	FPen	0.76				0.9	0.8

Source: IRDA, from Rivest (2003)

TABLE 4. TEXTURE CLASSES BASED ON IRDA'S SOIL CLASSIFICATION

Species	Code	Texture Class				
		Fine to very fine sand	Loamy sand to sandy loam	Loam to sandy clay loam	Clay loam to sandy clay	Silty clay to heavy clay
Hybrid poplar	HPop	0.3	1	1	0.5	0.2
Red ash	FPen	0.2	0.7	1	1	0.7
Classes		**Sandy**	**Coarse loamy skeletal-loam**	**Loamy**	**Fine loamy**	**Fine clay, very fine clay**
Hybrid poplar	HPop	0.3	1	1	0.5	0.2
Red ash	FPen	0.2	0.7	1	1	0.7

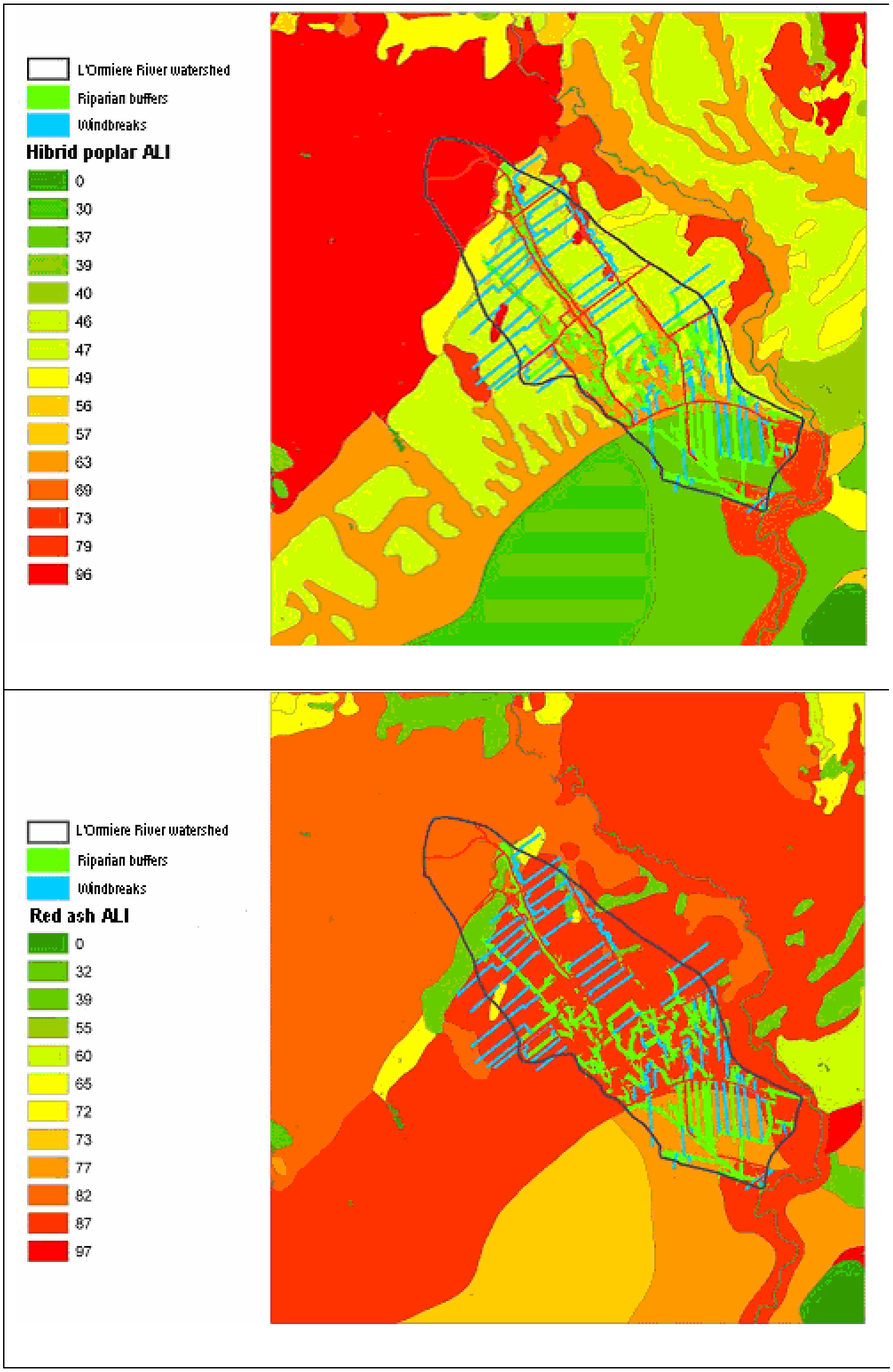
Source: IRDA, from Rivest (2003)

TABLE 5. TEXTURE CLASSES BASED ON IRDA'S SOIL CLASSIFICATION

Species	**Code**	**Drainage Class**				
		Rapid (I)	Good (II)	Moderate (III)	Imperfect (IV)	Poor (V)
Hybrid poplar	HPop	0.3	1	1	0.5	0.2
Red ash	FPen	0.2	0.7	1	1	0.7
Classes		**Very rapid drainage, rapid drainage**	**Good drainage**	**Moderate drainage**	**Imperfect drainage**	**Very poor drainage, poor drainage**
Hybrid poplar	HPop	0.3	1	1	0.5	0.2
Red ash	FPen	0.2	0.7	1	1	0.7

Source: IRDA, from Rivest (2003)

