The Watershed Evaluation of Beneficial Management Practices (WEB's)

The Bras d'Henri Watershed- On-farm Economics

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Abstract

The Watershed Evaluation of Beneficial Management Practices (WEB's) project is funded by Agriculture and Agri-Food Canada (AAFC). This study addresses the issue of non-point source agricultural pollution in the Bras d'Henri sub-watershed. It estimates the economic impact on the farm of an increased environmental constraint and the environmental and economic performance of Best Management Practices (BMPs) to satisfy this environmental constraint. The model's objective was to maximize net farm income subject to an environmental constraint, farm characteristics, and animal nutrient requirements. Results indicate that increasing the pollution emission constraint: (1) Reduces agricultural non-point source (NPS) pollution, (2) forces cropping patterns and farming practices to change, (3) reduces profit, and (4) induces average abatement cost and marginal abatement cost to increase at an increasing rate. Also, with comparable environmental constraints, farms are economically better off when the environmental constraint was set at the watershed scale as opposed to being set at the farm scale.

Le projet d'Évaluation des pratiques de gestions bénéfique à l'échelle du basin versant (EBB) est financé par Agriculture Canada (AAAC). Cette étude met l'emphase sur la problématique de pollution diffuse agricole présente dans le sous-bassin versant du Bras d'Henri. Cette étude fait l'estimation de l'impact à la ferme d'une contrainte environnementale croissante et de la performance environnementale et économique des Pratiques de Gestions Bénéfiques (PGB) pour satisfaire une contrainte environnementale. Les objectifs du model était de maximiser les revenus nets agricoles en ce conformant à une contrainte environnemental, à l'utilisation unique des champs, et au respect des besoins nutritionnels des animaux. Les résultats indiquent que la présence d'une contrainte environnementale croissante : (1) réduit l'émission de pollution diffuse agricole, (2) force les habitudes de production à changer, (3) réduit les revenus nets agricole, et (4) fait en sorte que les coûts moyens d'abattement et les coûts marginaux d'abattement augmentent et accélèrent. De plus, soumis à des contraintes environnementales similaires, les fermes sont économiquement gagnantes lorsque la contrainte environnemental est fixée à l'échelle de du bassin versant contrairement à une contrainte environnementale fixée à l'échelle de la ferme.

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Chapter 1: Introduction

1.1 Problem Statement

The Chaudière Watershed has one of the highest concentrations of animal production in Quebec and nearly two-thirds of its land is under crop production (AAFC, 2007a). Its Beaurivage sub-watershed, where the Bras d'Henri River is located, has 32% of its area in crop production and has 84.24 animals per square km (MDDEP, 2006a). The Beaurivage is also the second most populated sub-watershed in the Chaudière River Watershed with a population of 16, 395 (MDDEP, 2006a). Over time, the surface water quality in the Bras d'Henri sub-watershed has declined drastically and agricultural non-point source (NPS) pollution has been identified as being the main source for this water quality decline (MDDEP, 2006a).

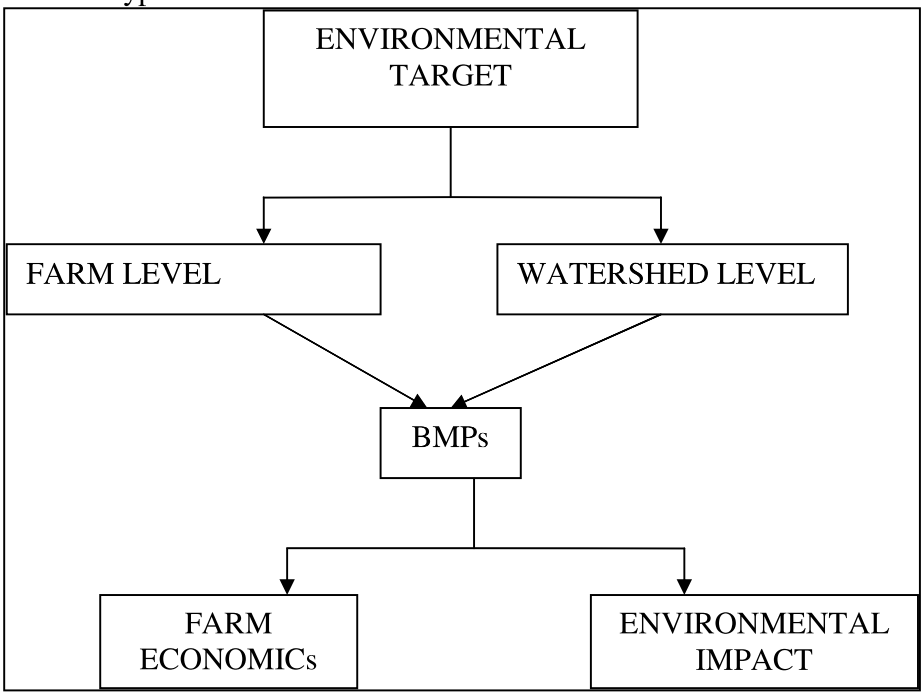
The WEB's project aims to reduce the amount of agricultural non-point pollution emitted by agricultural sources, and improve water quality by relying on the adoption of BMPs. The challenge of this project is to balance the needs of agricultural production with the health of the environment. Beneficial management practices can reduce agricultural contributions to sediment and contaminant loading in streams. However, the environmental and economic performance of these practices needs to be better evaluated. Results might have a huge impact on where our efforts are focused in the future (AAFC, 2007a). The BMPs considered in this study were the implementation of a buffer strip, the reduction in the use of pesticides in corn (atrazine), the use of a low ramp sprayer equipped with dribble bars to spread manure, the use of alternative cultivation practices, alternative crop mixes, and alternative animal mixes. Detailed definitions of each BMP are given in chapter 2.

BMPs may have a significant impact on surface water quality but they may also incur a significant economic cost to farmers who are adopting them. However, few studies report what this cost is, and even fewer studies have been undertaken with an integrated modelling approach where the environmental and the economic performance of BMPs are estimated together. The economic impact of satisfying a given environmental constraint was determined using the implementation cost of each BMP and their environmental efficiencies. If satisfying an environmental constraint has an impact on profit, this information can be used to analyse the change in farming practices, the trade off between lost profit and environmental target as well as the optimal distribution of BMPs to satisfy the environmental constraint i.e. should the abatement target be set at the farm level or at the watershed level? In both cases, what are the economic consequences to the farmer and what are the economic implications of such a policy implementation?

1.2 Hypotheses

As illustrated below, in Figure 1.1, the study tests the following hypotheses both at the farm scale and at the watershed scale: (1) implementing an environmental target reduces the amount of pollution emitted by agricultural producers, (2) implementing an environmental constraint forces the adoption of BMPs, and (3) the adoption of BMPs reduces profit. As a result of testing these hypotheses, conclusions can be drawn concerning the change in farming practices, the trade off between lost profit and environmental improvement as well as the optimal distribution of BMPs to satisfy a pollution abatement constraint.

Figure 1. 1 Hypothesized effects of an environmental constraint.



1.3 Objectives

The general objectives of this study were to reduce the amount of agricultural non-point source pollution emitted by agricultural sources and improve water quality by relying on the adoption of BMPs. The specific objectives of the study were:

(1) To survey farmers in the Bras d'Henri Sub-watershed and collect spatial data of each field as well as the applicability of each BMP on each field.

(2) Use the GIBSI (Gestion Intégré par Bassin Versant à l'Aide d'un Système Informatisé) model to generate abatement coefficients at the RHHU (Relatively

Homogeneous Hydrologic Unit) level and at the sub-watershed scale for each field activity and BMP.

(3) To incorporate the BMPs applications into a Linear Programming (LP) model.

(4) To run scenarios based on an increasing environmental constraint and test for the above hypotheses.

(5) To draw some conclusions concerning the change in farming practices, the trade off between lost profit and abatement target, as well as the optimal distribution approach of BMPs that would satisfy the environmental constraint.

1.4 General Method and Organization of the Study

The general method used in this study is related to the specific objectives mentioned above and was based on five steps.

(1) A survey of all farmers in the Bras d'Henri sub-watershed was undertaken. The data included the potential applicability of each BMP on each field.

(2) The use of a Geographical Information System to subdivide each field into the various hydrologic units using a weighted average procedure, i.e. each field is attributed to only one Relatively Homogeneous Hydrologic Unit (RHHU) or a weighted average of the RHHU values depending on whether the field was lying on only one RHHU or several.

(3) Using the GIPSI model, generate the environmental coefficients for each RHHU. This included estimating environmental coefficients for each field activity studied.

(4) Development of a Linear Programming model representing all fields on all farms that maximizes net farm income subject to an environmental constraint.

(5) The simulation of numerous scenarios. The base case scenario was a simulation where current practices were modelled and no environmental constraint was implemented. Subsequent scenarios were based on the implementation of an increase in the environmental constraint.

(6) The results of this analysis show the evolution of farming practices, the trade off between lost profit and abatement target, as well as the optimal distribution of BMPs to satisfy an environmental constraint.

The main contributions of this research are: (1) the modelling procedure can compare the economic impact of implementing a watershed scale constraint and a farm scale constraint, (2) to provide an economic estimation of the farmer's cost of implementing an environmental constraint, and (3) to estimate an abatement cost curve for an agricultural non-point source pollution situation.

Chapter 2: Literature Review

The literature review will cover several topics. First, the relationship between the agricultural production practices and water quality will be discussed. The environmental performance of best management farming practices when dealing with non-point source pollution abatement will be highlighted. The factors affecting the adoption of best management practices among farmers and several farming practices considered as best management practices will be described. Second, the necessity of site-specific information when conducting economic ecological modelling will be examined. The challenge that faces the design of socially and economically optimal environmental policies will be discussed and a link will be made with the existing Quebec/Canada and U.S. water pollution control policies. Third, the different sources of agricultural pollutants will be described as well as their environmental impacts. Finally, the development of mathematical modelling for environmental policy design will be reviewed. Linear programming, integrated biophysical modelling, and GIS (Geographic Information System) based DSS (Decision Support System) models will be discussed.

2.1 Agriculture and Water Quality

2.1.1 Agriculture and Its Link to Water Quality

Agriculture accounts for the largest part of the world's water use. Not surprisingly, agriculture has a large impact on water quality. The U.S Environmental Protection Agency (2002) has identified agriculture as the leading source of pollution in 48% of river miles, 41 % of lake acres, and 18% of estuarine waters. Even though irrigation and watering is seldom used in Quebec, the production practices and inputs used result in a number of pollutants entering watercourses (MDDEP, 2007a). In Quebec, the agricultural sector produces 70% more phosphorus pollutants than what the watersheds can handle (MDDEP, 2005). According to MDDEP (2003), more than 60 % of the agricultural enterprises with surplus phosphorus are located in the Etchemin River watershed, Chaudière River watershed, St-François River watershed, Yamaska River watershed, and l'Assomption River watershed.

In Quebec, the water needs for agriculture are normally supplied by rain fall and farmers are generally counting on sub-surface drainage to balance the water requirements of their crops. The effect of sub-surface drainage on water quality is not easily measured; however, several studies have shown that sub-surface drainage increases soil erosion, sediment erosion, pesticide washing and consequently the facilitation of the transportation of these elements to streams (AAFC, 2007b; Jacob and Gilliam, 1985; Cambardella et al., 1999; Sims et al., 1998).

2.1.2 Best Management Practices and Agriculture.

In the U.S., the soil conservation movement was the first initiative in an effort to develope practical methods of managing lands to protect water quality. In Craddock and Hursh (1949), they cite the U.S. Yearbook of Agriculture (p.56): "Today better land-management practices must be inaugurated to restore a more favourable plant cover and soil structure if we wish to maintain stream and land conditions to serve our present and future needs for usable water". These better land management practices were the predecessors of the BMPs of today (Ice, 2004). More recently, the concept of BMPs has been introduced for agriculture (CCME, 2004).

The world's water quality is worsening at an alarming rate and agriculture is partly responsible; and in some cases is a major contributor (Ice, 2004; Hilliard et al., 2002). Intensification of farming has occurred in order to prevent widespread famine (Ice, 2004; Hilliard et al., 2002). One means to address this situation is to adopt agricultural practices that decrease the negative impacts on the environment.

Implementing BMPs is widely accepted as being the best possible solution to the problem of non-point source pollution from agricultural sources (Ice, 2004; Hilliard et al., 2002). However, the problem is not simple. The interactions between ecological and economic systems are many. In addition, changes in the behaviour of resource managers toward sustainable resource use, even with large potential economic and social benefits, are hard to develop (Beukes et al., 2002).

Policy makers, researchers, and educators have been attempting to develop and extend agricultural production practices with fewer negative environmental impacts. However, voluntary implementation of BMPs, even encouraged by support services or other government programs, have rarely achieved expected results. Gustafson et al. (1998, p.181) conclude that: "with regard to the lack of participation in voluntary measures, intensive programs for information, education, and advisory services to farmers are requested and necessary in order to assess pollution abatement targets within a reasonable time period.". However, a managers' risk perceptions with regard to change in practices and adoption of BMPs as well as the cost sharing between farmer and society are all part of the complexity associated with the adoption of BMPs (Collentine, 2002).

2.1.3 Factors Affecting the Adoption of Sustainable Practices.

Agro-environmental programs that encourage the use of BMPs generally make assumptions about the marginal cost to producers or the loss of income following the implementation of a BMP. In economic terms, “if the marginal cost of the good is equal to or less than the return for production of the good, the producer will choose to produce it or in this case to participate in it” (Collentine, 2002, p.19). However, by not accounting for explanatory factors, such as the farmers' risk perceptions toward adoption of best management practices, important decision parameters are ignored. Traoré et al. (1998) suggest that health hazards of farm chemicals and the availability of adequate information related to the adoption of conservation practices explain farmers' increasing concerns for environmental degradation and their attitudes toward resource conservative technology. However, their economic and financial survival was found to be a more dominant factor in the adoption decision making process. This implies that any conservation policy that does not pay enough attention to this matter is likely to fail (Traoré et al., 1998).

Furthermore, risk averse farmers may be unwilling to voluntarily accept the risk implied by the implementation of BMPs even in cases where such practices increase their expected returns. Bosch and Pease (2000) suggest that uncertainty increases the farmers’ perceived costs and reduces their willingness to implement suggested practices. According to Traoré et al. (1998, p.117), the actual adoption of conservation practices by farmers is influenced by “the extent to which they perceive environmental degradation to be a problem, their educational level, the expected crop loss to pests and weeds, the perceived health effects of farm chemical applications, and the availability of adequate information on the best management practices".

Uncertainty may increase the perceived social benefits of water quality protection and therefore increase the society willingness to pay for water quality protection. In fact, one of the most controversial questions with regard to the adoption of best management practices is the determination of who is going to pay for the BMPs implementation cost? Or, what could be considered as an appropriate government transfer to the producers?

The agricultural community recognizes that the negative externalities associated with agricultural production practices need to change. However, changing farming practices requires time and money. In many cases, water quality protection practices are known to reduce the economic risk to adopters (Bosch and Pease, 2000). In such cases, the policy needs to provide non-adopting farmers with ways to obtain more information about the risks of the practices. In cases where water quality practices increase farmers' risks, the policy instruments need to help farmers manage their risks (Bosch and Pease, 2000). This brings us back to what Gustafson et al., (1998), Traoré et al., (1998), and Collentine, (2002) were saying about the lack of participation in the water quality improvement effort. Farmers require an intensive programme of information, education, and advisory services to inform and access their water quality problems. In addition, they must value potential solutions, such as BMP implementation, and decrease their perceived risk of adopting these practices.

2.1.4 Best Management Practices in Agriculture

The Ontario Ministry of Agriculture, Food and Rural Affairs (2007, p.2) proposed the following definition of a BMP: “a practical, affordable approach to conserving a farm's soil and water resources without sacrificing productivity”. Several other studies (Hilliard et al., 2002; Logan, 1990; and Clausen and Meals, 1989) defined BMPs only in terms of their environmental efficiency. These definitions ignore the socio-economic aspects of BMPs. Analysing BMPs only in terms of environmental effectiveness ignore half the problem.

The most recognized BMPs are: minimum-tillage, soil testing, no-till, cover crops, application timing, crop advisor services, nutrient management plans, buffer strips, variable rate fertilization, and reducing pesticide use. According to Brethour et al. (2007), in 2006 the majority of Canadian farms were at least somewhat familiar with most of the beneficial management practices identified above. Nationwide, soil testing and minimum tillage were the most commonly used BMPs, with about three-quarters of the farms using these practices. Over half of the farms use application timing (58%), crop advisor services (55%) and no-till (53%). The least used practice was variable rate fertilization (10%). Usage of these practices also differs by farm size. Typically larger farm operations have the highest level of BMP adoption. Among farm types, dairy producers adopted more BMPs than other types of operations. In Ontario and Quebec, farms with more than 320 acres had the highest adoption of soil testing (92%), application timing (87%), minimum-tillage, (84%), no-till (70%), and buffer strips (62%). For all of these practices, with the exception of minimum-tillage, adoption was not significantly higher for larger farms versus mid-size farms (161 to 320 acres). However, the difference was greater when compared to smaller operations (80 to 160 acres) (Brethour et al., 2007).