FIGURE 6. MAP OF ALI FOR HYBRID POPLAR AND RED ASH

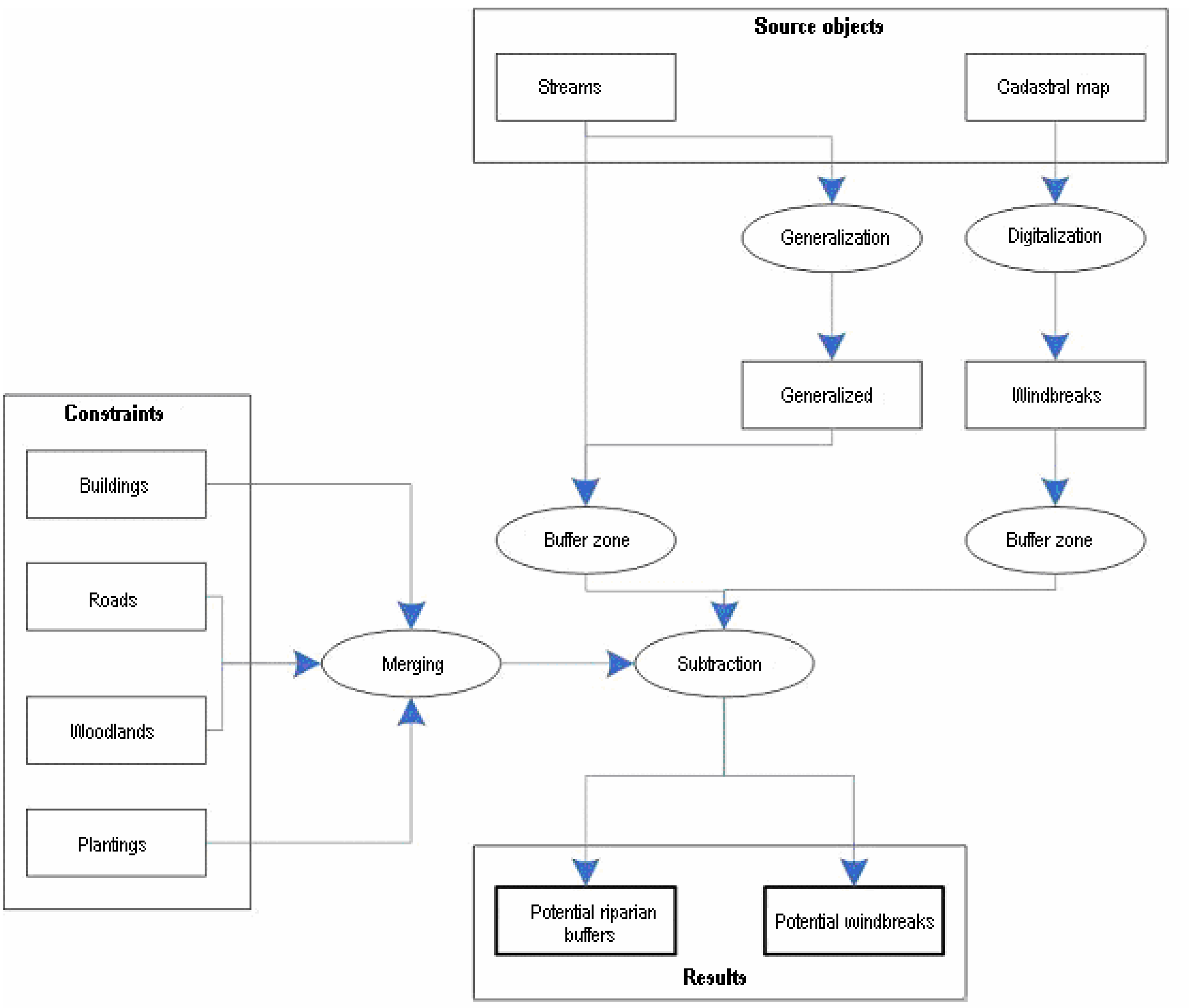


Source: Charland, P., for Econova

3.2. Potential area of riparian forest buffers and windbreaks in the L'Ormière River watershed

Figure 7 is a schematic representation of the spatial operations required to determine the potential area of windbreaks and riparian forest buffers. The selected agroforestry practices were delineated using source objects and the constraints were then subtracted from the potential planting areas in order to quantify suitable planting area.

FIGURE 7. DIAGRAM FOR CALCULATING THE POTENTIAL AREA OF RIPARIAN FOREST BUFFERS AND WINDBREAKS



Source: Charland, P. 2007, for Econova

Based on these calculations, the potential area of the riparian forest buffers is 144 ha and 47.5 ha for windbreaks for a total available area of 191.5 ha. The natural vegetation found within the watershed covers an area of 479 ha, to which 79 ha of plantings carried out by Louisiana Pacific Ltd needs to be added, for a total of 558 ha wooded cover. The two agroforestry practices together represent a 34% increase in the wooded area within the L'Ormière River watershed. The soils have an average to high ALI for hybrid poplar and red ash, which is satisfactory for establishing these species.

The calculation of the potential for implementing the two systems could have been improved by using remote imagery, such as orthoimages generated from 1:40,000-scale aerial photographs. Such a process would have made it possible to circumscribe the location and extent of the plantings, particularly for parcels of land located along sinuous rivers. The use of a refined large-scale digital terrain model would also permit the detection of zones with a significant erosion risk. Acquiring the data required for a more detailed analysis was beyond the scope of the present study, however.

FIGURE 8. VEGETATION BEFORE AND AFTER THE ANALYSIS OF PLANTING POTENTIAL

Before

After

Source: Charland, P. for Econova

4. Economic evaluation of agroforestry practices that support Carbon sequestration

In this section, the partial budget method was used to evaluate the costs associated with the implementation of agroforestry practices that contribute to Carbon sequestration. The OECD (2004) has used this approach in some of its studies, such as those on the dairy sector. It involves assessing the decrease or increase in costs caused by the adoption of new practices (a change in practices) on a farm.

Only those elements considered in the partial budget method are used in the present analysis:

1. New costs incurred (quantities and price/unit):
   - Labour costs;
   - New equipment or inputs.
2. Costs that are eliminated (quantities and price/unit):
   - Seed, fertilizer, pesticides;
   - Gasoline and energy;
   - Transportation and insurance;
   - Labour costs;
   - Feed inputs.
3. Drop in income (quantities and price/unit):
   - Reduction in yields;
   - Loss of cropland;
   - Loss of program payments.
4. Increase in income (quantities and price/unit):
   - Increase in yields;
   - Increase in area under cultivation;
   - Volumes of new products;
   - New program payments.

The economic impact analysis of riparian buffer systems is presented first, followed by those related to windbreaks. See section 2.1 for details on planting plans.

4.1. Planting of riparian forest buffers

In the upstream part of the watershed, the representative farm is a 114 ha dairy farm with 61 cows with 30% of the land devoted to field crops and 70% to forage. A riparian forest buffer is composed of hybrid poplar (*Populus*) and red ash (*Fraxinus pennsylvanica*). The strip is 20 m wide and its life expectancy (25 years) is equal to the lifespan of the slowest-growing species, that is red ash. The planting density is 816 trees/ha: two thirds hybrid poplar and one third red ash.

4.1.1. Loss of income from the reduction in area under cultivation

The loss associated with land taken out of production was calculated based on a study done in 2004 by ÉcoRessources Consultants on the reference threshold for putting in place an incentive program for the preservation and implementation of riparian buffer strips in agricultural zones (Nolet 2004). The study determined that maintaining an uncultivated one-metre-wide buffer strip along streams represented an average decrease of 0.20% per year in area under cultivation for each farm.

The riparian zone proposed in this study, regardless of the type of riparian forest buffer selected, is 20 m wide. Considering that producers are already required to maintain a 3-metre-wide crop-free zone along streams, the reduction in area under cultivation corresponds to the establishment of a 17-metre-wide system. A 3.4% decrease in crop area is therefore anticipated, which results in a reduction of 2.4 ha of forage and 1.3 ha of grain corn.

With respect to forage crops, it should be kept in mind that part of the forage is used as animal feed. However, the hay produced in the L'Ormière River watershed is known for its quality, and is prized by horse farms. Based on this fact, which was confirmed by local stakeholders, it was assumed that 20% of the forage land is devoted to hay production intended for export to the U.S. The remaining 80% is used to produce forage (particularly silage corn) for animal feed.

In order to calculate the income losses associated with removing cropland from production, it was assumed that the income from the sale of crops just covers production costs. Capital and labour costs are included in the production cost calculation. Based on information from producers who were interviewed, the price of hay for export is about $150/t. For grain corn, data compiled by Beauregard and Brunelle (2007) on the production cost of grain corn in 2006 was used. Also used from Beauregard and Brunelle (2007) was data on the production cost of hay for export and of silage corn.

The calculations take into account savings on operating costs (labour, machinery and inputs) for the areas removed from production. The loss of gross income resulting from the use of part of the cropland as a riparian forest buffer system was also assessed. According to the partial budget method, only the additional costs and gains associated with a change in practice are considered.

Establishing a riparian forest buffer system on the representative dairy farm results in a loss of 1.3 ha of grain corn and 2.4 ha of forage, the latter representing a loss of 1.9 ha of land used to grow forage for the herd and a loss of 0.5 ha of hay intended for export.

The discount rate used in this study is equivalent to the long-term Canadian Savings Bond rate, which stood at 8.48% from 1991 to 2005 according to Bank of Canada data.[6]

Table 6 presents the decrease or increase in costs and income associated with the area of land removed from production for riparian forest buffer establishment. The results show that the reduction in area under cultivation from creating a 20-metre-wide riparian buffers results in a decrease of about $3,900 in net operating income per year for the representative dairy farm in the upstream portion of the L'Ormière River watershed. Assuming annual inflation of 2%, this works out to a net discounted loss of $48,000 over a 25-year period, the average lifespan of a riparian forest buffer.

[6] See Canada Savings Bonds benchmark series: www.bankofcanada.ca

TABLE 6. LOSS OF INCOME ASSOCIATED WITH THE AREA REMOVED FROM PRODUCTION TO ESTABLISH A 20-METRE-WIDE RIPARIAN FOREST BUFFER IN THE DOWNSTREAM PART OF THE WATERSHED

	No Riparian Forest Buffer				With a 20-M-Wide Riparian Forest Buffer*			
	Grain Corn	**Hay for Export**	**Hay for Feeding Herd**	**Farm**	**Grain Corn**	**Hay for Export**	**Hay for Feeding Herd**	**Farm**
Area (ha)	37.8	14.04	56.16	108	36.50	13.56	54.24	104.30
Variable costs ($)	36,585	6,792	35,762	79,139	35,327	6,560	34,539	76,426
Fixed costs ($)	32,309	1,349	5,224		32,309	1,349	5,224	
Total costs ($)	**68,894**	**8,141**	**40,986**	**118,021**	**67,636**	**7,909**	**39,763**	**115,308**
Selling price/ha ($/ha)	1,428	1,050	2,000		1,428	1,050	2,000	
Stabilized price per hectare ($/ha)	1,740	1 050			1,740	1,050		
Total sales ($)	**65,757**	**14,742**	**112,320**	**192,819**	**63,496**	**14,238**	**108,480**	**186,214**
Net income ($)	**74,798**				**70,906**			
Annual loss of income ($)	**3,892**							
Net present value of income losses (25-year horizon) ($)	**$47,958**							

Source: ÉcoRessources Consultants

* Note: represents an actual loss of cropland of 17 m

4.1.2. Costs associated with planting and tending riparian forest buffers

Establishing a riparian forest buffer calls for an initial investment and generates operating costs, which are assessed in this section. To evaluate these costs, it is assumed that the producer does the necessary work for a flat fee.

The technical details of the work involved in establishing and maintaining a riparian forest buffer system are not covered here as they are not required to estimate costs. The technical and economic feasibility study completed by the firm Le Portageur Enr (2003) in the L'Ormière River watershed provided the baseline data for our calculations. The net present value (NPV) of the expenses incurred is based on an average lifespan of 25 years for the plantings. The results are shown in Table 7.

TABLE 7. COSTS OF PLANTING AND TENDING A 20-METRE-WIDE RIPARIAN FOREST BUFFER

	Net Present Value (NPV) of Costs Over a 25-Year Horizon ($/ha)	Present Value of Costs Over a 25-Year Horizon (for 3.7 ha) ($)
Planting and maintenance costs	$11,406	$42,203

Source: Compiled by ÉcoRessources Consultants from the data of Le Portageur Enr. (2003)

A cost of $2 to $3/seedling was used, in keeping with the MRNF references consulted, combined with an average density of 816 stems/ha. The net present value per hectare amounts to $11,406/ha, which, given an area of 3.7 ha, works out to a discounted cost of $42,203 for the representative dairy farm in the upstream part of the watershed.