2.1.5 Description of the BMPs

More specifically, here is a brief description of the BMPs considered in this study.

1) Riparian Buffer strip: Sediment and contaminant transport from agricultural soils to ditches and streams is exacerbated by steep stream banks and ditch side slopes, continuous annual row cropping, and a general lack of erosion control methods. Efforts to address these issues include establishing riparian buffer strips. Riparian buffer strips are planted, at the edge of the stream, when they capture soil particles, which protect the riparian ecosystem and slows down the migration of soil particles, fertilizer components, and pesticides from the fields (MAPAQ, 2007; SWCC, 2007; MDDEP, 2007a; and MDDEP, 2007b).

2) Reduced herbicide use: A weed control program that requires herbicide reduction, i.e.less herbicide (Atrazine), on corn fields. Several studies (Leblanc et al., 1995; Hamill and Zhang, 1997) have demonstrated that reducing herbicide use does not necessarily impair crop yields and can have financial and environmental benefits.

3) Hog slurry management: Hog slurry is being applied using a low-ramp spreader equipped with trail hoses or dribble bars. Also called surface banding, this method applies manure on the surface of the soil with less manure exposure to the surface air (Amrani, 2004). For example, a fan spreading pattern of broadcast increases odour and ammonia emission during manure spreading since manure is sprayed under pressure into the air and

travels some distance before hitting the ground. Banding, such as using a dribble bar, causes less odour problems by releasing manure near the ground at low pressure, while reducing the air contact time (Chen et al., 2001). The practice is expected to reduce nitrogen loss through ammonia volatilization and soil incorporation.

4) Animal Mix Management: Manure is a significant source of surface and ground water contamination (OMAFRA, 2007; MDDEP, 2007b; and AMAFRD, 2007). Animal mix management, as a BMP, is the production decision that decreases the amount of manure by reducing the number of animals or the mix of animals. At a certain point, this practice may be considered by the producer to satisfy the environmental constraint. The assumption is that if less manure is produced then the manure applied per ha decreases, which would have positive effects on water quality.

5) Crop Rotation: The recommended practice of gradually introducing perennial crops, such as alfalfa into the crop rotation, will protect surface soils and enhance nutrient uptake while improving soil structure, thereby improving water quality. Harvesting alfalfa can export twice the volume of nitrates as corn for the same amount of dry matter removed. Also, the use of perennial crops in rotation with corn will help to break pest cycles, while providing both positive environmental and economic benefits (AAFC, 2006; and MAPAQ, 2007).

6) Minimum tillage: The adoption of conservation practices, such as no-till, adjacent to surface water has been shown to be less harmful to the soil structure, reduces nutrient run-off, and contributes to an increase in surface residue. In addition, it keeps the soil aerated and stable (Snyder, 1999). In many situations where no-till has been adopted, soil erosion and water run-off have been significantly reduced. Eroded soil means loss of

nutrients, organic matter, future crop productivity and more nitrogen, phosphorous, and pesticide run-off into streams and rivers (MAPAQ, 2007).

2.3 Agricultural Non-point source Pollution

2.3.1 Agricultural pollutants and their sources.

There are a number of potentially negative impacts that agricultural practices may have on water quality. These includes: sediment loading, nutrient addition, pesticide pollution, which are a direct consequence of inadequate agricultural practices. In addition water quality can decrease from pathogen contamination, enrichment with organic matter, and contamination with miscellaneous chemical compounds, which are an indirect consequence of inadequate agricultural practices. Agricultural practices can also damage habitat and stream channels. Agricultural activities that cause Non-point source pollution includes confined animal facilities, grazing, ploughing, pesticide spraying, irrigation, fertilizing, planting, and harvesting activities (Hilliard et al., 2002; and USEPA, 2007).

2.3.2 Impact of Agricultural Practices

Sediment: Sedimentation occurs when wind or water run-off carries soil particles from an area, such as a farm field, and transports them to a water body, such as a stream or lake. Excessive sedimentation clouds the water, which reduces the amount of sunlight reaching aquatic plants, covers fish spawning areas and food supplies. In addition, other pollutants like phosphorus, pathogens, and heavy metals are often attached to soil particles and end up in water with the sediment. Producers can reduce erosion and sedimentation significantly by applying adequate management measures. BMPs associated with sediment control are: buffer strips, no-till, crop rotation, hog slurry management, and animal mix management (AAFC, 2006).

Nutrient: phosphorus, nitrogen, and potassium in the form of fertilizers, manure, sludge, irrigation water, and crop residues are applied to land to enhance production. When they are applied in excess of plant needs, or in a way that contravenes "the four rights" 1) Right Rate and Balance of Nutrients, 2) Right Fertilizer Form, 3) Right Placement, and 4) Right Timing. They can wash into aquatic ecosystems where they can cause excessive plant growth (CCME, 2007). This reduces swimming and boatsing opportunities, creates a polluted taste and odour in drinking water, and affects aquatic animals (CCME, 2007). Appropriate nutrient management implies that farmers implement a nutrient management plan that helps maintain high yields and does not waste money on inappropriate fertilizer use. This results in a reduction of NPS pollution. In Quebec, the Agro-Environmental Fertilizer Plan is a tool that helps producers to value their organic fertilizer and balance the nutrient need of their fields. It is also a required document, according to "Le Règlement sur les Exploitations Agricoles" that informs the authorities of the amount of organic and inorganic fertilizer applied on each field (CCAE, 2007; REA, 2007). BMPs associated with nutrient control are hog slurry management, animal mix management, as well as crop rotation.

Pesticide: used to kill pests and control the growth of weeds and fungi, these chemicals can enter and contaminate water through direct application, run-off, wind transport, and atmospheric deposition. They can kill fish and wildlife, poison food sources, and destroy the habitat that animals use for protective cover. To reduce NPS contamination from pesticides, people can apply Integrated Pest Management (IPM) techniques based on the specific soils, climate, pest history, and cropping patterns for a particular field (AAFC, 2006). IPM helps limit pesticide use and manages necessary applications to minimize pesticide movement from the field. BMPs associated with pesticide and pesticide run-off controls are: reduction of herbicide use, crop rotation, buffer strip, and minimum tillage.

2.3.3 Control Programs.

Managing the stability and the quality of the water resource is not simple: climate changes, drought, floods, expansion and intensification of agricultural activities, the growing population, and increasing water needs are all potential problems for policy makers. An integrated management plan for water resources that incorporates the economic, social, and environmental needs of a region is required to address these problems (Parson, 1995; MDDEP, 2007c).

The Federal Government of Canada relies on several regulations to assess water quality improvement and pollution control including NPS pollution. Among them the Canadian Water Act, which contains provisions for formal consultation and agreements with the provinces, the International River Improvements Act, which provides licenses for the activities that may alter the flow of rivers flowing into the United States, and the Department of Environmental Act, which assigns the national leadership for water management to the Minister of the Environment.[1] Furthermore, all provinces and territories have water pollution regulations (Environment Canada, 2007). In 2002,

[1] Other important federal regulations are the International Boundary Waters Treaty Act, Canadian Environmental Protection Act, the Fisheries Act, Navigable Water Protection Act, Northwest Territories Waters Act, Mackenzie Valley Resource Management Act, Nunavut Waters and Nunavut Surface Rights Tribunal Act, Arctic Waters Pollution Prevention Act, Canada Shipping Act, and the Dominion Water Power Act (Environment Canada, 2007).

Quebec enacted the Quebec Water Act. The goals of this regulation were to ensure protection of the resource, to manage the resource from a sustainable development perspective, and consequently to ensure public and ecosystem health. One of the measures stated in the regulation was the establishment of a watershed integrated management plan. "As a society, too often we manage water and its uses on a sectoral basis that varied according to the authorities in place or under jurisdiction on the territory. […] Sectoral water management makes it harder to assess cumulative impact. Therefore, an overall assessment approach from a sustainable-development perspective appears necessary so that actions and projects can be prioritized while taking into account their cumulative impact on the environment" (MDDEP, 2007c, p.5). Following this legislation and government orientation, several watershed and sub-watershed organizations and associations have been created to educate, and inform their respective populations of the importance of sustainable water resource use (ROBVQ, 2007; MDDEP, 2007c).

2.3.4 Necessity of site specific information

Watersheds are large geographical entities that can include several municipalities, counties, and perhaps several farms. Considering agricultural NPS pollution, differences in several physical, spatial, and economic characteristics of the watershed can impact water quality. As a result of this variation and heterogeneity, the government could not assess the water quality problem effectively with a homogeneous tool. A way to account for the heterogeneity is to use a scaling-up approach based on site specific information in order to obtain an appropriate description of the heterogeneity of a watershed.

Lovell et al. (2002, p.25.) explain that according to the "temporal, bio-physical, and institutional scale issues and their associated physical and social contexts and dynamics, a successful approach in integrated natural resource management is likely to be location-specific and time-specific to some extent. Rules or relationships that hold at one scale may not transcend scales, and "successful" approaches at one scale may even cause problems downstream". Several studies (Newbold, 2002; Frissell et al., 1986; Heathcote, 1998) have used this approach to address the heterogeneity situation in watersheds. Agricultural watersheds usually contain several farms that have different spatial, physical, and economic characteristics. In most cases, NPS pollution control programs are based on implementing BMPs. However, the optimal BMP for each farm will vary because of the heterogenous physical and economic characteristics of the farm (Lant et al., 2005; Collentine, 2002). BMP adoption is based on producers making production decisions. A uniform environmental policy on BMPs can lead to economic distortions and may not produce the results that were expected by the policy. The problem faced by policy makers is to identify adequate control strategies that are a "practical, affordable approach to conserve farm's soil and water resources without sacrificing productivity" (OMAFRA, 2007. P.9). What constitutes a BMP will depend upon local circumstances and characteristics.

In light of this, it is clear that effective NPS pollution control requires recognising of site-specific characteristics at the farm scale. No single policy is optimal across all farm types. Physical, spatial, social, and economic characteristics are all factors that make homogenous BMP policies inefficient (Taylor et al., 1992; Lintner and Weersink, 1999; Anderson and Farooqi, 2003). Environmental constraints can be placed at either the farm or the watershed scale. If applied at the farm scale it is similar to a regulatory standard that is used in industry that has heterogeneous physical, spatial, social, and economic factors.

Behavioural responses and perceptions to different policy measures must also be incorporated in the model in order to investigate the most cost effective way to achieve a given reduction in water pollution. However, lack of data, money, and time are often limiting factors in the development of a behavioural risk perception models. As reported earlier in section 2.1.3, farm managers' perception of risk with regard to the implementation of BMPs can induce cost ineffectiveness (Skop and Schou, 1998).

2.3.5 Nature of the Pollutants

NPS has become an important environmental concern for authorities in Canada and U.S. This can be explained by the nature of the NPS pollution and the complexity of assessing NPS problems. Moreover, the lack of a market for natural capital, as described by Lant et al. (2005), results in an NPS pollution problem that is a market failure. In addition, the stochastic nature of NPS pollution has an impact on the relationship between agricultural production activities and environmental quality (Shortle and Horan, 2001; Taylor et al. 1992; Weersink et al., 2002). Solutions to environmental problems are usually more efficient when they prevent pollution at the source rather than addressing the problems once the pollution is released to the environment. However, the existence of a large number of contributors makes it difficult to separate damages across farms and subsequently assign liability. The costs of monitoring such activities in agriculture are high because of the complexity of the production and environmental fate process. This makes it difficult to directly assign emissions to individual farm inputs. As a result, policy analysts increasingly rely on bio-physical models which estimate or predict environmental flows and simulate agronomic processes. While such bio-physical models will never be perfect substitutes for monitoring of actual flows, they can serve as important tools for analysis (Yiridoe et al., 1997).

2.4 Agricultural Economic Sustainability

A doubling in global food demand projected for the next 50 years poses challenges for the sustainability of food production, ecosystems and the services they provide to society. "Agriculturalists are the principal managers of global useable lands and will shape, perhaps irreversibly, the surface of the Earth in the coming decades. New incentives and policies for ensuring the sustainability of agriculture and ecosystem services will be crucial if we are to meet the demands of improving yields without compromising environmental integrity or public health" (Tilman et al., 2002, p.675).

2.4.1 Concept of Sustainability

Agricultural sustainability has been defined in many ways. Brown et al. (1987, p.715) state that "an average definition would include such elements as soil fertility and productivity (rotations, integrated pest management and biological control, tillage methods, and crop sequences), controlling pesticide and fertilizer pollution, management strategies (choice of hybrids and varieties, low cost inputs, etc.), human needs (demands for basic food and fibres), economic viability, social acceptability, ecological soundness, time span (long term as opposed to short term profitability), and philosophical ethics (implying satisfaction of spiritual and material goals of mankind)". This definition incorporates environmental, economic, and social aspects of the concept of sustainability. More as an ideal, in reality the concept of sustainability is constrained in several ways. Modern agriculture is facing two challenges. One is an economic challenge and the other is an environmental challenge (Rotz and Coiner, 2005).

2.4.2 Is Sustainability Sustainable?

Technological advances and current economic forces, including large agricultural subsidies in the United States, EU and Japan, have both increased food availability and decreased the real costs of agricultural commodities over the past 50 years. However, the resulting agricultural practices have generated externalities such as: loss in biodiversity, loss of ecosystem services, emergence of pathogens, and the long-term instability of agricultural production. Tilman et al. (2002, p.675) wrote: "The goal of sustainable agriculture is to maximize the net benefits that society receives from agricultural production […] and from ecosystem services […] and this requires increased crop yields, increased efficiency of nitrogen, phosphorus and water use, ecologically based management practices, judicious use of pesticides and antibiotics, and major changes in some livestock production practices. […] In addition, advances in the fundamental understanding of agro-ecology, biogeochemistry and biotechnology that are linked directly to breeding programmes can contribute greatly to sustainability".

"Sustainable agriculture will require that society appropriately rewards ranchers, farmers and other agriculturalists for the production of both food and ecosystem services" (Hansen 1996, p.120). One way to address this situation is for agricultural subsidies in the

United States, EU and Japan to be redirected to reward sustainable practices (Tilman 1999; Hansen, 1996; Farshad and Zinck, 1993; Schaller, 1993). As stated earlier, society must define what it wants from the agricultural industry and be aware of the environmental consequences of its choices (UPA, 2007). The authors suggest that agriculture is facing two major challenges in order to remain a viable industry. The first is an economic challenge that has contributed to the development of the second challenge, the farm impact on the environment (Rotz and Coiner, 2005).

2.5 The Mathematical Modelling Approach

2.5.1. The Linear Programming and Derivation

The mathematical modelling approach consists of building a model that can predict the costs or returns of adopting an alternative practice and then comparing these with estimates from conventional practices. Linear programming (LP) is a mathematical technique for optimizing an objective within a set of constraints. LP allows: 1) scenario analyse, 2) "what-if" analyses, and 3) to study the sensitivity of the model to changes in a given variable or a given constraint, for example trade off analysis. LP has been used to investigate agriculture and environmental economic problems. A large literature exists on linear programming and a vast number of studies have used LP as a modelling procedure.

2.5.2 Integrated Economic Bio-Physical Modelling

The application of LP that incorporates bio-physical and economic data to measure the environmental performance and economic impact of environmental regulations is called Integrated Economic Bio-Physical Modelling. Beukes et al. (2002)

considered an ecological economic simulation model to compare different management strategies and their cost effectiveness in the Nama Karoo (South Africa) region. In their model 7000 ha of farm land were represented. The model contained three interactive sub-models: vegetation, a production, and financial models. They assumed each ha to be homogeneous and selected an *annual* time step for the simulation. As a result, the farms' spatial and temporal heterogeneity were not taken into account. This article provides insight into the modelling of different beneficial management practices but does not address the problem of spatial heterogeneity. Taylor et al. (1992) used a similar approach to examine the economic incentives and other mechanisms to offset NPS pollution from agriculture using a bio-physical simulator for representative farms in the Willamette Valley in Oregon. However, they did not include the spatial heterogeneity of the farms.