4.1.3. Income from the sale of wood

According to the study by Le Portageur Enr (2003), deciduous species do not generate income in the short term, because it can take from 50 to 75 years to obtain good quality wood. In the case of red ash, harvesting can be done as early as the 25th year. Planting hybrid poplars in the riparian strip makes it possible to earn income in the medium term, that is, after the trees have been growing for 15 years. According to Nolet (2004), farmland is an ideal planting site for fast-growing hybrid poplars, which can grow to a diameter of 30 cm in less than 15 years.

For calculation purposes, all of the income from the riparian buffer system and the wood harvesting costs are allocated to the 25th year of operation. Table 8 presents the data used to calculate the harvesting costs and the income from the sale of wood, as well as the results obtained. Data from Ménétrier (2006) and Kennedy (2007)[7] were used to estimate the average merchantable yield of hybrid poplar and red ash over a 25-year period. The costs associated with the harvesting activities are those proposed by Nolet (2004) and validated by the forest engineering firm DelDegan Massé Associés. The price of the wood was estimated based on information from the Syndicat des producteurs de bois de l'Estrie.

TABLE 8. INCOME FROM THE SALE OF WOOD FROM THE RIPARIAN FOREST BUFFER

		Year 0 to Year 24	Year 25	Discounted Total
Harvest cost ($25/m^3 harvested from 3.7 ha forest buffer) ($)	HPop	0	21,090	
	FPen	0	6,937	
TOTAL COST Harvesting ($)		0	28,028	3,663
Sale ($34/m^3 harvested for HPop and $67.54/m^3 for FPen for 3.7 ha forest buffer) ($)	HPop	0	28,488	
	FPen	0	18,742	
TOTAL SALES ($)		0	47,231	6,173
Net income from the sale of wood ($)		0	**19,203**	
Discounted net income from the sale of wood ($)	**2, 510**			

Source: ÉcoRessources Consultants

Based on these calculations, net income of $19,000 can be earned over 25 years, which represents discounted net income of about $2,500 from the sale of timber.

4.1.4. Financial assistance from government programs

Programs such as Prime-Vert and Greencover Canada provide producers with compensation for planting trees or shrubs in the riparian zone; however, at present the farms in the watershed studied do not qualify for this assistance. To be eligible for financial assistance, a farm must be located in one of the watersheds with degraded water quality, which is not the case for the L'Ormière River watershed, itself part of the Maskinongé River watershed. Consequently, producers located in the L'Ormière River watershed do not

[7] The estimated merchantable yield of red ash is 105 m^3/ha for a density of 250 stems per hectare and a 25-year horizon (Kennedy, 2007), whereas the estimated yield for hybrid poplar is 400 m^3/ha for a planting with a density of 1,111 stems/ha over 25 years (Ménétrier 2006 and personal communication).

qualify for financial assistance under those programs for the establishment of riparian forest buffer systems.

However, in the case of a producer participating in a joint project with at least one other producer, Greencover Canada provides assistance covering up to 50% of the eligible expenses (up to $20,000/farm), and this assistance may be supplemented by financial assistance from the Prime-Vert program equivalent to 20% of costs. In the present case, each producer would be eligible to receive $20,000 from the Greencover Canada program, supplemented by a $8,440 (20% of total costs) contribution from the Prime-Vert program for a total of $28,440 from government financial assistance programs.

Table 9 presents a summary of the decrease or increase in costs and income associated with the establishment of a riparian forest system on the representative dairy farm in the upstream part of the L'Ormière River watershed. Taking into account Greencover Canada and Prime-Vert financial assistance, assuming that the producer participates in a group project to install riparian tree belts, the loss of income over a 25-year period is estimated at $59,200; without government assistance, the loss of income is $87,600.

TABLE 9. SCENARIO 1: ESTABLISHMENT OF A RIPARIAN FOREST BUFFER ON THE REPRESENTATIVE DAIRY FARM

	Increase in Discounted Income ($)	**Decrease in Discounted Income ($)**
Reduction in area under cultivation		47,958
Costs associated with planting and tending the system		42,203
Income from the sale of wood	2,510	
Financial assistance from government programs (if collective project)	28,441	
Total	30,950	90,161
Net loss of income (with government assistance)		**59,211**
Net loss of income (without government assistance)		**87,651**

Source: ÉcoRessources Consultants

4.2. Planting of windbreak systems

The second representative farm, in the downstream part of the watershed, is an average field crop farm (grain corn and soybeans) based on the characterization used by the Financière agricole du Québec to calculate farm income stabilization insurance (ASRA). Downstream, on the lowlands, where grain corn is the predominant crop, planting windbreaks is the recommended agroforestry practice. In this study, a windbreak consists of three rows of trees spaced 9 apart and and the windbreaks themselves spaced 150 m apart. Under the Kyoto Protocol, a forest must cover an area of at least 0.05 ha, so each windbreak must be at least 55.5 m long, Ten windbreaks are required in this scenario and since 70% of the land area is planted to grain corn and 30% to soybeans on the average farm, 7 windbreaks would be planted on plots of land devoted to grain corn and the remaining 3 on land used for soybean production.

4.2.1. Losses or gains associated with the reduction in crop area and increased productivity

Establishing a windbreak requires that some cropland be taken out of production. However, there is evidence in the literature that windbreaks can actually boost crop yields.

Reduction in the area under cultivation

Planting windbreaks on the representative field crop farm has the effect of decreasing the cultivated area by 1.5 ha (3 tree rows spaced 9 m apart, 55.5 m long with 10 windbreak per farm or 55.5 m x 3 x 9 m x 10 ≈ 15 000 m^2). The decreases in crop area are as follows: 1 ha of grain corn and a half-hectare (0.5 ha) of soybeans.

For calculation purposes, we used the data compiled by Beauregard and Brunelle (2007) on grain corn and soybean production costs for 2006. The decrease in income associated with the removal of land from production was calculated, along with the reduction in costs (operating costs: machinery, labour and inputs) resulting from the decrease in crop area.