A more complex economic bio-physical model is described in Cai et al. (2003); where physical, spatial, behavioural, and economic heterogeneity were considered. The proposed model, applied to a case study of water management in the Syr Darya River basin in Central Asia, has the ability to dresses interrelationships between essential hydrologic, agronomic, and economic components and to explore both economic and environmental consequences of various policy choices. In order for the model to adequately simulate water allocation mechanisms and policies, agro-climatic variability, multiple water uses and users, several physical indicators, economic data, and behavioural relationships are considered. Furthermore, they are integrated into a system whose core is a multi-period network model of the river basin, ranging from crop root zones to the river system, and whose objective is to maximize total water use benefit from irrigation, hydropower generation, and ecological water use. Many other studies have used a similar approach to respond to heterogeneous, environmental, and economic problems. For example, Forster et al. (2000) employed a bio-economic model of the Erie Basin in Ohio to examine the relationship between alternative tillage practices and environmental and economic impacts. McKinney et al. (1999) and Rosegrant et al. (2000) introduced an integrated economic hydrologic modelling framework that accounts for the interactions between water allocations, farmer input choice, agricultural productivity, non-agricultural water demand, and resource degradation in the Maipo River Basin in Chile. Qiu (2005) used a Multi-Criteria Decision Making model (MCDM) to help farmers select a farming system from a finite set of alternative farming systems. Schou et al. (2000) presented an integrated economic and environmental model of agricultural production effects on the environment in Denmark.

2.5.3 Integrated Decision Support System Tool in Agriculture

The problem with Integrated Economic Bio-Physical modelling is its limited flexibility. Characteristics of a model that estimates the effect of agricultural practices on resource quality should include: the intensive and extensive management choices available to producers, multiple objectives to be optimized, and heterogeneity (Weersink et al., 2002). These types of models are called Decision Support System (DSS) models. In general, DSS models are computerized systems that help make decisions (Georgetown University, 2007). Agricultural decision making is an area where DSS modelling can be particularly effective when addressing questions of economic and environmental trade-off. This is because DSS has the capacity to integrate a wide range of management choices, can handle multiple objectives, and can account for the spatial, environmental, and economic heterogeneity.

2.5.3.1 GIS Based Decision Support System for Water Quality Management.

Although many definitions of Geographic Information Systems (GIS) have been proposed, the most commonly used "is a system for capturing, storing, checking, integrating, manipulating, analysing and displaying data which are spatially referenced to the earth. This is normally considered to involve a spatially referenced computer database and appropriate applications software" (Association for Geographic Information, 1997, p.6). When integrated with a DSS and used for water quality management, a GIS can be a very powerful tool when dealing with economic, agronomic, institutional, behavioural, and hydrologic heterogeneity. Srinivasan and Engel (1994) developed a spatial DSS model to assess agricultural NPS pollution using a GIS. With minimal user interaction, the spatial DSS assists with extracting the input parameters. Further, the spatial DSS assists with visualizing and analyzing the output for multiple objectives and parameters. Other studies have used a similar modelling approach (Lant et al., 2005; Engel et al., 2003; Osmond et al., 1997; McKinney and Cai, 2002).

2.6 Summary

In this literature review, several topics were discussed. First, the interrelationship between the agricultural sector and water quality and the use of best management farming practices to deal with NPS pollution problems was highlighted. This included describing factors affecting the adoption and the non-adoption of best management practices among farmers, and described several farming practices considered as best management practices. Factors that were highlighted included asymmetric information, risk perception, and the farm economic context. Second, the necessity of site-specific information when conducting economic ecological modelling was stressed. Following this, NPS pollution and the challenges that face policy makers and the agricultural community to control such pollution were discussed. Existing control regulations in Quebec/Canada and the U.S. were described. The political paradox related to agriculture and environment was explained and the concept of sustainability and its relevance in the context of modern agriculture were discussed.

Furthermore, the mathematical modelling and linear programming advantages, derivations, and numerous applications were described. The concept of mathematical modelling was extended to include integrated bio-physical economic modelling and its advantages and disadvantages were described. This concept was extended to integrated decision support system dealing with water quality issue. A GIS based DSS was introduced and several articles and studies that used similar approaches for agricultural water quality were discussed.

Chapter 3: Methods

3.1 The WEB's Project

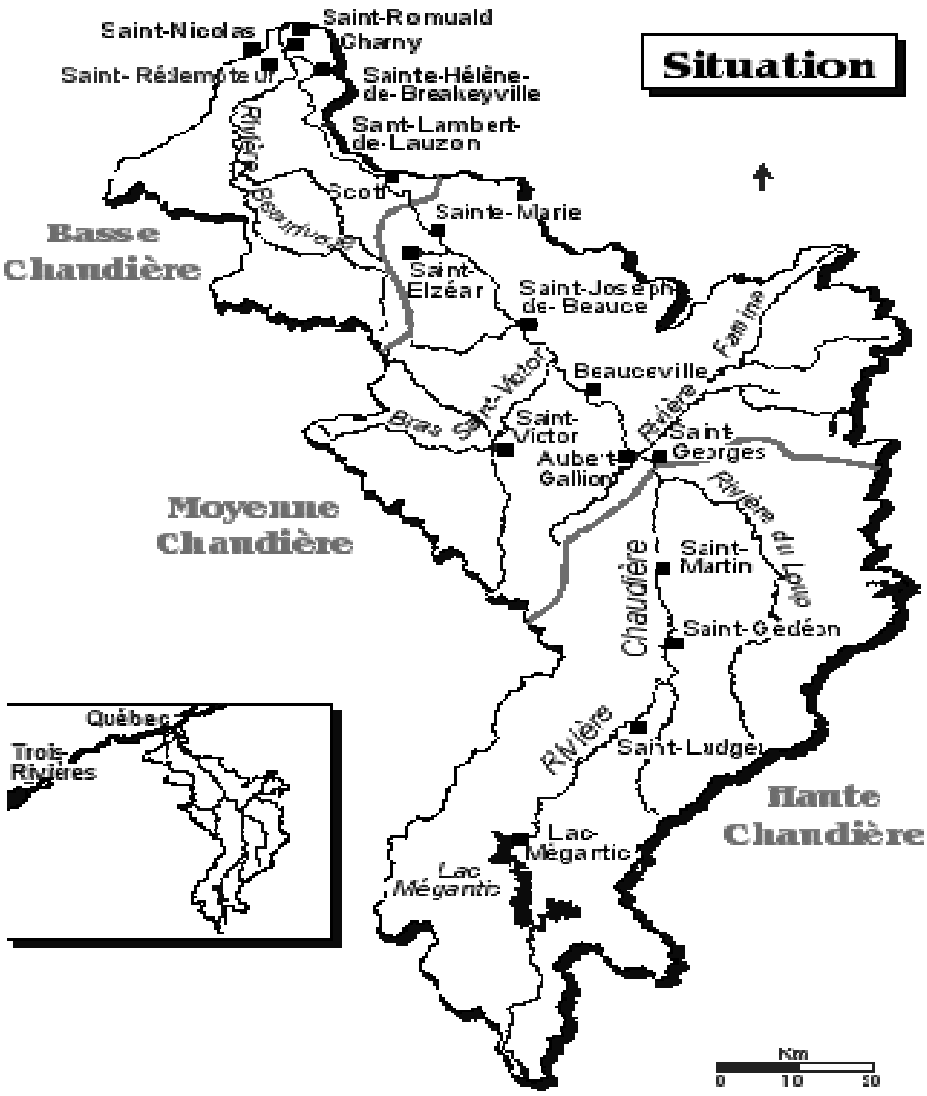
The Watershed Evaluation of Beneficial Management Practices (WEB's) project includes seven watershed sites across Canada. The Quebec WEBs study is located in the Chaudière River Basin. Organizations involved in the project include: Agriculture and Agri-Food Canada (AAFC), the Research and Development Institute for the Agri-Environment (IRDA), and the Club de Fertilisation de la Beauce inc. (CFB), in collaboration with Laval University and McGill University. More specifically, the economic part of the study addresses the issue of agricultural NPS pollution in the Bras d'Henri sub-watershed of the Chaudière River Watershed. Its objectives were to quantify, on a watershed scale, the relative environmental and economic performance of selected beneficial management practices to mitigate such things as soil erosion, run-off, and sedimentation into streams and rivers. The WEBs project was begun in 2004 (AAFC, 2007a).

3.2 Description of the Watershed

3.2.1. Location of the Chaudière River Basin.

Located on the south shore of the St-Lawrence River near Quebec City, the Chaudière River Watershed drains an area of 6, 682 km^2. Bound in the south by the U.S. border, in the east by the Etchemin, Daaquam and Saint-Jean-Sud-Ouest watersheds and in the west by the Saint-François, Bécancour, du Chêne, and du Ruisseau Bourret Watersheds. The Chaudière River takes its source from Lake Megantic at the very south end of the watershed and flows northerly toward the St-Lawrence River. The Watershed has 12 sub-watersheds. Its four primary sub-watersheds are: Du Loup River, Famine River, Le Bras St-Victor, and the Beaurivage River (MDDEP, 2007d). The others are Basse Chaudière, Haute Chaudière, Abénaquis, Araignées, Samson, Tring, Arnold, and Veilleux. See Appendix 1 for a map of all the Sub-Watersheds.

Figure 3. 1 Location of the Chaudière River Basin.

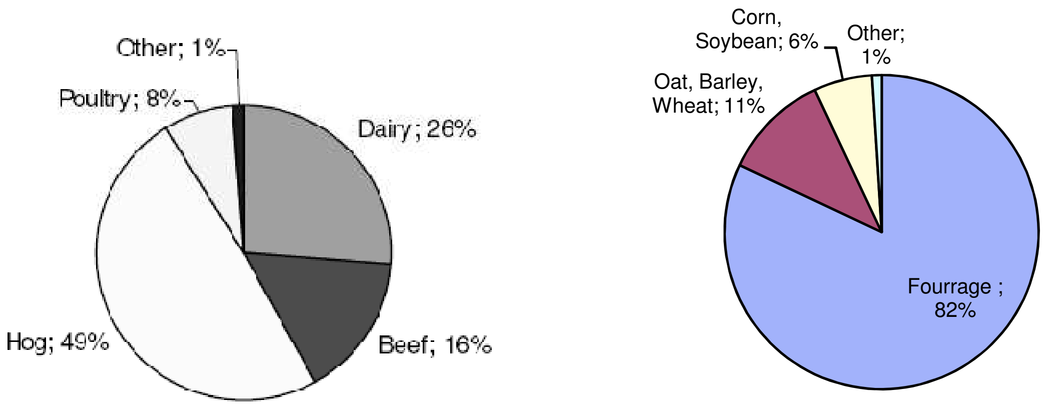


Source : MDDEP, 2007d.

3.2.2. Watershed Environment.

The Chaudière River Basin has approximately 63% of its area in forest. The agricultural land covers 33% of the watershed, but the cultivated agricultural land covers only 17%, which represents 112,303 ha. Forage crops cover 82% of the cultivated agricultural land of 92,088 ha. There are 178,000 animal units in the watershed; where 49 % are hog, 26 % are dairy cattle, 16 % are beef, and 8 % are poultry. The industrial sector is diversified and is made up of more than 650 small and medium sized enterprises in the manufacturing industry. Among them, approximately 75 enterprises are prove to have significant effects on water quality and more than 30 are in the agricultural industry. There are 2,888 farms and 173,129 people in the watershed. Overall, the watershed contains 113 municipalities.

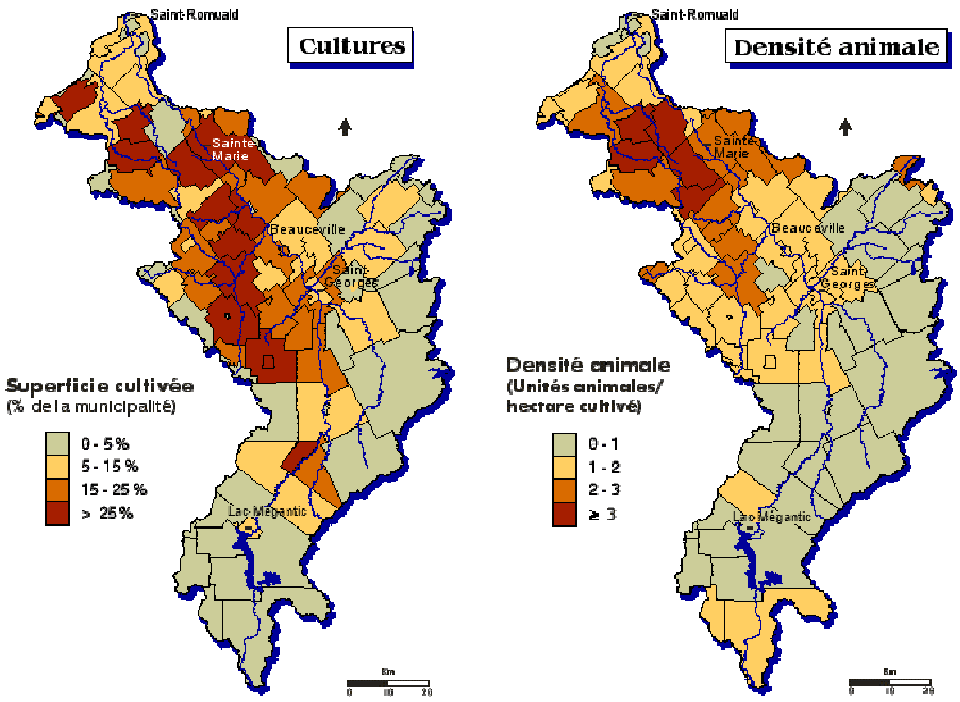
Figure 3. 2 Description of the livestock herd of the Chaudière River Watershed.



Source: MAPAQ, 2006 and MDDEP, 2007d.

Figure 3.3 maps of the intensity of crop and animal production in the Chaudière River watershed. A particularly intensive sector of the basin is in the north-west of the basin where the Beaurivage sub-watershed is located. The Beaurivage sub-watershed (see Appendix 1) has been identified as the sub-watershed where agricultural practices have the greatest impact on water quality (MDDEP, 2007d). More than 50% of the intensively cropped land is located in the Beaurivage sub-watershed. Furthermore, the Beaurivage sub-watershed also has very high animal density. Over 50% of its area has more than 2 animal units per ha and 30% has more than 3 animal units per ha (MDDEP, 2007d).

Figure 3. 3 Map of the intensity of animal production and crop production.



Source: MDDEP, 2007d.

In 1996, the water quality indexes indicated a satisfactory quality for the Chaudière River basin and its main tributaries (MDDEP, 2007d). However, the Bras St-

Victor River, the Beaurivage River, and the Bras d'Henri River showed a significant level of water pollution. Phosphorous and nitrogen concentrations were important factors in determining the poor water quality in the Beaurivage sub-watershed where the Bras d'Henri River is located. These high concentrations were the result of untreated sewage waste of some municipalities and the intense agricultural activities in these sub-watersheds (MDDEP, 2007d).

3.3 Best Management Practices

3.3.1 Riparian Buffer Strip.

There are three riparian buffer strips widths considered in the model: 1m, 3m, and 5m. The implementation costs are in $ per meter of buffer strip per year and only the 5m wide buffer strip is wide enough to generate revenue. The following assumptions were made concerning the buffer strips: (1) buffer strips did not significantly affect the yield of the field where they were implemented, and (2) the price of implementing a buffer strip was homogeneous throughout the sub-watershed. The model took into account the opportunity cost of implementing a buffer strip. The cost of implementing a buffer strip was estimated by CRAAQ (2007). In CRAAQ (2007) they estimate the cost of implementing 1000 meters long double sided buffer strip of 1m, 3m, and 5m wide. $/m were obtained by dividing the estimated cost by 2000 (1000X2).

Table 3. 1 Costs of the riparian buffer strip

Buffer Strip Width	*1m*	*3m*	*5m*
Costs			
Inputs	$19.04	$57.12	$17.60
Cultural Operations	$13.00	$31.43	$70.23
Other expenses	$0.00	$0.00	$28.90
Total cost per 1000 m for two sided strips (A)	$32.04	$88.55	$116.73
Total cost per 1000 m for one sided strips B=(A/2)	$16.02	$44.28	$58.37
Total cost per m of buffer strip (B/1000)	$0.016	$0.044	$0.058

Source: CRAAQ, 2007.

3.3.2 Reduced pesticide use on corn

This BMP consisted of applying 70% of the recommended pesticide application rate. Therefore, this implies a 30% reduction in herbicide costs. The costs were estimated on a yearly basis per hectare and were homogeneous throughout the watershed. The model accounts for the opportunity cost of reduced herbicide application on corn. Following an e-mail message from Professor Alan K. Watson[2] (July 16th 2007), it was assumed that this BMP would reduce corn yield by 15%. The herbicide cost reduction was determined using Agri-réseau (2007a) and estimated to be $32.92 per ha per year.

Table 3. 2 Reduced herbicide on corn.

Cost reduction	$32.92

Source: Agri-réseau, 2007a.

3.3.3 Hog slurry management.

Utilization of a low ramp sprayer equipped with dribble bar requires extra cultivation time. The Ministère de l'Environnement, du Développement Durable et des

[2] Professor, Department of Plant Science, Macdonald Campus of McGill University.

Parcs (MEDDP) estimates that this extra time costs $0.25 per m3 of manure (MDDEP, 2006b).

3.3.4 Animal mix management.

Animal mix, as a BMP, reduces the amount of manure produced on the farm by decreasing animal numbers or types. In this study, dairy production, hog production, beef production, and poultry production were modelled. However, this BMP was only available for hog and beef production. Dairy and poultry production are produced under supply management and therefore it was assumed that these would remain constant. However, in hog and beef production animal numbers can be viewed as decision variables. Table 3.3 presents the cost of production per animal capacity per year excluding the feeding costs of each animal production, for example if a fattening hog producer has 2,000 places as capacity, it was assumed that he is doing 2.95 production cycles per year, which gives (2.95 * 2000)=5,900 animals. The costs of producing these 5,900 animals were divided by the number of places available, which gives the cost of production per year per animal capacity. It was assumed that the cost of production and the number of production cycles were homogeneous throughout the watershed.

In the dairy production budget it was assumed that each cow produced 8,000 litres of milk. Costs of producing heifers were included in the cost of producing a dairy cows. The model accounted for the nutritional requirement costs of the animal. It was assumed that each cow had one calf per year. This budget includes the revenue from selling the calf and excludes nutritional costs. The fattening beef production budget was based on a farm having 1.27 cycles of production per year. For the fattening hog production budget, it was assumed that the farm had 2.95 cycles of production per year. The piglet production budget was based on a farm having 6.84 production cycles per year. The piglets arrived at the nursery at approximately 20 days of age at 5.5 kg and leave at approximately 60 days of age at about 20 kg. Afterwards, the piglets were transferred to the fattening facility. The sow production budget was based on a farm that produced 21.9 piglets per year per sow and the piglets were sold at 5.5 kg at approximately 20 days old. The production budget for broilers was based on a farm having 6 production cycles per year.

Table 3. 3 Animal production budget per year per animal capacity ($).

	Dairy cows[1]	Cow Calf[2]	Fat. Beef (1.27 cycle)[3]	Fat. Hog (2.95 cycles)[4]	Piglet (6.84 cycles)[5]	Sow[6]	Broiler (6 cycles)[7]
Revenue	$5 986.45	$919.33	$1 452.26	$453.09	$402.19	$984.74	$13.30
Expenses	$2 415.64	$279.53	$918.81	$214.70	$258.83	$359.32	$4.32
I. S. A. T.O [8]	$2 413.05	$295.00	$48.11	$61.66	$40.22	$223.03	$1.01
Net Farm Income	$1 157.76	$344.80	$485.34	$176.73	$103.15	$402.39	$7.97

(1) Source: CRAAQ, 2004. (2) CRAAQ, 1998. (3) CRAAQ, 1999. (4) CRAAQ, 2006a. (5) CRAAQ, 2006b. (6) CRAAQ, 2006c. (7) CRAAQ, 2008. (8) I.S.A.T.O stands for Interest, Salary and cost of life, Amortization, Taxes, and Other expenses.

3.3.5 Crop management

The BMP crop rotation consists of optimizing the crop mix on the farm. The farm maximizes the net return from its crop mix taking into account the nutrient requirements of its herd and/or the environmental constraint. The conventional crop budget is described in Table 3.4 and the conventional crop yield in Table 3.5. Inputs represent the cost of all inputs such as: fertilizers, pesticides, and seeds. Cultural operations account for the cost of operations such as: ploughing, seeding, spraying, harrowing, harvesting, and transporting. Other costs include drying, storing, and marketing costs.

Table 3. 4 Crop cost of production for conventional tillage practices ($ per ha).

	Hay	Corn	Forage Corn	Oats	Barley	Wheat	Soybean	Canola
Inputs	$223.17	$563.61	$373.57	$204.50	$294.80	$325.80	$358.98	$239.83
Cultural Operations	$105.22	$125.08	$211.64	$79.83	$81.83	$137.68	$119.80	$110.22
Other	$219.21	$648.44	$193.85	$323.57	$350.95	$376.76	$231.76	$305.16
Total expenses	$547.60	$1 337.13	$779.05	$607.90	$727.58	$840.24	$710.54	$655.21

Source: Agri-réseau, 2007a, 2007b, 2007c, 2007d, 2007e, 2007f, 2007g, 2007h.

3.3.5.1 Minimum tillage

Minimum tillage was considered in the model for every crop except hay, i.e. corn, oats, barley, wheat, soybean, canola, and forage corn. The costs of production were assumed to be homogeneous throughout the watershed. Table 3.5 presents the crop production yields by tillage practices and Table 3.6 presents the costs of production of each crop under minimum tillage practice.

Table 3. 5 Crop production yields by tillage practices (kg per ha)

	Hay	Corn	Forage Corn	Oats	Barley	Wheat	Soybean	Canola
Conventional till	4 997.5	6 591.0	14 863.0	1 853.0	2 083.5	2 083.5	2 287.0	1 239.0
Minimum tillage	N/A	6 063.7	14 863.0	1 791.3	2 083.5	2 083.5	2 172.7	1 239.0

Source: (FADQ, 2007; Morand, 2004; Agri-réseau, 2007a, 2007b, 2007c, 2007d, 2007e, 2007f, 2007g, 2007h.

Table 3. 6 Crop cost of production for minimum tillage practices ($ per ha)

	Corn	Forage Corn	Oats	Barley	Wheat	Soybean	Canola
Inputs	$563.61	$373.57	$207.78	$294.80	$325.80	$358.97	$239.83
Cultural Operations	$85.76	$178.72	$52.08	$45.61	$101.52	$79.49	$74.76
Other	$623.46	$190.00	$325.75	$348.63	$374.68	$224.84	$306.52
Total expenses	$1 272.83	$742.29	$585.61	$689.03	$802.00	$663.30	$621.12

Source: (FADQ, 2007; Morand, 2004; Agri-réseau, 2007a, 2007b, 2007c, 2007d, 2007e, 2007f, 2007g, 2007h.

3.4 Animal Nutrient Requirement

Animal nutrient requirements were estimated from three sources: (1) Dissart (1998), (2) the National Research Council (NRC) (1994), (3) NRC (1998), (4) NRC (2000), (5) NRC (2001), and (6) Cheeke (1999). Each was used as a reference and guideline to construct the nutrient requirement component of the model. It should be understood that these estimates were sometimes based on diets and dietary energy concentrations provided by NRC and local organizations. Since crops grown by selected farmers are not identical, the values given below should be viewed as estimates.

The model considers various types of animal production and nutrient requirements vary by animal production. However, in general the nutrient estimates include energy, protein, and macro minerals.

3.4.1 Dairy Production

Dairy farm heterogeneity in terms of number of animals was considered in the model. However, milk production per cow (i.e. 8000 l per cow) average weight per animal (i.e. 650 kg per cow) milk composition (i.e. 4 % M.F) and the yearly life cycle (i.e. 307 days in lactation and 58 dry days) was considered to be homogeneous among all dairy farms in the watershed. The following elements were chosen to estimate the dairy cattle nutrient requirements. Dry Matter Intake (DMI) and Total Digestible Nutrient (TDN) were used because data were available for both the energy requirement of the animals and the value of the feeds. These are reported as TDN, Net Energy for Lactation (NEL), which expresses the requirements for maintenance, pregnancy, milk production and live weight change, and other energy requirements; such as Metabolic Energy (ME) and Digestible Energy (DE) for both cows and heifers, and Net Energy for body Gain (NEG) and Net energy for maintenance (NEM) for heifers only. The Degradable Intake Protein (DIP) and Undegraded Intake Protein (UIP) system, based on absorbed protein (AP) was not used to estimate the nutrient requirements of dairy cattle because of the lack of extensive data on the degradability of protein in feeds limits the use of the absorbed protein (AP) system in this case. Other nutrients that were included were: Calcium (Ca), Phosphorous (P) and Potassium (K).

Table 3. 7 Dairy Cattle Nutrient Requirements.

Nutrients	Dairy cows (650 kg)	Dry Cows (650 kg)	Heifer 0-6 months (150 kg)	heifer (6-15 months) (250 kg)	heifer (>15 months) (400 kg)	Mature Bull
Dry Matter Intake (kg)	8 541.00	4 982.25	1 423.50	2 602.00	3 577.00	4 000.00
Total Digestible Nutrients (kg)	1 646.15	2 179.05	982.22	1 717.32	2 181.97	2 200.00
Net Energy for Maintenance (Mcal)	0.00	0.00	2 419.95	4 111.16	5 007.80	4 600.00
Net Energy for body Gain (Mcal)	0.00	0.00	1 537.38	2 549.96	2 933.14	0.00
Net Energy for Lactation (Mcal)	12 811.50	4 887.35	0.00	0.00	0.00	0.00
Metabolisable Energy (Mcal)	23 146.11	8 015.40	3 701.10	6 426.94	8 119.79	8 000.00
Digestible Energy (Mcal)	26 733.33	9 573.95	4 298.97	7 519.78	13 199.13	9 720.00
Crude Protein (kg)	1 366.56	408.80	227.76	364.28	429.24	400.00
Calcium (kg)	49.54	15.70	7.40	10.67	10.37	12.00
Phosphorus (kg)	31.60	9.49	4.41	7.81	8.23	7.60
Magnesium (kg)	17.08	7.97	2.28	4.16	5.72	280.00
Potassium (kg)	76.87	32.38	9.25	16.91	23.25	26.00

Source: (Cheeke, 1999; NRC, 2001; and Dissart, 1998)

3.4.2 Hog Production

Hog farm heterogeneity, in terms of the number of animals, was considered in the model. However, the overall nutrient requirements of each animal were assumed to be homogeneous throughout the watershed. Each weight category of animal and length of time on feed was considered and weighted to determine the global nutritional requirement of a piglet, for example the piglets have three different feeding phases that take 20 days from 0 to 5 kg, 22 days from 5 to 10 kg, and 22 days from 10 to 20 kg. The overall nutrient requirements of piglets was broken down into 31% in phase one and 34% in each of phases two and three. Afterwards, the piglets were transferred to a fattening facility and again each weight category time length was considered and weighted to determine the global nutritional requirement of a fattening hog, for example the piglet were transferred to the fattening facility at 20 kg and 64 days old. The first fattening feeding phase takes 43 days from 20 to 50 kg, and the second fattening phase takes 73 days from 50 to 110 kg. The overall fattening hog ration was allocated 37 % to the first phase and 63% to the second phase. Furthermore, sows have different nutrient requirements depending on their life cycle. The yearly life cycle of a sow is 114 days of gestation, then 23 days of lactation, and then 12 days of reconditioning. A sow produces 2.44 cycles per year, which is 56 days of lactation and 309 of non gestation. A similar approach was used for piglets and fattening hogs to estimate the nutrient requirement of a sow. As a result, the unit of measurement was per year per animal capacity since the rotation rate of the herd was considered.

The following elements were used for the swine nutrient requirements. Digestible Energy (DE) was used since it is more accurate than Metabolizable Energy (ME) (Cheeke, 1999). Also, DE values are available for most commonly used feeds. Crude content was not taken into consideration because utilization of crude fiber by non-ruminants has been shown to vary considerably (Cheeke, 1999). Other nutrients included in the analysis were: Crude Protein (CP), Calcium (Ca), Total Phosphorus, and Magnesium (Mg). Table 3.8 shows the swine nutrient requirements.

Table 3. 8 Nutrient requirement of swine farm per year per animal capacity.

Nutrients	Piglet (6.84 cycle 0-20 kg)	Growing and Finishing Pig (2.95 cycle 20-110 kg)	Adult Boars	Sow (56 days lact. 309 days n-lact[1].)
Digestible Energy Intake, Kcal	820.65	3098.30	2316290.00	2953588.72
Metabolizable Energy Intake, K cal	783.64	2982.33	2226135.00	2838628.68
Crude Protein (kg)	46.79	123.30	83.22	109.09
Calcium	1.82	4.80	5.20	6.63
Phosphorus	1.51	3.89	4.16	5.31
Sodium	0.24	0.91	1.04	1.48
Magnesium	0.10	0.36	0.28	0.35

Source: Cheeke 1999; NRC, 1998; and Dissart, 1998.
(1) "lact." Stands for lactating and "n-lact." stands for non-lactating.

3.4.3 Poultry Production

Poultry farm heterogeneity in terms of number of animals was included in the model. However, each animal was assumed to be homogeneous throughout the watershed. Table 3.9 describes the nutrient requirements for broiler production. The unit of measurement was animal capacity per year, which incorporated the rotation rate of the flock. By knowing how many animal places a producer has, the nutrient requirement for one year per place could be determined. A broiler has three feeding phases. Phase 1: 21 days, phase 2: 21 days, and phase 3: 14 days. Consequently, the total nutrient requirements of broilers were divided as follows: 38 % in phase one, 38% in phase 2, and 24 % in phase three. A corrected-nitrogen ME for nitrogen retained in the body was used. The following nutrients were included: crude protein (CP), calcium (Ca), and phosphorus (P).

Table 3. 9 Nutrient Requirement of Poultry farm per year per animal capacity.

Nutrient	Broiler (6 cycle of 8 weeks)
N-corrected Metab. Energy (Kcal)	36 864.00
Crude Protein (kg)	2.39
Calcium (kg)	0.11
Phosphorus (Kg)	0.05

Source: Source: Source: Cheeke, 1999; NRC, 1994; and Dissart, 1998.

3.4.4 Beef Production.

The number of beef animals varied by farm. However, each animal was assumed to be homogeneous throughout the watershed. Table 3.10 describes the nutrient requirements of cow-calf production and fattening beef production. Each cow was assumed to have one calf per year and the nutrient requirements of the calf were included in the nutrient requirements of the cow. The unit of measurement was animal capacity per year. In other words, the rotation rate of the herd was considered. By knowing how many animal places a producer has, it was possible to determine the nutrient requirements for one year per place. The following elements were used to estimate the nutrient requirement: Dry Matter (DM), Energy for body Gain (Eng), Energy for maintenance, Protein (P), Calcium (Ca), and Phosphorus (P).

Table 3. 10 Nutrient requirement of beef cattle.

Nutrient	Cow & Calf	Fattening Beef (1.27 cycles 430-635kg)
Dry Matter (kg)	3 766.55	4861.00
Energy for Maintenance (Mcal)	4 520.16	N/A
Energy for body Gain (Mcal)	2 668.00	N/A
Total Net Energy (Mcal)	7188.16	6430.92
Total Digestible Nutrient	1315.23	N/A
Protein (kg)	727.01	636.88
Ca (kg)	17.12	5.57
P (kg)	12.6	3.9

Source : Cheeke, 1999; NRC, 2000; Shur Gain, 2006.

3.4.5 Crop Nutritional Values and Prices.

The following is a description of the nutritional values for each crop (Table 3.11). Note that raw soybean and raw canola are not part of the nutritional values. They have to be transformed to be consumed by animals. Canola is not included in the table because soybean is the feed used in this area. Table 3.11 provides the prices for each crop in the region.

Table 3.11 Crop production price in $ per ton**

Price	Hay	Corn	Wheat	Oats	Barley	Soybean	Canola	Forage Corn
$/t	130	209.2	350.63	345.78	326.54	336.53	631	50

Source: Agri-réseau, 2007a, 2007b, 2007c, 2007d, 2007e, 2007f, 2007g, 2007h.
** For corn, wheat, oats, barley, soybean, and canola the prices listed above account for the ASRA compensation.

Table 3. 12 Crop nutritional values in kg or Mcal per kg of ingredient.

	Hay	Corn	Oats	Barley	Wheat	Corn Forage	Soybean Crab	Supp. dairy cows	Supp. Dry Cow	Supp. Heifer (>15)	Supp. Heifer (7-15)	Supp. (0-6)
Dry Matter (kg)	0.8900	0.8662	0.8800	0.8610	0.8809	0.3500	0.8913	0.9900	0.9900	0.8884	0.8800	0.9900
Crude protein (kg)	0.1500	0.0765	0.1293	0.1150	0.1397	0.0291	0.4800	0.0000	0.0000	0.4000	0.4000	0.0000
Total Energy (Mcal)	4.8200	7.5600	5.7000	6.7400	7.4300	2.2540	7.5500	0.0000	0.0000	6.2000	0.0620	0.0000
Total Digestible Nutrient (kg)	0.2786	0.0303	0.0991	0.0742	0.0358	0.1043	0.0604	0.0000	0.0000	0.0860	0.0860	0.0000
Calcium (kg)	0.0076	0.0001	0.0008	0.0005	0.0005	0.0009	0.0022	0.1212	0.0350	0.0230	0.0230	0.1212
Phosphore (kg)	0.0025	0.0026	0.0035	0.0037	0.0035	0.0009	0.0068	0.0808	0.0700	0.0130	0.0130	0.0808
Magnesium (kg)	0.0021	0.0010	0.0013	0.0013	0.0015	0.0006	0.0028	0.0404	0.1000	0.0080	0.0080	0.0404

Source: Shur Gain, 2006.