Table 10 shows the change in income resulting from the planting of 10 windbreaks on the representative grain farm. The result is a decrease in income of about $961 per year for the representative farm. Assuming annual inflation of 2%, this is equal to a net discounted loss of $11,800 over a 25-year period.

TABLE 10. ANNUAL CHANGE IN INCOME ASSOCIATED WITH THE AREA REMOVED FROM PRODUCTION TO ESTABLISH WINDBREAKS

	Without Windbreaks			With Windbreaks		
	Grain Corn	**Soybeans**	**Farm**	**Grain Corn**	**Soybeans**	**Crop Area Lost 1.5 ha**
Area (ha)	202.6	83.3	285.9	201.6	82.8	284.4
Variable costs ($)	196,086	49,608	245,694	195,119	49,310	244,428
Fixed costs ($)	70,318	12,328	82,647	70,318	12,328	82,647
Total costs ($)	**266,405**	**61,936**	**328,341**	**265,437**	**61,638**	**327,075**
Selling price/ha ($/ha)	1,428	870		1,428	870	
Stabilized price per hectare / Stabilized income – for soybeans ($/ha)	1,740	974		1,740	974	
Total sales ($)	**352,445**	**81,153**	**433, 598**	**350,705**	**80,665**	**431,371**
Net income ($)	**105,257**			**104,296**		
Loss of income ($)	**961**					
Discounted loss of income ($) (25-year horizon)	**11,840**					

Source: ÉcoRessources Consultants

Increase in productivity

In fields protected by a windbreak, yields can be expected to increase by 6% to 8% for grain corn and by 40% for soybeans[8]. A windbreak protects a length of field equivalent to about 15 times its height. In addition, it is assumed that the trees will reach a height of about 20 m at maturity (15 years for hybrid poplars, which represent most of the trees in the windbreak) and the trees remain at least that height for the life of the windbreak, that is, for 25 years. The productivity gains achieved each year attributable to a windbreak system were calculated and discounted. Each 55.5 m long windbreak is composed of three rows of trees. There are 7 windbreaks on land used for grain corn production and three on cropland used for soybeans production. At maturity, the windbreaks will protect 35 ha of grain corn and 15 ha of soybeans.

[8] Scientific reviewers mentioned that a 40% yield increase for soybean appears to be unlikely and that a value between 9 and 12% would have been more realistic. Nevertheless, even though a lower value would change some figures in the report, it would not modify the study's main conclusions.

TABLE 11. AREA PROTECTED BY WINDBREAKS AND ADDITIONAL ANNUAL INCOME

	Year 0	Year 1	Year 2	...	Year 15	...	Year 25
Grain corn hectares protected (ha)	0	2.3	4.6	...	35	...	35
Productivity increase for grain corn (7%) (additional t per farm)	0	1.2	2.3	...	17.6	...	17.6
Additional income for grain corn ($)	0	240	481	...	3,607	...	3,607
Soybean hectares protected (ha)	0	1	2	...	15	...	15
Productivity increase for soybeans (40%) (additional t per farm)	0	1.2	2.4	...	18	...	18
Additional income soybeans ($)	0	390	781	...	5,857	...	5,857

Source: ÉcoRessources Consultants

To calculate the increase in productivity, a yield of 7.2 tonnes per hectare was used for grain corn and 3 tonnes per hectare for soybeans, based on the data of the Financière agricole for 2006. In addition, according to Beauregard and Brunelle (2007), the stabilized price for grain corn was $204.66/t in 2006, and the stabilized price for soybeans corresponding to the stabilization income for the same year was $325.74/t sold.

Table 12 shows the discounted value of the additional income generated by the productivity increase associated with windbreak establishment. If increase in productivity resulting from the windbreaks is considered, the discounted supplementary income is $50,800 for the representative crop farm over a 25-year period.

TABLE 12. DISCOUNTED INCOME RESULTING FROM THE INCREASE IN PRODUCTIVITY ASSOCIATED WITH WINDBREAKS

	Present Value – NPV of Income Over a 25-Year Horizon ($)
Increase in productivity associated with windbreak establishment (grain corn)	19,361
Increase in productivity associated with windbreak establishment (soybeans)	31,445
TOTAL	**50,807**

Source: ÉcoRessources Consultants

4.2.2. Costs associated with windbreak establishment and maintenance

In this section, the costs associated with the initial investment for windbreak establishment are assessed, along with the operating costs incurred for maintenance of the windbreaks. It is assumed that the producer carries out the work for a flat fee.

Data from Le Portageur Enr (2003) were used to calculate the planting and maintenance costs per hectare for a riparian forest buffer systems.

The results in Table 13 indicate that the present value of the expenses required to plant and maintain a windbreak amounts to approximately $18,400 per farm over a 25-year period.

TABLE 13. COSTS OF PLANTING AND MAINTAINING A WINDBREAK

	Present Value – NPV of Costs Over a 25-Year Horizon ($/ha)	**Present Value of Costs Over a 25-Year Horizon** (for 1.5 ha) ($)
Planting and maintenance costs	12,291	18,437

Source: ÉcoRessources Consultants

Income from the sale of wood

A typical windbreak consists of two thirds hybrid poplar and one third red ash. An average density of 1,200 stems per hectare is required to provide effective protection against prevailing winds. For calculation purposes, it was assumed that a system of windbreaks, occupying an area of 1.5 ha, generates all its income in year 25; the wood harvesting costs are likewise calculated for that year.

Table 14 presents the data used to calculate the harvesting costs and the income from the sale of wood, along with the results obtained. Productivity can vary widely depending on the clones used, site fertility, geographic situation, the type of windbreak and competition between the species (which is significant here because of the high planting density), as well as wind strength (Ménétrier, personal communication). As with the riparian forest buffer system, the data of Ménétrier (2006) and Kennedy (2007)[9] were used to estimate the average merchantable yield of hybrid poplar and red ash over a 25-year period. As the table shows, a discounted net income of about $1,500 is earned from the sale of wood.

[9] The merchantable yield estimated for red ash is about 105 m^3/ha for a density of 250 stems per hectare over a 25-year horizon (Kennedy, 2007); the merchantable yield estimated for hybrid poplar is 400 m^3/ha for a plantation with a density of 1,111stems/ha over 25 years (Ménétrier, 2006 and personal communication).

TABLE 14. DISCOUNTED NET INCOME FROM THE SALE OF WOOD FROM WINDBREAKS

		Year 0 to 24 ($)	Year 25 ($)	Discounted total ($)
Harvesting cost ($25/m^3 for 1.5 ha of windbreaks)	HPop	0	12,600	
	FPen	0	4,163	
TOTAL COST Harvesting		0	16,763	2,191
Sales ($34/m^3 harvested for HPop and $67.54/m^3 for FPen for 1.5 ha of windbreaks)	HPop	0	17,020	
	FPen	0	11,245	
TOTAL SALES		0	28,265	3,694
Net income from the sale of wood		0	**11,503**	
Discounted net income from the sale of wood	**1,503**			

Source: ÉcoRessources Consultants

Losses or income from government programs

In this analysis, a producer participating in a group project with at least one other whose farm is likewise located in the Maskinongé River watershed can receive funding from Greencover Canada covering up to 50% of the eligible expenses (the payment limit is $10,000/farm); this funding may be supplemented by financial assistance from the Prime-Vert program covering 20% of the eligible costs. The total funding from the two programs covers 70% of the expenses incurred, or $13,687 on the representative farm.

Table 15 shows the increase or decrease in costs associated with the establishment of windbreaks on the representative grain farm in the downstream part of the L'Ormière River. If we factor in government assistance, which is contingent on the producer being involved in a group project, there is an increase in income of about $35,700. Assuming that government assistance is not available, the increase in income would be about $22,000 over a 25-year period.

TABLE 15. SCENARIO 2: PLANTING OF WINDBREAKS ON THE REPRESENTATIVE CROP FARM

	Increase in Discounted Income ($)	Decrease in Discounted Income ($)
Reduction in area under cultivation		11,840
Additional income from increased productivity	50,807	
Costs associated with planting and maintaining windbreaks		18,437
Income from the sale of wood	1,500	
Financial assistance from government programs (if joint project)	13,687	
Total	65,998	30,277
Increase in income (with government assistance)	**35,720**	
Increase in income (without government assistance)	**22,033**	

Source: ÉcoRessources Consultants

4.3. Summary of the economic analysis

Table 16 shows the gains or losses resulting from the implementation of agroforestry practices contributing to Carbon sequestration on the two representative farms used in the analysis.

TABLE 16. GAINS OR LOSSES FROM THE IMPLEMENTATION OF AGROFORESTRY PRACTICES CONTRIBUTING TO CARBON SEQUESTRATION ON INDIVIDUAL FARMS

		Increase in Discounted Income ($)	Decrease in Discounted Income ($)
Scenario 1: Implementation of riparian forest buffer systems on the representative dairy farm in the upstream part of the L'Ormière River watershed	Reduction in area under cultivation		47,958
	Cost of establishing and maintaining plantings in the riparian area		42,203
	Income from the sale of wood	2,510	
	Assistance from government programs (if group project)	28,441	
	Total	30,950	90,161
	Loss of income (if group project)		**59,211**
	Loss of income (if not a group project)		**87,651**
Scenario 2: Establishment of windbreaks on the representative crop farm in the downstream part of the L'Ormière River watershed	Reduction in area under cultivation		11,840
	Additional income from increased productivity	50,807	
	Costs associated with planting and maintaining windbreaks		18,437
	Income from the sale of wood	1,503	
	Assistance from government programs (if group project)	13,687	
	Total	65,998	30,277
	Increase in income (if group project)	**35,720**	
	Increase in income (if not a group project)	**22,033**	

Source: Compilation by ÉcoRessources Consultants

According to data compiled by MAPAQ (2006), there are 10 dairy farms and 11 grain farms in the L'Ormière River watershed. In the watershed as a whole, the establishment of riparian forest systems would result in losses of $592,110 if all the producers were participating in a cooperative project, compared with a loss of $876,510 if they were not. The gains associated with the establishment of windbreaks at the watershed scale would be about $357,200 if all producers qualified for government assistance and $220,330 if none of the producers were participating in collective projects.

In light of this analysis and based on the study assumptions, riparian forest buffers are not cost-effective whereas windbreaks are from the point of view of individual producers. This finding can be explained by the fact that a significant source of supplementary income associated with the establishment of windbreaks comes from the increase in crop yields and not from the sale of wood fibre.

The finding does not change if the agroforestry scenario is modified, for example, if the trees are harvested after 10 years rather than 25 years. The results show that even if the income from the sale of wood fibre tripled, the general conclusions would not change. However, if the agroforestry scenario that is selected reduces the effectiveness (i.e. function) of the windbreak system, the per-hectare yields could be adversely affected and the system's cost-effectiveness would decline substantially even if the scenario boosted sales of wood fibre.

Non-timber forest products in agroforestry systems is being evaluated for additional income generation potential (Smith and Cameron 2007; Chamberlain 2007). Some crops (e.g, fruit shrub species, medicinal plants and mushrooms) could provide value-added forest products and help to make riparian forest buffers cost-effective while also increasing the cost-effectiveness of windbreaks. In addition, some riparian forest buffer systems, if perpendicular to prevailing winds, can also function as windbreaks, a possibility not explored in our analysis.

Finally, if a cooperative approach were adopted within the watershed, this might generate positive economic impacts. At present, in a watershed that does not have degraded water quality, only group projects qualify for government assistance covering up to 70 % of eligible costs. Furthermore, group projects would enable producers to reduce their planting and harvesting costs (economies of scale), pool their forest products and negotiate a better price. Group projects would also permit the aggregation of Carbon reduction credits, give producers more negotiating power with brokers and reduce transaction costs (which are very high for agricultural and agroforestry projects), discussed later.