3.5 Environmental Coefficients

3.5.1 Overview of GIBSI

The GIBSI (Gestion Intégré par Bassin versant à l'aide d'un Système Informatisé) model comprises a hydrologic, soil erosion, agro-chemical transportation, and a water quality simulation model. It includes several management modules, such as land use, agricultural production, and reservoir management modules, that assist in the simulation process. Furthermore, GIBSI includes a geographical information system (GIS) that links together all of the spatially heterogeneous information from the different modules. In other words, GIBSI is a grouping of management modules that interact and share information together via the GIBSI framework in order to generate simulations of various water quality parameters.

Following are the models that GIBSI interacts with in the simulation process. HYDROTEL is a hydrologic distributed model that computes various hydrologic parameters. Thus, the hydrologic calculations are done independently on the Relatively Homogeneous Hydrologic Unit (RHHU) in order to account for the spatial variability of the topography, crops, soil types, and of the meteorological variability within the watershed (INRS-ETE, 2007). Algorithms of the Revised Universal Soil Loss Equation (RUSLE) for sediment transport are used to model soil erosion and sediment transport. Modelling of agricultural-chemical transport and transformations are based on the N, P, and pesticide transport algorithms of the Soil and Water Assessment Tool (SWAT). The water quality model is built around QUAL2E, a standard water quality model that simulates various environmental parameters such as the N and P cycle, coliform growth, and water temperature. The sediment routing algorithm of SWAT and EPIC, which accounts for streambed deposition and bed degradation, has been added to QUAL2E. The computational units used in GIBSI consist of elementary sub-watersheds units called RHHU. Table 3.13 presents summary statistic and description of RHHU.

Table 3.13 Summary statistics and descriptions of the RHHUs.

RHHU descriptions and details.	**Minimum**	**Maximum**	**Std. Dev.**	**Average**	**Sum**
RHHU size (ha)	0,44	569,24	99,34	150,40	9174,68
% of RHHU cultivated	17,70	99,80	22.38	66,73	63,00
% of RHHU cultivated in hay and pasture	14,47	94,07	15,72	55,61	55,75
% of RHHU cultivated in cereal	0,45	52,88	12,06	19,61	19,54
% of RHHU cultivated in corn	0,00	84,98	18,40	24,78	25,30

Source: INRS-ETE, 2007

3.5.2 The environmental parameters

GIBSI allows for a wide range of environmental parameters to be measured. In this study five environmental parameters were included: (1) Nitrogen, (2) Phosphorus, (3) Sediment, (4) E.Coli., and (5) Pesticide (atrazine). The reasons for this selection were: (1) in every case, agriculture is known to be a major source of emission, and (2) each selected environmental parameter was known to have a severe environmental impact on either human health or the ecosystem balance. Following is a short description of each environmental parameter.

1) Nitrogen and Phosphorus are nutrient elements that when found in excess in water, can accelerate the aging of lakes and rivers and make them eutrophic. As a result, it causes algae blooms that consume oxygen, which severely affects the ecosystem. The primary source of nitrogen and phosphorus pollution is

agriculture and the main abatement strategy is agricultural BMPs (Carpenter et al., 1998). Table 3.14 presents summary statistic of nitrogen coefficients and table 3.15 presents the summary statistics of phosphorus coefficients. The coefficients from 3m wide buffer strip and 5m wide buffer strip have been excluded from the table for simplicity.

Table 3.14 Summary statistics of nitrogen coefficients.

Base case scenario				1m wide Buffer Strip			Pesticide reduction	Dribble bar		
Summary Statistic	on hay	on cereal	on corn	on hay	on cereal	on corn	on corn	on hay	on cereal	on corn
	kg per ha	kg per ha	kg per ha	kg per m	kg per m	kg per m	kg per ha	kg per m3	kg per m3	kg per m3
Min	1,24E-03	2,22E-03	5,88E-04	-4,98E-03	-7,69E-03	-3,95E-03	-1,03E-02	6,89E-10	3,82E-06	0,00E+00
Max	6,98E-02	2,14E-01	2,34E-01	-1,83E-07	-2,14E-06	-3,08E-06	2,89E-06	1,15E-06	3,06E-01	1,37E+01
Average	1,66E-02	4,65E-02	4,40E-02	-4,38E-04	-8,84E-04	-5,40E-04	-1,85E-03	3,46E-07	4,82E-02	4,47E-01
Std. dev.	1,59E-02	4,62E-02	5,33E-02	8,16E-04	1,35E-03	7,78E-04	2,18E-03	3,28E-07	6,46E-02	1,79E+00
Median	1,02E-02	2,82E-02	2,34E-02	-1,38E-04	-4,26E-04	-2,59E-04	-1,00E-03	2,42E-07	1,82E-02	5,35E-02

Table 3.15 Summary statistics of phosphorus coefficients.

Scenario de Base				1m wide Buffer Strip			Pest. reduction	Dribble bar		
Descriptive Statistic	on hay	on cer	on corn	on hay	on cer	on corn	kg per ha	kg per m3	kg per m3	kg per m3
	kg per ha	kg per ha	kg per ha	kg per m	kg per m	kg per m	Corn per ha	hay per m3	Cer per m3	corn per m3
Min	0,00E+00	0,00E+00	1,16E-04	-4,20E-03	-2,43E-03	-2,00E-03	0,00E+00	-1,03E-13	-2,59E-17	-1,99E-17
Max	2,97E-02	1,07E-01	1,93E-01	3,88E-10	0,00E+00	-2,99E-06	0,00E+00	1,16E-13	2,71E-17	1,16E-14
Average	5,09E-03	1,69E-02	3,36E-02	-3,24E-04	-2,12E-04	-3,46E-04	0,00E+00	5,24E-15	2,39E-19	7,42E-16
Std. dev.	6,20E-03	2,18E-02	4,44E-02	6,96E-04	4,24E-04	4,67E-04	0,00E+00	2,78E-14	5,08E-18	1,76E-15
Median	2,72E-03	8,19E-03	1,55E-02	-8,51E-05	-7,51E-05	-1,37E-04	0,00E+00	-2,27E-18	0,00E+00	1,72E-16

2) Sediment refers to the loose particles of clay, silt and sand that suspend in a body of water and eventually settle to the bottom. It is a natural component of an ecosystem, but in excessive amounts creates harmful conditions for plants and animals. During periods of rain or melting snow, soil and other particles flow off the land and into waterways. Suspended sediment clouds the water, preventing light from penetrating the leaves and stems of submerged aquatic vegetation. High concentrations of toxic

materials also may be present in sediment, which further contaminate waterways. In addition, sediment often carries excess nutrients, particularly phosphorus (Cohen et al., 1993). Table 3.16 presents summary statistics of sediment coefficients. The coefficients for 3m wide buffer strip and 5m wide buffer strip have been removed for simplicity.

Table 3.16 Summary statistic of sediment coefficients

	Base Case			1m wide Buffer Strip			Pest. Reduction	Dribble bars		
Summary Statistic	hay per ha	cer per ha	corn per ha	on hay	on cer	on corn	on Corn	ab. Hay	ab. Ceresl	ab. Corn
	t per ha	t per ha	t per ha	t per m	t per m	t per m	t per ha	t per m3	t per m3	t per m3
Min	2,9E-07	5,0E-07	0,0E+00	-2,6E-04	-3,0E-04	-3,0E-04	0,0E+00	-1,0E-14	0,0E+00	0,0E+00
Max	6,8E-03	1,6E-02	2,6E-02	-2,0E-10	-5,0E-10	-2,9E-07	0,0E+00	1,2E-14	0,0E+00	0,0E+00
Average	7,6E-04	1,7E-03	3,1E-03	-1,9E-05	-2,5E-05	-4,2E-05	0,0E+00	5,8E-16	0,0E+00	0,0E+00
Std.Dev.	1,3E-03	2,7E-03	5,2E-03	4,5E-05	5,2E-05	6,2E-05	0,0E+00	3,0E-15	0,0E+00	0,0E+00
Median	2,5E-04	6,5E-04	9,2E-04	-3,5E-06	-7,6E-06	-1,2E-05	0,0E+00	0,0E+00	0,0E+00	0,0E+00

3) E. coli is the common abbreviation of Escherichia Coli. It is one of the members of the coliform that results from fecal contamination. It is used as an indicator of the potential presence of pathogens (Parveen et al., 1999). Table 3.17 presents summary statistics of E. coli coefficients. Note that the E. coli coefficients are not crop specific.

Table 3. 17 Summary statistics for E. coli coefficients.

Summary Statistic	**Base case**	**1m buffer strip**	**3m buffer strip**	**5m buffer strip**	**Pest reduction**	**Dribble bars**
	kg per ha	kg per m	kg per m	kg per m	Kg per m3	kg per m3
min	6,296E+07	-5,661E+06	-8,041E+06	-9,516E+06	-2,395E+05	-1,135E+03
max	9,432E+08	-8,311E+01	-8,311E+01	-8,311E+01	1,039E+06	3,410E+03
average	4,631E+08	-3,781E+05	-5,379E+05	-6,371E+05	2,088E+04	7,378E+01
Std. dev.	3,212E+08	9,939E+05	1,413E+06	1,674E+06	1,404E+05	5,011E+02
median	5,589E+08	-4,755E+04	-6,756E+04	-7,999E+04	-2,024E+01	-2,303E-01

Source: INRS-ETE, 2007

4) Atrazine is a systemic herbicide, commonly used to control broadleaf and grassy weeds in corn, rapeseed and low brush blueberries, and for general weed control. Atrazine was first introduced in Canada in 1960 and was widely used for a number of years. Its use is now half of what it was in 1983 (CCME, 2007). Atrazine can enter the aquatic environment through run-off from treated fields. In areas where atrazine is used extensively, there has been significant and persistent contamination of groundwater aquifers and surface water bodies such as streams, lakes, and rivers. Atrazine has the potential to cause health effects in people who are exposed to levels higher than recommended. Furthermore, atrazine has been shown to be toxic to freshwater fish, invertebrates, and especially aquatic plants (CCME, 2007). Table 3.18 presents summary statistics of pesticide coefficients.

Table 3. 18 Summary statistics for pesticide coefficients

Summary Statistic	Base case	1m buffer strip	3m buffer strip	5m buffer strip	Pest. Resuction	Dribble bars
	kg per ha	kg per m	kg per m	kg per m	kg per ha	kg per m3
	on corn	on corn	on corn	on corn	on corn	on corn
min	0,000E+00	-3,033E-05	-4,201E-05	-4,885E-05	-1,004E-04	0,000E+00
max	3,429E-04	0,000E+00	0,000E+00	0,000E+00	0,000E+00	0,000E+00
average	1,166E-04	-1,304E-06	-1,801E-06	-2,091E-06	-3,459E-05	0,000E+00
Std. dev.	9,242E-05	4,072E-06	5,638E-06	6,556E-06	2,713E-05	0,000E+00
median	8,883E-05	-1,855E-07	-2,551E-07	-2,956E-07	-2,653E-05	0,000E+00

Source: INRS-ETE, 2007

3.5.3 The studied region.

This study modelled the Bras d'Henri River sub-watershed. This sub-watershed is located in the western part of the Beaurivage sub-watershed and is representative of the region. Appendix 1 and Appendix 2 have illustrations of the Beaurivage sub-watershed and the Bras d'Henri sub-watershed. Appendix 3 presents the watershed environmental situation for phosphorous, E-Coli, IQBP, and toxicity. The agricultural activity in the sub-watershed is very intensive and the main production is hog production. There are 133 farms in the Bras d'Henri sub-watershed. Of these, 58% are hog farms, 21% are dairy farms, 5% are cattle farms, and 16 % are other types of farms such as poultry, maple syrup farms, and various other productions (MAPAQ, 2006). The hog, dairy, beef, and poultry farms summed up to 112 farms (MAPAQ, 2006).

3.5.4 The farm survey.

A survey was conducted in the Bras d'Henri sub-watershed during the period from April 24th to May 5th 2007. All 112 farms in the Bras d'Henri sub-watershed were contacted. Nineteen producers refused to answer the survey or were not available to meet us. Most producers that refused to answer the survey were large farms and/or integrators with several production sites. Therefore, it was difficult to interview the director/owner of those farms. A potential consequence of the exclusion of the large farms in the survey procedure is biased model estimations. Presumably, large farms have greater impact on their environment than smaller farms. Therefore, excluding larger farms when measuring the impact of the adoption of BMP on the environment would potentially overestimate the environmental impacts of the adoption of BMP and as a consequence, abatement costs would then be underestimated as well as marginal abatement costs.

As a result, 93 farms were interviewed. Of those who answered, 28 responses were from producers who had gone out of business or did not have any animal or cultivated land. These farms were excluded from the model. In total, 65 responses were usable for the modelling procedures. Overall, 77% ((65/84)*100) of the farms in the Bras d'Henri sub-watershed were modelled. The information collected from each farm was: their crop mix, animal mix, spatial location, and management practices. Using the survey information, it was possible to determine the total amount of manure produced on each farm and map each farm spatially according to their farm location. Each field was attributed to only one RHHU or a weighted average of the RHHU values depending on whether the field was lying on only one RHHU or several. See Appendix 4 to 10 for the farm survey and spatial map and Appendix 17 and Appendix 18 for the field characteristics by farm. When testing for the existence of spatial autocorrelation within the farm data. Results indicate to not reject the null hypothesis. Spatial autocorrelation test have been conducted for farm total revenue (M.I.: 0.06, Z:0.81, CV:1.96), animal mix e.g. number of hog (M.I.:0, Z: 0.16, CV:1.96), and crop mix e.g. number of ha in corn (M.I.: 0.02, Z: 0.38, CV: 1.96). M.I. stands for Moran Index, Z is the Z score in standard deviation, and CV stands for the critical value at 0.05 level significance.

3.5.5 Generation of the environmental coefficient.

Each farm surveyed was spatially represented by the location of their field, their crop mix, and their animal mix using the GIS application of GIBSI. The crop mixes were grouped into three categories (1) hay and pasture, (2) cereal productions, and (3) corn production. GIBSI allows for the modification of the management parameters at the RHHU level. GIBSI processes a simulation for each of the 61 RHHUs in the sub-watershed, for five environmental parameters: (1) Nitrogen, (2) Phosphorus, (3) Sediment, (4) E. Coli, and (5) Pesticide; using seven different management scenarios: (1) 1m wide buffer strip, (2) 3m wide buffer strip, (3) 5m wide buffer strip, (4) reduced use of pesticides, (5) manure application by dribble bars, (6) minimum tillage, and (7) the base case scenario; i.e. conventional production. Using the information for each RHHU, production, BMP, and environmental parameter results in a specific set of environmental coefficients being estimated for each field (see appendix 11). When testing for the existence of spatial autocorrelation within the RHHU data. Results indicate to not reject the null hypothesis. Spatial autocorrelation test have been conducted for all pollution coefficient, for example, phosphorus coefficient for hay (M.I.: 0.03, Z:0.57, CV:1.96), the nitrogen coefficient for cereal (M.I.: 0.01, Z:0.25, CV:1.96), and pesticide coefficient for corn (M.I.:-0.01, Z: 0.02, CV:1.96) where M.I. stands for Moran Index, Z is the Z score in standard deviation, and CV stands for the critical value at 0.05 level significance. Note that spatial autocorrelation for E. coli coefficients cannot be calculated since the coefficients are not crop specific. The only pollution coefficient that presents spatial autocorrelation is the sediment coefficient for hay, that is (M.I.: 0.2, Z:2.2, CV: 1.96). In other words, the sediment coefficients for hay are significantly correlated with themselves through space. The implications of this autocorrelation pattern in the modelling procedure are considered in chapter 5.

3.5.7 The base case scenario.

The base case scenario represents the solution of the farm model when constrained to the actual production practices and spatial representation of each field. This includes the actual: crop production, animal mix, environmental coefficients, and no BMP implementation. See appendix 19 for the farm's base case environmental parameters.

3.5.8 Pollution and abatement coefficients

The environmental coefficients measure the simulated amount of pollution in the water of each RHHU in the Bras d'Henri sub-watershed. However, in order to incorporate the environmental coefficients into the farm optimization model, each environmental coefficient needs to be rearranged into a production unit or into a BMP unit. The pollution coefficients for each conventional and minimum tillage cropping practice were obtained by dividing the total amount of pollution generated when placing the whole RHHU into one type of production by the number of ha in the RHHU. For the other management scenarios, there was no need to obtain pollution coefficients since they were classified as BMPs. In these cases, only abatement coefficients were required. For the buffer strips, the abatement coefficients were determined as follows: the RHHU was allocated to a production, for example corn and a quantity of pollution was estimated. This was then re-run with a buffer strip (1m, 3m, or 5m) for the length of the water course and the quantity of pollution was estimated. Taking the quantity of pollution from the initial run and subtracting the BMP level of pollution and dividing it by the number of linear meters of watercourse provided the abatement coefficient in terms of pollution reduction per linear meter of buffer strip.

The dribble bar abatement coefficient was estimated by taking the e-coli quantity in water from conventional spreading of manure on a crop and subtracting the quantity using the dribble bar and dividing by the total amount of manure sprayed (in cubic meter). Pesticide abatement coefficients were estimated by subtracting pollution generated by the pesticide reduction BMP from the conventional use of pesticides and divided by the number of ha of corn[3] in the RHHU. These pollution coefficients for each conventional and minimum tillage crop were in kg per ha, the abatement coefficients for each buffer strip were in kg per m, the abatement coefficient for pesticide was in kg per ha, and the abatement coefficients for the dribble bar were in kg per m3 of liquid manure. For simplicity, the environmental coefficients of conventional tillage production and minimum tillage production are pollution coefficients. These coefficients are used to estimate the total amount of pollution emitted from each farm. Only buffer strips, reduced pesticide use, and the dribble bar have been transformed into abatement coefficients. Pollution coefficients for conventional manure spraying were not available; however, manure pollution was incorporated into the model through the e-coli pollution coefficient of each crop production. See Appendices 12 to 16 for the pollution and abatement coefficients.

3.6 The Model

A LP model was used to assess the cost of placing an environmental target into the sub-watershed. The objective function of the model was to maximize the Net Farm Income (NFI) derived from crop and animal production activities subject to four types of constraint: (1) the characteristics of the farm, (2) the animal nutrient requirements and nutrient allocation, (3) the environmental constraint, and (4) the BMP constraints. The model included 65 farm models and one watershed model built using the same types of constraints, decision variables, and coefficients. The watershed model is simply the summation of the 65 farm model.

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[3] Pesticide (atrazine) is only used on corn.

3.6.1 Field-by-field approach justification.

This study started by estimating the crop and animal budgets for the farms. Then the pollution and abatement coefficients were estimated and converted onto a per unit basis; such as per ha in production, meter of buffer strip, or cubic meter of liquid manure spread. Having all the data on a per unit basis allowed the model to simulate the decision making processes of farmers.

3.6.2 Single period model justification.

One reason why producers often do not adopt alternative farming practices is the negative impact these practices may have on their short-term farm profits. It is acknowledged that environmental constraints and alternative agricultural practices have an impact on the long-run profitability of farms through changes in the productivity of the soil. However, farmers often think of production decisions in terms of short-term tradeoffs. Therefore, a single period LP was used to estimate the short term impact of an environmental constraint on NFI for the year 2006. The model determines the farmers' single period decision for profit maximization subject to: (1) satisfying the animal nutrient requirements and nutrient allocation constraints, (2) the environmental constraints and, (3) the BMP constraints.

3.6.3 Assumptions

The applicability of LP is limited by several assumptions. As in all mathematical models, assumptions are made to reduce the complex real world problems into a simplified form. The major assumptions are: (1) certainty of data, (2) linearity of objective function, (3) linearity of constraints, (4) non-negativity of decision variables,

(5) additivity of activities, (6) divisibility of variables, and (7) independence of coefficients (Turban and Meredith, 1985). To minimize uncertainty regarding the reliability of the results, the following additional assumptions were made. First, unless it cannot be fed to an animal, for example hay to swine and poultry, crops were used on-farm and grown to satisfy animal requirements. However, a farm can always, up to a certain level, purchase crops to fulfill its animal requirement from the rest of the watershed or sell to the rest of the watershed. Second, prices remain constant throughout the year both for product sales and purchased inputs. Third, the watershed model is constituted by the sum of the 65 farms, which are assumed to be representative of the whole Bras d'Henri sub-watershed. Fourth, there is no adoption of new technology. Fifth, exchanges with the rest of the watershed (outside the studied region) are limited to zero unless allowed to do so and there are no transportation costs. Thus studied region is assumed to be a closed world where agents evolve and trade services and commodities without interaction with these outside of the sub-watershed. Without this closed world assumption, the model could buy all its commodities from outside of the sub-watershed, pay for it and transfer the pollution to outside of the sub-watershed. This would be a legitimate trade off. However, since no information from outside the sub-watershed economy is considered in the model, trades were assumed to occur only within the studied region. Sixth, land that was outside the Bras d'Henri sub-watershed was excluded from the model. This was important for some farmers whose fields were both in and outside the sub-watershed. For those farms, the numbers of animals were reduced proportionally to the area inside the watershed. This rule applied to dairy and poultry production since their animal numbers were fixed and not determined by the model.

When animal numbers on a farm were reduced, the nutritional requirements and the production of manure were reduced proportionally as well.

3.6.4 The objective function

The objective function maximizes the sum of field net margins of the 65 farms of the sub-watershed subject to the satisfaction of: (1) the farm characteristics, (2) the animal nutrient requirements and nutrient allocation, (3) the environmental constraint, and (4) the BMP constraints, and (5) crop mix constraint. In other words the objective function maximizes the net return of each field activity for each farm, plus the net return on animal production, plus the net return on manure management. $\Psi_j^i \bullet A_\Psi$ in eq.1 is the cost of each field activity of each farm. It is the cost of each crop production for each tillage practice of each field on each farm, plus the implementation cost of buffer strips for each buffer strip width on each production, plus the additional cost of spraying manure using dribble bars, plus the net return on reduced use of pesticides on corn (eq. 2). The objective function allows purchasing feed from the rest of the watershed (within the studied region), and feeds are purchased and sold at the same price. Since soybean and canola is fed to animals as meal, raw soybean and raw canola are not available to animals. Producers have to buy the soybean meal as an input, and canola meal is not available. Therefore, canola has to be sold in the market since raw canola cannot be consumed on the farm. In mathematical terms, the objective function was written as follow:

Equation 1: The objective function.

$$\text{MAX} \sum_{i=1}^{65} \left[\Psi_j^i \bullet \mathrm{A}_\Psi + \mathrm{Y}_b^i \bullet \Delta_b + (\mathrm{EX}^i - \mathrm{IM}^i) \bullet \Phi + (\Gamma_p^i - \mathrm{H}_p^i) \bullet \mathrm{K}_p \right]$$

Such that: $$\Psi_j^i \bullet \mathrm{A}_\Psi = x_{jpt}^i \bullet \Lambda_p + \mathrm{N}_{jpw}^i \bullet \mathrm{O}_w + \lambda_j^i \bullet \rho + \Pi_{jp}^i \bullet \Theta$$

where:

ψ is a field activity,
i is the farm number,
j is the field number,
A_ψ is the cost of each field activity,
Y is the number of animals,
b is the type of animal production,
Δ_b is the net return on each animal production,
EX^i is the quantity of manure exported by each farm,
IM^i is the quantity of manure imported by each farm,
Φ is the price of exporting or importing manure,
p is the type of crop production,
Γ^i_p is the quantity of each crop sold by each farm,
H^i_p is the quantity of each crop bought by each farm,
K_p is the price of each crop,
t is the tillage practice,
x^i_{jpt} is the number of ha produced of each crop by each field of each farm for each tillage practice,
Λ_p is the cost of production for each crop,
N^i_{jpw} is the quantity of buffer strip on each field of each farm by crop, and for each width of buffer strip,
O_w is the cost of each width of buffer strip per unit of buffer strips,
Π^i_{jp} is the quantity of liquid manure sprayed using a dribble bar on each field of each farm on each production,
Θ is the additional cost of spraying liquid manure using a dribble bar per m3,
λ^i_j is the number of ha in each field of each farm where reduced use of pesticide is implemented,
ρ is the revenue (cost saved) from reduced pesticide use.

3.6.5 Constraints

3.6.5.1 Farm characteristic constraints

There are four different farm characteristic constraints. These constraints are there to allocate field activities while taking into account field size. The first constraint is field area. The variables that impact field size are the number of ha allocated to a crop, the tillage practice, and the number of ha allocated to buffer strips, i.e. 1m of 1m wide buffer strip represents 0.0001 ha, 1 m of 3 m wide buffer strip represents 0.0003 ha, and 1m of 5m wide buffer strip represents 0.0005 ha. The right hand side (RHS) constraints are the number of ha of each field of each farm $\overline{x_j^i}$ and the left hand side (LHS) is the total number of ha allocated by the model to each crop, and tillage practice, and buffer strips.

Equation 2: Field size contraints

$$x_{jpt}^i + 0.0001 \cdot \mathrm{N}_{jp1}^i + 0.0003 \cdot \mathrm{N}_{jp3}^i + 0.0005 \cdot \mathrm{N}_{jp5}^i \leq \overline{x_j^i}$$

The second constraint is the manure application constraint. This constraint ensures that farmers apply a reasonable manure application rate. Manure application was constrained in the following way to avoid non-linearity problems. In order to spray 1 cubic meter of liquid manure on a corn field, the field must be at least 0.023 ha. This is to ensure that not more than 43.5 cubic meters of liquid manure is sprayed per ha (Agri-réseau, 2007i).

Equation 3: Manure application constraint 1.

$$x_{jpt}^i - 0.023 \cdot \Pi_{jpcm}^i \geq 0$$

The subscript C indicates the consistency of the manure. It can be either solid or liquid manure. The subscript M indicates the method using to spray the manure. The method is either conventional spraying or dribble bar.

The third constraint, forces the model to allocate the dribble bar application on a particular crop on a particular field only if that particular crop is grown on that particular field. The constraint is written as follows.

Equation 4: Manure application constraint 2.

$$10000x^{i}_{jpt} - \Pi^{i}_{jpcm} \geq 0$$

Again, the subscript C indicates the consistency of the manure. That is either solid or liquid manure, and the subscript M means the method using to spray the manure. The method can be either conventional or dribble bar. This constraint unable the model to spray manures where there are no field in production. However, since x^{i}_{jpt} is in ha and Π^{i}_{jpcm} is in cubic meters there is a mismatch in the unit of measurement. To solve this problem the number 10,000 has been added.

The fourth constraint is the manure management constraint. This constraint ensures that the total manure produced plus the imported manure minus the exported manure is sprayed or exported. σ_{cb} represents the amount of manure produced by manure consistency (solid or liquid). Note that this is the only strict equality in the model.

Equation 5: Manure management constraint.

$$\sigma_{cb} \bullet \mathrm{Y}_b^i + \mathrm{IM}_c^i - \mathrm{EX}_c^i - \Pi_c^i = 0$$

3.6.5.2 Best Management Practice Constraints.

The buffer strip constraint was introduced into the model taking into account field location and the location of the water courses in the sub-watershed. The RHS of the constraint represents the length of buffer strips available in each field $\overline{\mathrm{N}_j^i}$ and the LHS represents the allocation of the buffer strips in each field, on each farm, with each production, and for each buffer strip width (N_{jpw}^i). Note that only the 5m wide buffer strip allows for harvesting. The 1m wide or 3m wide buffer strips are not harvested and therefore are excluded from the cultivated area. The 5m wide buffer strips on a hay field are considered as part of the field since it can be harvested.

Equation 6: Buffer Strip Constraint

$$\mathrm{N}_{jpw}^i \leq \overline{\mathrm{N}_j^i}$$

A constraint also forces the model to allocate the buffer strips on a particular field for a particular production only if that particular production is grown on that particular field. This constraint ensures that the model takes into account the impact of the buffer strip for a particular production and that production is in the field. For example, if 100m of a 3m wide buffer strip is allocated on corn, this occurs only on a corn field. However, since x^{i}_{jpt} is in ha and N^{i}_{jp} is in meters there is a mismatch in the unit of measurement. To solve this problem the number 0,0001 has been added. The constraint is written as follows:

Equation 7: No field, no buffer strip.

$$x^{i}_{jpt} - 0.0001 \cdot N^{i}_{jp} \geq 0$$

The next constraint in this group was the animal production constraint. The numbers of dairy and poultry animals were kept constant because of the institutional regulations associated with supply management. However, the size of the hog and beef herd were allowed to change, but the model does not allow switching from dairy or poultry production to hog or beef production or vice versa. Nor does it allow switching from dairy to poultry or vice versa. Furthermore, the model does not allow switching from beef to hogs or from hogs to beef. Instead, the model can decrease and/or increase the number of beef animals and hogs on the farm and the watershed. In eq. 9, the LHS represents the number of dairy and/or poultry animals on each farm. The RHS represents the number of dairy and/or poultry animals on the farm currently $\overline{\Upsilon^{i}_{b(poultry,dairy)}}$. The LHS of equation 10 represents the number of beef and/or hog animals on each farm. The RHS represents the number of beef and/or hog animals on the farm currently $\overline{\Upsilon^{i}_{b(hog,beef)}}$.

Equation 8: Poultry and dairy production constraint

$$\Upsilon^{i}_{b(poultry,dairy)} = \overline{\Upsilon^{i}_{b(poultry,dairy)}} \text{ for poultry and dairy production.}$$

Equation 9: Beef and hog production constraint

$$Y^{i}_{b(hog,beef)} \leq \overline{Y^{i}_{b(hog,beef)}} \text{ for beef and hog production.}$$

The next BMP entered into the model was the reduced use of pesticide constraint. The number of ha where the reduced use of pesticide BMP was used, is less than or equal to the total number of ha in corn. Note that the BMP for reduced used of pesticides was only applied to corn production.

Equation 10: Pesticide reduction constraint.

$$-\lambda^{i}_{jcorn} + x^{i}_{jt,corn} \geq 0$$

3.6.5.3 Crop Inventory Constraints.

The next group of constraints were the crop inventory balance constraints. This constraint ensures that each farm sells and/or consumes what they produce and/or what they buy, but no more. The LHS of this constraint is the quantity of each crop produced, minus the quantity of each crop consumed on the farm, plus the quantity of each crop bought, minus the quantity of each crop sold minus the quantity of corn lost by the application of pesticide reduction on corn and lastly, plus the quantity of hay generated by the application of a 5m wide buffer strip. The RHS of this constraint is greater than or equal to zero.

Equation 11: Crop inventory balance constraint.

$$x^i_{pt} \bullet Z_{pt} - \eta^i_p + H^i_p - \Gamma^i_p - 0.15 \cdot Z_{corn} \bullet \lambda^i_j + 0.0005 \cdot Z_{hay} \bullet N^i_{w=5} \geq 0,$$

where:

Z_{pt} is the yield of each crop with each tillage practice,
η^i_p is the quantity of each crop consumed on each farm by all animals,
$0.15 \cdot Z_{corn}$ is the 15% loss of corn productivity (yield), following the implementation of reduced use of pesticide,
λ^i_j is the number of ha in each field on each farm where reduced use of pesticide is implemented,
$0.0005 \cdot Z_{hay}$ is the quantity of hay produced with the application of a 1 meter by 5m wide buffer strip, and
$N^i_{w(5meters)}$ is the number of meters of 5m wide buffer strip implemented on each farm.

3.6.5.3 Animal Nutrient requirement constraints.

The first constraint in this group is the nutrient requirement constraint. This set of constraints ensures that the nutrient requirements of each animal are fulfilled.

Equation 12: Animal nutrient requirement constraint.

$$\eta^i_p \bullet \varepsilon_{pr} - Y_b \bullet \ell_{br} \geq 0,$$

where ε_{pr} are the crop nutritional values for each crop, for each nutrient requirement. The nutrient requirements are: Dry Matter, Crude Protein, Total Energy, Total digestible Nutrient, Calcium, Phosphorus, and Magnesium. ℓ_b represents the nutritional requirements of each animal type.

The second constraint in this group was the maximum nutrient requirement constraint. Since it is hard to exactly fulfill the nutritional requirement of each animal, this group of constraints allows the nutritional feeding value to exceed, up to a certain limit, the needs of the animal. It also ensures that the nutritional requirements are positively bound and respected up to a certain level. For example, the nutritional requirements were allowed to exceed the nutritional needs by 5% for dry matter, 10% for crude protein, 5% for total energy, 20% for TDN, 30% for calcium, and 30% for magnesium.

Equation 13: Maximum animal nutrient requirement constraint.

$$\eta_p^i \bullet \varepsilon_{pr} - \Upsilon_b \bullet \ell_{br} \leq \Upsilon_b \bullet \ell_{br} \cdot adjustment_r$$

Such that $adjustment_r$ is the adjustment (%) applied to each nutritional requirement. This has also for effect to leave the model more flexibility in the selection of the ration.

3.6.5.4 Environmental constraints

First, the model sums up all the pollution produced from each field on each farm for crops produced (p) given their practices (t), and the environmental parameter (f). This summation is written as follows:

Equation 14: Summation of the pollution

$$\sum_{pt} \left[x_{jpt}^i \cdot D_{jptf}^i \right] = S_{jf}^i$$

Such that (D) is the pollution coefficient for farm (i), environmental parameter (f), tillage practice (t), production (p), and field (j). Note that the result obtained is farm, field, and environmental parameter specific. The summation of these values is represented by S^{i}_{jf}.