The economic calculations presented here do not take into account Carbon sequestration resulting from agroforestry practices and the financial benefits that could accrue from carbon sequestration if a system of compensation existed, such as carbon reduction credits or government assistance supporting the implementation of agroforestry practices that sequester Carbon. In the following section, we analyze the monetary value that could be assigned to Carbon sequestration associated with agroforestry practices, and a cost-benefit analysis for producers is provided.

5. Economic evaluation of Carbon sequestration through agroforestry practices

In this section, our goal is to assess Carbon sequestration achieved through the implementation of the above-described agroforestry practices (i.e. riparian forest buffer and windbreak establishment). By assigning monetary value to Carbon sequestration, we can perform a new cost-benefit analysis for the two representative farms, taking into account the economic impacts of the adoption of agroforestry practices that contribute to Carbon sequestration.

5.1. Estimation of Carbon sequestration through agroforestry practices

Here, we assess the Carbon sequestration potential of two agroforestry systems, riparian forest buffers and windbreaks, both composed of red ash and hybrid poplar.

This is a theoretical approach based on existing calculation methods, in particular, the research work done by Gaboury and his collaborators at the Université de Québec à Chicoutimi, as well as by Ouellet and his group with the MRNF in La Tuque.

The formula used to calculate CO_2 sequestration per hectare is as follows:

ESTIMATION OF CARBON SEQUESTRATION BY A FOREST

CO_2 (kg/ha) = [(total biomass (m^3/ha) * bone dry density of wood (kg dry/m^3))* Carbon/dry matter (kg/kg)] * CO_2/Carbon (kg/kg)] + C contained in the litter and dead wood (kg/ha)

The calculation assumptions related to Carbon sequestration in agroforestry systems are as follows.

- The merchantable yield of the planting is assumed to be 300 m^3/ha for the riparian forest buffer system and 400 m^3/ha for the windbreak system (Ménétrier 2006 and Kennedy 2007);
- Total biomass consists of above-ground biomass (estimated by multiplying the merchantable biomass by 1.64) and root biomass (estimated by multiplying the above-ground biomass by 0.222);
- The bone dry density (kg dry/m^3) of the candidate species is as follows:
  - Red ash: 0.539 kg dry/m^3;
  - Hybrid poplar: 0.424 kg dry/m^3;

- The carbon content of the bone dry mass is 50%;
- The carbon content of the litter and dead wood is equal to 15% of the carbon accumulated in the total biomass;
- One kg of carbon is equal to 3.67 kg of CO_2;
- It is assumed that the CO_2 emissions associated with the project are negligible.

Based on these assumptions, for the riparian forest buffer system, we calculated a mean sequestration capacity of 587 tonnes of CO_2 per hectare over a lifespan of 25 years, or a mean of about 23 t CO_2/ha/year. For the representative dairy farm, this represents estimated annual CO_2 sequestration of 86 t CO_2/year for 3.7 ha of riparian buffers. For the windbreak system, the value obtained is significantly higher, owing to the greater planting density. A windbreak system would sequester about 782 t/ha over a 25-year period, or 31 t CO_2/ha/year. For the representative crop farm, this would amount to 47 t CO_2/year for a total of 1.5 ha of windbreaks.

5.2. Participation in an offset system and value of sequestration credits from agroforestry practices

An offset system is designed to allow major industrial emitters whose GHG emissions exceed their allowable limit to purchase carbon reduction credits from sectors whose GHG emissions are below the allowable limit.

In the case of riparian forest buffers, which result in net losses for individual farms even with government funding, what price would have to be paid per tonne of CO_2 removed from the atmosphere to offset the costs incurred to implement these systems? Furthermore, would compensation for Carbon sequestration provide sufficient incentive to encourage agricultural producers to adopt the agroforestry practices?

In setting prices for carbon reduction credits attributable to agroforestry practices, it is necessary to consider the temporal (non-permanent) nature of the Carbon sequestration associated with such projects. This is because the carbon absorbed by forests or soils can end up being re-emitted to the atmosphere, and certain actions, whether intentional or not (fire, harvesting, processing of wood), can result in the complete or partial release of the CO_2 molecules stored in plant tissues. The value of a tonne of CO_2 that has been temporarily sequestered through agroforestry projects, for example, is lower than that of a tonne of CO_2

removed from the atmosphere permanently. Furthermore, the long-term value of reduction credits is greater than the short-term value of reduction credits.[10]

In order to assign monetary value to Carbon sequestration, it is necessary to consider the temporary nature of the reduction achieved through agroforestry projects. In addition, as mentioned earlier, it is necessary to take into account the market price of permanent Carbon reduction credits. In this study, we will assume that the price of permanent reduction credits is $15 per tonne of CO_2[11].

According to Olschewski and Benítez (2005), the equivalence between prices of temporary carbon reduction credits and prices of permanent credits can be calculated as follows:

$$\boxed{\text{Price temporary reduction credit} = \text{Price permanent reduction credit} * (1-(1+r)^{-T})}$$

In this equation, 'r' is the discount rate and 'T' is the lifespan of the project.

If we apply a discount rate of 8.48%, that is, the average long-term Canada Savings Bond rate for the period 1991 to 2005, the value of a temporary reduction credit is equal to about 87% of the value of a permanent reduction credit over a 25-year period. Institutions that purchase carbon credits are willing to pay a price for temporary credits that is equivalent to 10% and 30% of the value of permanent credits, depending on the quality of the temporary carbon reductions. If the price of a permanent reduction is $15/t, a penalty of 50% applied to the value of temporary credits results in $7.50/t for temporary credits.

A distinction needs to be made between the market price and the monetary value of reduction credits for agricultural producers. A GHG mitigation project must go through several stages before it generates credits that can be sold on the market. The project must be planned, validated and implemented. Not only do the emission reductions need to be measured, the credits also have to be certified before they can be put on the market. In the agriculture sector, it is necessary to aggregate the carbon reduction credits from a multitude of small projects in order to market the credits. Each of the stages in this overall process entails costs, which are referred to as transaction costs. Marbek Consultants (2004) estimated that the transaction costs for agricultural projects can be as high as $18.56/tonne, whereas the costs associated with sanitary landfill sites can be as low as $0.05/tonne of carbon reduction. In the present analysis, it was assumed that the transaction costs were $2.50/tonne and that, consequently, agricultural producers would receive about $5/tonne for sequestration credits.