Next, the model sums up all the pollution abated by all the BMPs. This summation is written as follows:

Equation 15: Summation of the abatement

$$\sum_{wp}\left[N^{i}_{jpw}\cdot G^{i}_{jpfw}+\lambda^{i}_{jp=corn}\cdot H^{i}_{jp=corn,f=pesticide}+\Pi^{i}_{jp}\cdot Q^{i}_{jpf}\right]=U^{i}_{jf}$$

Where (G) is the abatement coefficient for farm (i), environmental parameter (f), crop (p), field (j), and buffer strip width (w). Note that the result obtained is farm, field, and environmental parameter specific. The summation of these values is represented by U^{i}_{jf}.

The model is able to constrain environmental pollution at two scales. These are: (1) constrained each farm to their base case pollution level or below, and (2) to constrain all farms as a group at or below the base case pollution level of the group. Given this model structure, it is necessary to have two different environmental constraints that can be interchanged depending on the scale of the analysis being undertaken. The environmental constraint can be set at the farm scale by incorporating it as a RHS constraint. For each farm, S^{i}_{jf} is the RHS environmental constraint for each field and environmental parameter.

Equation 16: Environmental constraints at the farm scale

$$\sum_{j}\left[S^{i}_{jf}-U^{i}_{jf}\right]\leq\overline{S^{i}_{f}}\ \textbf{for all i and all f}$$

$$\sum_{j}\left[S^{i}_{jf}-U^{i}_{jf}\right]\geq 0\ \textbf{for all i and all f}$$

$$\left[S^{i}_{jf}-U^{i}_{jf}\right]\geq 0\ \textbf{for all j of all i and for all f}$$

At the watershed scale, the environmental constraints are introduced as a RHS constraint. In this case, S_f is the environmental constraint for all farms, all fields, and for each environmental parameter.

Equation 17: Environmental constraints at the sub-watershed scale

$$\sum_{ij}\left[S^{i}_{jf}-U^{i}_{jf}\right]\leq\overline{S_{f}}\ \textbf{for all f}$$

$$\sum_{ij}\left[S^{i}_{jf}-U^{i}_{jf}\right]\geq 0\ \textbf{for all f}$$

$$\left[S^{i}_{jf}-U^{i}_{jf}\right]\geq 0\ \textbf{for all j of all i and for all f}$$

3.6.5.5 Crop constraints.

A crop constraint has been added to the model in order to avoid distortion in the crop mix by the model.

(1) The model was constrained to allocate zero ha of minimum tillage production. The reason for this is the lack of relevant pollution coefficients for such tillage practices.

(2) The model was also constrained to allocate not more than 5% of the total ha in production in the base case to wheat, 5% to barley, 5% to oats, 5% to soybean, and 5% to canola.

3.7 Summary

A linear programming (LP) model was used to assess the costs of implementing an erosion constraint at the farm and the watershed scales. The model was based on three types of data: crop and animal budgets, animal nutrient requirements, and environmental coefficients. This study was conducted in the Chaudière River Basin for Agriculture and Agri-Food Canada (AAFC) and several other organizations. More specifically, this study addresses the issues of agricultural non-point source pollution in the Bras d'Henri sub-watershed and its objectives were to quantify at the farm and at the watershed scale, the relative economic impact of an environmental constraint using BMPs to mitigate sediment, phosphorus, nitrogen, e-coli, and pesticide pollution.

The farm data originated from an on-farm survey, where the spatial location of each field on each farm and the farm characteristics were collected. The animal nutrient data were estimated from published information. These estimates should be taken as approximations only. The estimated nutrient requirement depended on the type of animal production, and included energy, protein, calcium, and phosphorus requirements. Finally, nutritional values of crops grown on-farm were estimated. A Geographical Information System was used to subdivide each field into the various hydrologic units using a weighted average procedure, i.e. each field is attributed to only one RHHU or a weighted average of the RHHU values depending on whether the field was laying on only one RHH or several.

The environmental coefficients were estimated for 5 environmental parameters: (1) Pesticide, (2) Nitrogen, (3) Phosphorus, (4) Sediment, and (5) coliform bacteria. The objective function maximizes the sum of field net margins subject to five sets of constraints: (1) farm characteristics, (2) best management practices (3) animal nutrient requirements, (4) environmental constraints, and (5) crop mix constraints. See appendix 20 for the model user guide.

Chapter 4: Results and discussion

4.1 Introduction

The following procedure was used in the analysis. First, the base case pollution emissions estimates were estimated by solving the model with the current livestock, field crop, and production practices. These current practices were obtained from the producer survey. This solution provided the starting point for reductions in pollution emissions.

Second, the model was run to optimize the allocation of crop production given the base case level of pollution. This provided an estimate of how current practices differed from optimal practices. Finally, the model was run to optimize farm income for a number of scenarios that constrained pollution emission to 90%, 80%, 70%, 60%, 50%, 40%, and 30% of the base case emissions for each environmental parameter. Note that no solutions were found for % less than 30% of emission reduction. This procedure was run first when the constraint was applied to each farm and then for the watershed as a whole. In other words, at the farm scale the RHS of the environmental constraint is the total emission of each farm and, at the watershed scale, the RHS of the environmental constraint was the summation of all field emissions across all farms.

The computer program “What’s Best” (Lindo Systems, 2009) was used to optimize the LP model. “What’s Best” uses a branch and bound algorithm to solve the model. A detailed description of the branch and bound algorithm can be found in Eppen et al. (1993).

The net farm income and gross revenue for the LP model for the base case and the optimized base case are given in table 4.1. The results indicate that the base case solution is lower but similar to the optimized current practice solution. For the watershed, the optimized solution is $53,000 higher than the base case solution, while the gross revenue is $403,000 higher. This would indicate that current production practices are close to the optimal solution.

Table 4. 1: Results of the different models

Model	Net farm income	Gross revenue
LP model in base case	$7 022 763.00	$24 062 482.00
LP model optimized	$7 075 722.00	$24 465 288.00

4.1.1 Parameters of Interest.

The cost of complying with environmental constraints can be estimated in several ways. Parameters of interest for the analysis were: sediment load, phosphorus load, nitrogen load, coliform load, pesticide load, the Objective Function Value (OFV), corn hectare, hay hectare, the number of meters of buffer strip used (1m, 3m , and 5m), corn hectare grown under reduced use of pesticide, the cubic meter of manure spread using a dribble bar, and the number of beef and hogs animals. From these parameters, marginal and average abatement costs curves, as well as trade-off curves, were estimated.

4.2 Base case scenario

The base case scenario solution corresponds to the model solved with no environmental constraints and with the current farming practice on each farm. Table 4.2 provides the estimated environmental pollution from the current farming practices. These values will be used as the starting point for the reduction in pollution. The individual farm pollution results can be found in Appendix 19.

Table 4. 2 : Watershed's base case environmental parameters

Parameters	Unit per day	Watershed (sum of all farm)
Sediment	t	5,22E+00
Phosphorus	kg	4,59E+01
Nitrogen	kg	8,51E+01
Coliform	NCF[1]	1,441E+12
Pesticide	Kg	6,43E-02

(1) NCF stands for the number of coliform.

4.3 Subsequent scenario

The model was run at two scales, i.e. at the farm and at the sub-watershed scale, and setting the environmental constraint to different levels of the base case pollution. These scenarios included setting the environmental constraint at 90%, 80%, 70%, 60%, 50%, 40%, and 30% of the base case emissions at the watershed scale. In some of the farm scenarios a solution could not be found for the larger emission reductions.

4.3.2 Objective function as a function of pollution emission

Figure 4.1 illustrates the OFV as a function of the emission reductions of the environmental parameters. It shows that the OFV does not fall as quickly for pesticide reductions as the other curves for similar emission reductions. The BMP attached to the reduction of pesticide was inefficient in reducing pesticide loading. The model satisfied the constraint reduction by not growing corn, which used the pesticide. To satisfy the constraint the hectarage to corn decreased by 65% and the hectarage of hay increased by 60%. Since there was no significant change in the animal mix in the watershed, more corn was bought from outside the farm and the surplus hay was sold off the farm. In the ration less corn and more hay were consumed by the animals, and the ration was completed by additional vitamins and supplements. The impact on the OFV was small for pesticide reduction because (1) the buying and selling prices was the same for each commodity, and (2) the cost of buying vitamins and supplements counter-balanced the cost of the ration with less corn. The decrease in the number of ha allocated to corn was expected since corn is the only crop that was controlled for pesticide.

Figure 4. 1 : OFV as a function of each environmental parameter

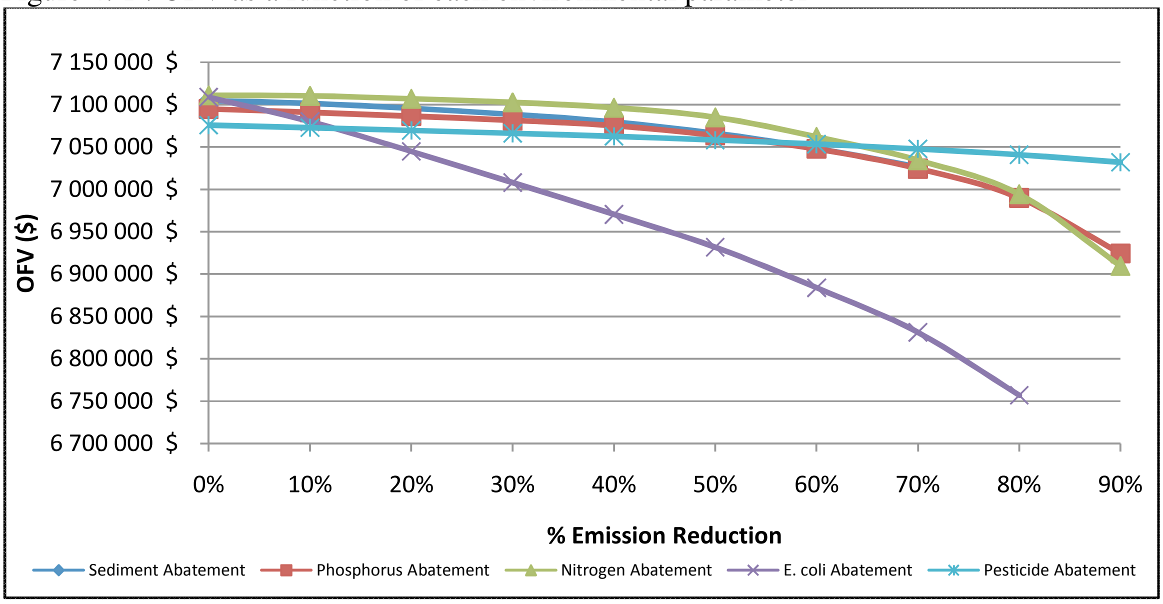


Figure 4.1 also shows that e-coli was the environmental parameter that fell the fastest when the emission reduction was increased. The BMP attached to the reduction of e-coli pollution was found to be an inefficient means of reducing e-coli load. Consequently, the model did not spread liquid manure with a dribble bar. Again, the model reduced e-coli emissions, by reducing the hectarage of corn grown (72%). No other significant change was noted either in the crop mix or in the animal mix. Since there was no significant change in the animal mix of the sub-watershed, the fact that e-coli was the environmental parameter that fell the fastest when an increase in the emission reduction was increased is explained by (1) more corn was bought from outside the farm, and (2) less corn was consumed on the farm and the ration was completed by additional vitamins and supplements. The impact on the OFV from a reduction in e-coli was the largest of all environmental pollutants. This result, however, is a function of the model's limitation to reduce e-coli pollution; the model simply selects the fields where e-coli pollution coefficients were high and puts them out of production, i.e. producing nothing. The reason for this was because the pollution coefficients did not differentiate between the types of production (it is specific to e-coli coefficient) and therefore all crop production had the same pollution coefficient within a given RHHU. As a result, the model could not find, in a given RHHU, a better crop mix than to produce nothing. Consequently, it is not feasible to compare watershed and farm scale e-coli emission reductions because of this data limitation.

The rest of the environmental pollutants moves in a similar manner as emission reductions were increased. The change in management practices occurring with sediment, phosphorus, and nitrogen emission reductions were implementing buffer strips and changes in crop mix. In addition, the dribble bar was found to have an impact but to a lesser extent. As seen in figure 4.1 and in Tables 4.3 to 4.7, the farms in the watershed could adjust their production decisions to satisfy a policy objective to decrease the amount of pollution emitted. Note that all environmental constraints were binding except nitrogen and e-coli. The nitrogen and the e-coli emission reductions were used to satisfy a change in crop mix. Note also that not all the emission reduction curves start at the same OFV. This is happening because when constraining a specific environmental parameter, the others were settled allowing for variations.

Table 4. 3 : Sediment emission constraint and results (RHS and LHS)

LHS			**RHS**	
Sediment emission (t)	Δ in sediment emission (t)	Δ in NFI ($)	% emission reduction	Sediment emission (t)
5,217			0%	5,217
4,695	0,5217	3359,04	10%	4,695
4,174	0,5217	5792,99	20%	4,174
3,652	0,5217	7205,93	30%	3,652
3,130	0,5217	8991,19	40%	3,130
2,609	0,5217	13329,44	50%	2,609
2,087	0,5217	17837,14	60%	2,087
1,565	0,5217	22039,42	70%	1,565

Table 4. 4 : Phosphorus emission constraint and results (RHS and LHS)

LHS			**RHS**	
phosphorus emission (kg)	Δ in phosphorus emission (kg)	Δ in NFI ($)	% emission reduction	phosphorus emission (kg)
45,870			0%	45,870
41,283	4,587	4005,38	10%	41,283
36,696	4,587	4459,34	20%	36,696
32,109	4,587	4982,01	30%	32,109
27,522	4,587	6212,84	40%	27,522
22,935	4,587	11640,93	50%	22,935
18,348	4,587	15736,56	60%	18,348
13,761	4,587	23351,74	70%	13,761
9,174	4,587	34573,21	80%	9,174
4,587	4,587	65563,15	90%	4,587

Table 4. 5 : Nitrogen emission constraint and results (RHS/LHS)

LHS			RHS	
nitrogen emission (kg)	∆ in nitrogen emission (kg)	∆ in NFI ($)	% emission reduction	nitrogen emission (kg)
80,458			0%	85,130
68,930	8,513	710,89	10%	76,617
67,143	8,513	3348,92	20%	68,104
61,099	8,513	4290,96	30%	59,591
52,734	8,513	6223,02	40%	51,078
50,629	8,513	11314,61	50%	42,565
47,956	8,513	23103,44	60%	34,052
38,298	8,513	27718,51	70%	25,539
27,466	8,513	40035,01	80%	17,026
16,575	8,513	84710,27	90%	8,513

Table 4. 6 : E. coli emission constraint and results (RHS and LHS)

LHS			RHS	
ecoli emission (coliform)	∆ in ecoli emission (coliform)	∆ in NFI ($)	% emission reduction	ecoli emission (coliform)
1,423E+12			0%	1,441E+12
1,297E+12	1,26179E+11	28797,87	10%	1,297E+12
1,153E+12	1,441E+11	35227,36	20%	1,153E+12
1,009E+12	1,441E+11	36802,86	30%	1,009E+12
8,646E+11	1,441E+11	37528,82	40%	8,646E+11
7,205E+11	1,441E+11	38755,20	50%	7,205E+11
5,764E+11	1,441E+11	47889,61	60%	5,764E+11
4,323E+11	1,441E+11	52619,73	70%	4,323E+11
2,882E+11	1,441E+11	74180,53	80%	2,882E+11

Table 4. 7 : Pesticide emission constraint and results (RHS and LHS)

LHS			RHS	
pesticide emission (kg)	∆ in pesticide emission (kg)	∆ in NFI ($)	% emission reduction	pesticide emission (kg)
0,064			0%	0,064
0,058	0,006435	3003,18	10%	0,058
0,051	0,006435	3174,91	20%	0,051
0,045	0,006435	3359,85	30%	0,045
0,039	0,006435	3690,94	40%	0,039
0,032	0,006435	4357,16	50%	0,032
0,026	0,006435	4814,27	60%	0,026
0,019	0,006435	5726,65	70%	0,019
0,013	0,006435	6870,02	80%	0,013
0,006	0,006435	8917,29	90%	0,006

Tables 4.3 to 4.7, show the relationship between the costs of reducing pollution emissions in terms of loss NFI of for each level of emission reduction. In chapter 1, it was hypothesized that decreasing pollution emissions would reduce the amount of pollution emitted from agricultural production. This hypothesis was not rejected.