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[10] See Table 2. Value of non-permanent carbon credits relative to permanent credits.

[11] The regulatory framework that the federal government published on April 6, 2007 enables companies to meet their targets by investing in a technology fund at a cost of $15/tonne.

The cost-benefit analysis shows that when riparian forest buffers are established on the representative dairy farm in the upstream part of the L'Ormière River watershed, net income losses of $87,600 are incurred over a 25-year period. On an annual basis, 87 tonnes of CO_2 are sequestered in its riparian forest buffers, which, at a price of $5/t, represents income of $435. If we estimate a CO_2 reduction of 2,170 tonnes over 25 years on the representative dairy farm for the riparian forest buffer systems, large industrial emitters would have to pay $40/t in order to offset the expected losses associated with these systems. Note that this price is eight times higher than the maximum amount of $5/tonne of CO_2 determined above. If, on the other hand, a producer is participating in a cooperative riparian forest buffer project with at least one other producer whose farm is located in the same watershed, each producer would qualify for government assistance, which would reduce the losses to about $59,200 per farm. This represents a price of $27/t of CO_2 sequestered, which is more than five times the estimated price of $5/t of CO_2.

For windbreak systems established on the representative crop farm located in the downstream part of the L'Ormière River watershed, a producer would achieve a $22,000 increase in income, without receiving any government assistance, or $35,700 where the producer is participating in a cooperative project and receives government funding. Under this scenario, the gains resulting from the sale of Carbon reduction credits would not go toward covering costs, but would instead be net gains for the producers. Since, according to our calculations, the windbreak systems would permit the sequestration of about 47 tonnes of CO_2 annually per farm, the producer would earn supplementary income of up to $235/year, based on a maximum price of $5/t.

These results are for individual farms. In the following section, Carbon sequestration potential at the watershed scale is outlined.

5.3. Economic evaluation of Carbon sequestration potential at the watershed scale

According to our spatial analysis of the agroforestry potential of the L'Ormière River watershed, the area available for implementing riparian forest buffers within the L'Ormière River watershed is 144 ha, whereas for the windbreak systems the potential area is 47.5 ha. Based on the assumptions used in this study and a 25-year period, one hectare of riparian forest buffers would have a sequestration potential of 587 tonnes of CO_2 equivalent, whereas one hectare of windbreaks would sequester 782 tonnes of CO_2 equivalent.

At the watershed scale, the Carbon sequestration potential would amount to 121,673 tonnes of CO_2 equivalent, which would generate about $608,365 in income from the sale of carbon reduction credits over a 25-year period. Of this amount, $425,855 ($18,114 per year for the entire watershed) is associated with riparian forest buffers and $182,510 with windbreak systems ($7,300 per year for the entire watershed). This is a theoretical potential gain, meaning that the entire area available for the establishment of riparian forest buffers and windbreaks would have to be devoted to those agroforestry practices.

6. Conclusion

The primary goal of this study was to assess whether Carbon sequestration would provide sufficient incentive for agricultural producers to adopt agroforestry practices on their farms. Under current market conditions and based on the assumptions made in this study, it appears that sequestration potential does not provide sufficient incentive.

The findings show that CO_2 sequestration levels associated with riparian forest buffers and windbreaks are too low to warrant the adoption of such practices for this reason alone. Carbon sequestration in itself is not a sufficient incentive for producers to establish windbreaks or riparian forest buffers. Based on the assumptions applied in the study, the sale of carbon credits is not an economic argument that carries weight in terms of the adoption of agroforestry practices.

In this study, the cost-benefit ratios were found to vary widely for the two agroforestry practices. For example, the establishment of riparian forest buffers appears to result in a net loss for agricultural producers, whereas the planting of windbreaks generates significant gains for producers because of the associated increase in crop productivity.

It follows that Carbon sequestration potential is not the sole attraction of agroforestry. In fact, the promise of agroforestry practices relates more to other ecological goods and services which were not taken into account in this study, but which can include reductions in non-point source pollution, erosion control, the opportunity to increase or maintain biodiversity and landscape enhancement. The only agroforestry benefits that were examined in the study were increases in agricultural yields (for windbreaks) and fibre production (for both practices).

A number of factors besides environmental benefits can encourage producers to adopt agroforestry practices, as has been demonstrated extensively in the literature: increase in the economic returns for individual producers, particularly through the establishment of species that provide value-added timber and non-timber forest products; value assigned to ecological goods and services; the establishment of windbreaks on a priority basis given their capacity to generate supplementary income; and the adaptation of certain riparian forest buffers so they can act as windbreaks simultaneously.

Lastly, a cooperative approach would make it possible to generate economies of scale related to planting and harvesting costs, give producers greater negotiating power for selling their forestry products and reduce the transaction costs associated with carbon reduction credits. Aside from the potential economic benefits of group projects, other benefits are possible, such as the pooling of expertise and the forging of ties among the producers of a given watershed, or the creation of a larger territory than that of a farm within which environmental benefits can be obtained (Carbon sequestration but also erosion control, reduction in non-point source pollution, increase in or maintenance of biodiversity, enhancement of landscape value, etc.).

This study has shown that the carbon market in itself is not sufficient incentive to encourage agricultural producers to implement riparian forest buffers and windbreaks. Nevertheless, agricultural producers can contribute to carbon sequestration through a variety of practices on their farms. Even if a given agroforestry practice does not generate enough carbon credits to justify participation in the emissions trading market, a broader set of such practices might generate a volume of credits that translates into significant supplementary income for producers. Research into a broader range of agroforestry practices would provide the opportunity to examine this possibility in greater depth. The fact remains that, on an individual basis, agricultural producers cannot generate enough Carbon emission reduction credits to participate in the emissions trading market because their transaction costs are too high in relation to the income that can be earned from the sale of carbon credits. Therefore, consideration should be given to cooperative approaches that would make it possible to aggregate producers' Carbon emission reduction credits and reapportion the proceeds of the sale of those credits among the participants.

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Appendix

Persons consulted

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