In addition, it was hypothesized that implementing a pollution reduction constraint would reduce profits. This hypothesis was not rejected. Tables 4.3 to 4.7 provide the estimated decrease in profit resulting from a given pollution reduction level. For example, for a sediment emission reduction of 10% from the base case solution, it would cost $3,359 to reach this objective. It can be seen from Tables 4.3 to 4.7, that reducing the pollution emission reduces profits at an increasing rate. This relationship occurs for every environmental parameter.

4.3.3 Cropping patterns as a function of pollution emission

Figures 4.2 to 4.6 show the relationship between corn and hay hectarage, the total hectarage in production, and the % of pollution emission reduction. It was hypothesized in chapter 1 that implementing an erosion constraint would force cropping patterns and farming practices to change. This would occur because higher net margin crops were substituted by lower net margin crops as the pollution emission constraint increased. This hypothesis was not rejected. Hence, implementing a pollution constraint results in a change in cropping patterns and farming practices.

In Figures 4.2 to 4.4 it is possible to distinguish two phases in the cropping pattern evolution as the constraint on the pollutant emission increases. In the first phase, the number of corn hectares decrease continuously and the number of hay hectares increase continuously. In the second phase, the number of hay hectares and corn hectares decrease. Furthermore, the total number of hectare in production starts to decrease. In Figure 4.5, only phase 2 is observed and in Figure 4.6 only phase 1 is observed.

Figure 4. 2 : Corn and hay ha with sediment emission reduction

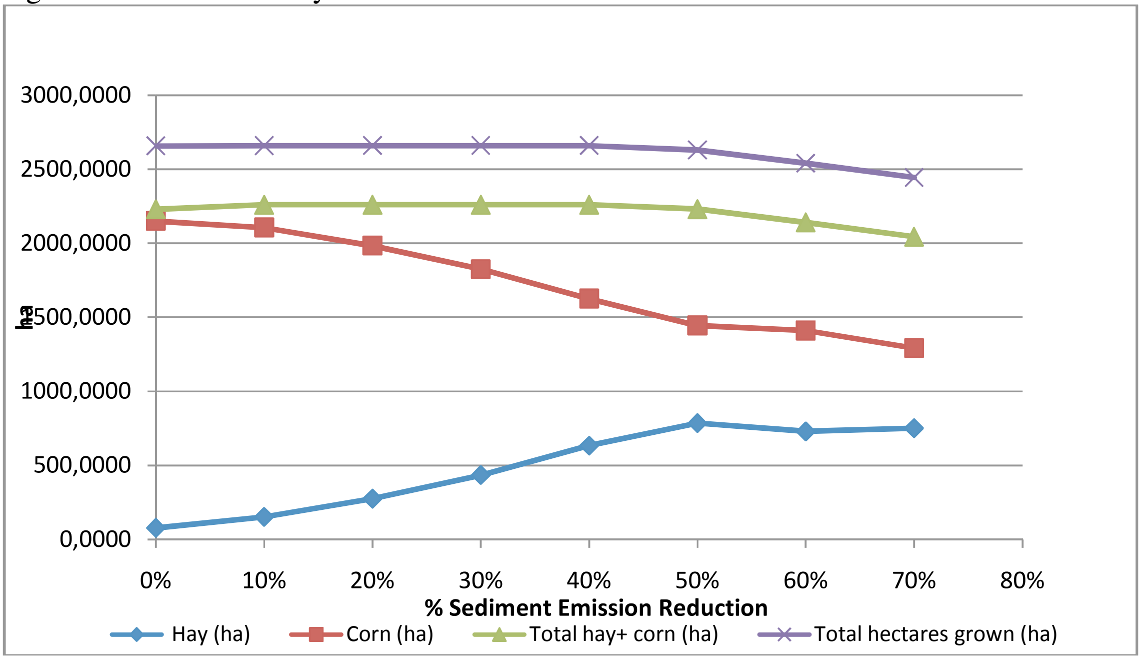


Figure 4. 3 : Corn and hay ha with phosphorus emission reduction

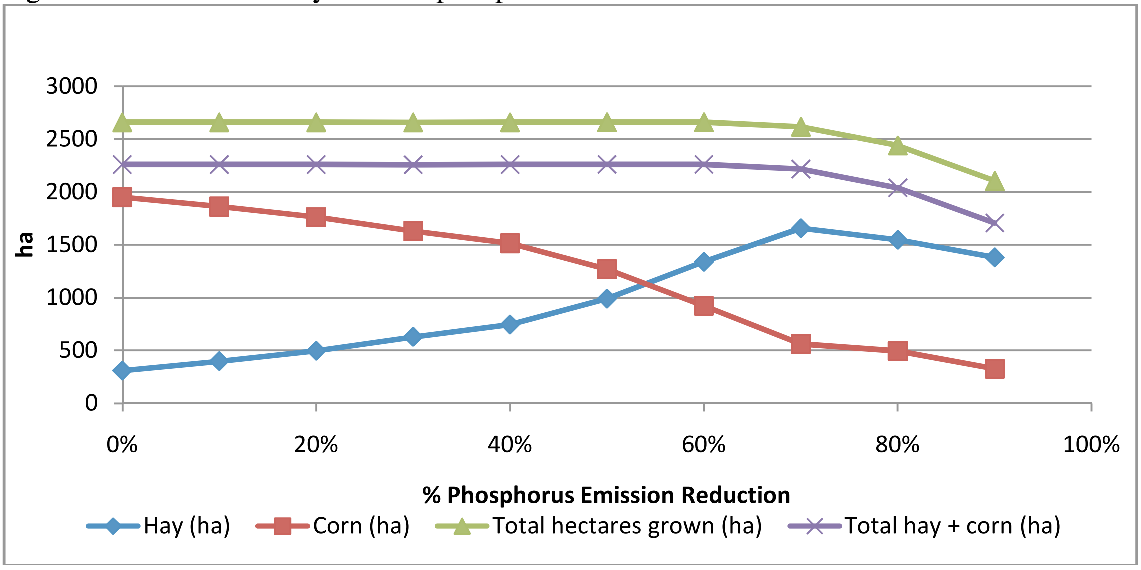


Figure 4. 4 : Corn and hay ha with nitrogen emission reduction

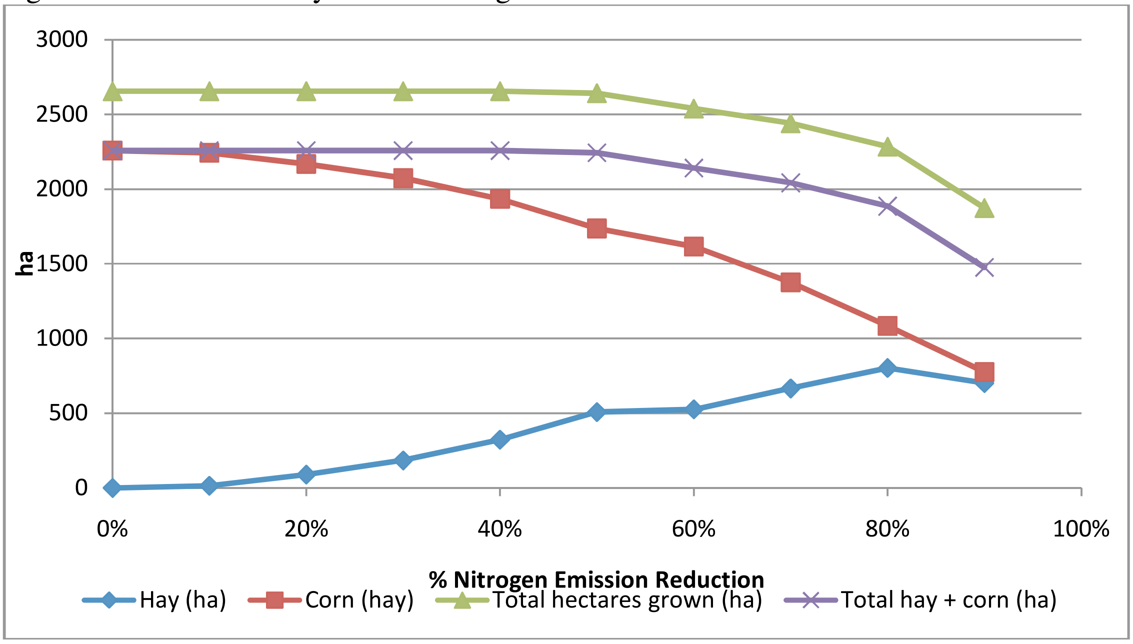


Figure 4. 5 : Corn and hay ha with e. coli emission reduction

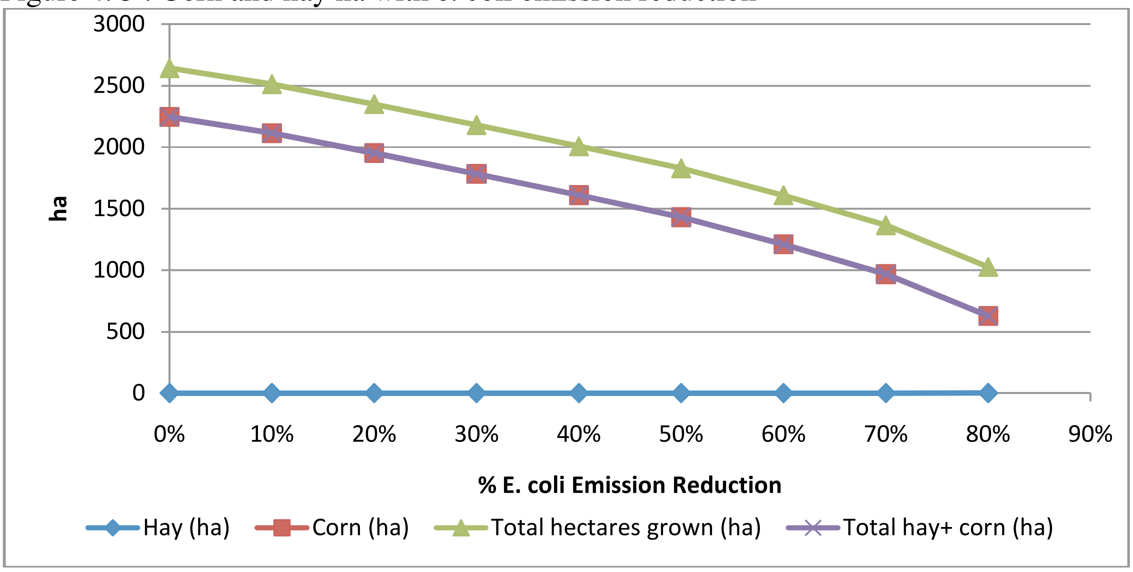
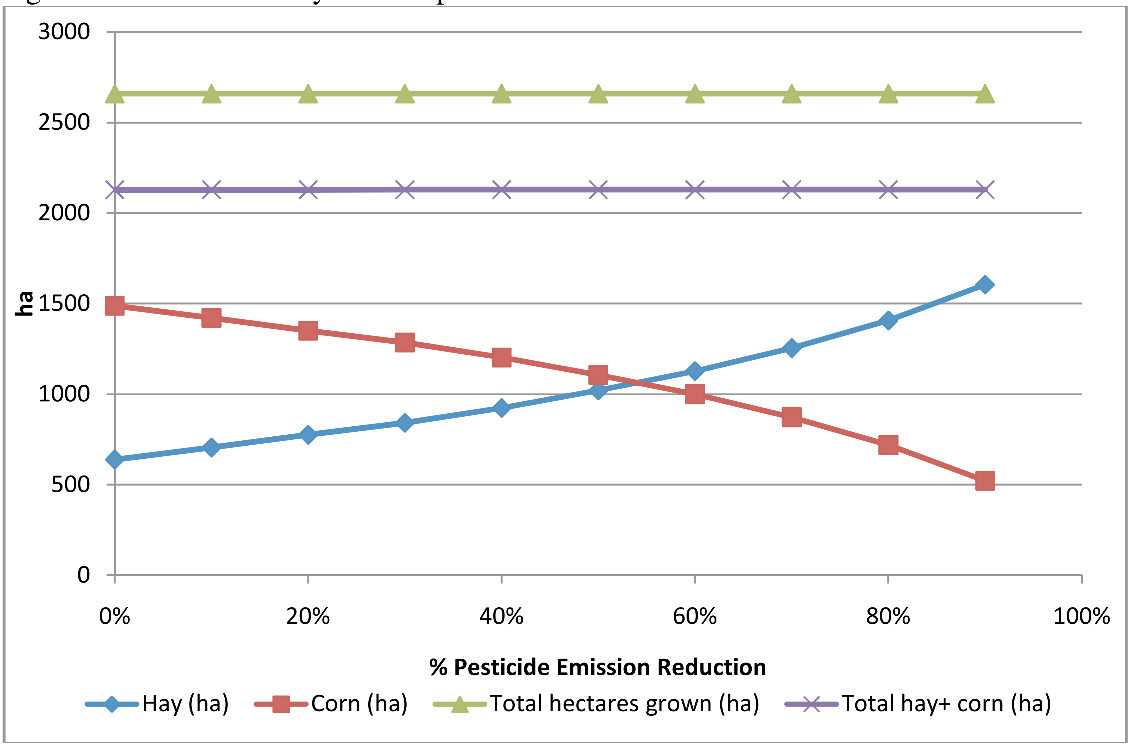


Figure 4. 6 : Corn and hay ha with pesticide emission reduction



The explanation of this change in cropping pattern is as follows. In the first phase, corn was first chosen because it provides the highest net margin. Hay production was lower because it has the lowest net margin. What was observed as the pollution emission constraint increased, was a gradual decrease in corn hectares and a gradual increase in hay hectares in order to satisfy the pollution emission constraint. Hay was the only crop that could achieve a very low level of pollution emissions and provide a positive net margin. A large portion of the animal nutrients were purchased from outside the watershed. In this situation, net margins from crop production were decreasing and the cost of purchasing inputs was increasing. This resulted in a decrease in the OFV as the emission constraint increased. Phase 1 was observed for sediment, phosphorus, nitrogen, and pesticide emission reductions.

In phase 2, as the % of emission reductions pass a certain point both corn and hay hectares decrease for certain environmental pollutants. After this level of emission reduction, this results in a decrease in the total number of hectare in production. This means that there were no other alternative crop patterns or BMPs that could reduce emissions beyond this level and as a result the model reduces the total amount of hectares in production. This was done by leaving fields vacant. For sediment, this occurs after a 50% of reduction in the base case emission. For phosphorus, it occurs after 70%, and for nitrogen after 50%.

Phase 2 was not observed for pesticides. This was mainly due to environmental data limitations since pesticide reductions were only accounted for by decreases in pesticides use for corn. Thus, all other crop production did not emit pesticide. Therefore, the model simply selects other crops and therefore phase 2 was never observed.

Phase 1 was not observed for e-coli. The reason for this was that the environmental data in the model for e-coli was not crop specific, i.e. every crop has the same e-coli coefficient. Therefore, the model was unable to find better crop allocations than no crop production, and therefore the total hectares in production decreased. As a result, only phase 1 was observed when e-coli emissions were constrained. As e-coli emissions were reduced there was no noticeable impact on animal mix. This was also due to data limitations. There were no e-coli coefficients attached to the conventional method of spraying manure directly. The model accounts for this indirectly when considering the production of a crop. That is the e-coli coefficients of any crop accounted for predetermined average amounts of manure being sprayed using the conventional method of spreading manure. Unfortunately, as reported earlier, e-coli coefficient were not crop specific, and therefore there was no production distinction in terms of e-coli emissions in the model. This is another reason why phase 2 was not observed when e-coli emissions were reduced.

Additionally, barley, oats, and wheat hectares remained constant as emissions were reduced. This occurs because they supply energy to the animal diets, similar to corn, but have lower net margins than corn. Therefore the model prefers to select corn. Furthermore, soybean and canola were rarely produced even though they are protein suppliers and protein needs were high. It was cheaper to buy soybean/protein from outside the farm rather than grow it. This happens since net margin from corn is higher.

4.3.4 Marginal and average cost as a function of pollution emissions

Marginal and average costs are respectively a measure of the change in the cost of a given change in output and a measure of the cost per unit of output. Marginal and average costs are additional ways of estimating the cost of implementing the pollution emission constraint. Marginal and average costs of reducing pollution emissions were calculated using the following formulas:

$$\text{Marginal cost}=\frac{(OFV_i - OFV_{i-1})}{emission_i - emission_{i-1}}$$

$$\text{Average cost}=\frac{(OFV_i - OFV_{\max})}{emission_i - emission_{\max}}$$

Figures 4.7 to 4.11 present the average cost and marginal cost curves of emission reductions for the various environmental pollutants. It shows that marginal and average costs were always non-negative and increase at an increasing rate as reductions in emissions were increased. For example, a 10% change in sediment emission reduction from 30% to 40% results in a 25% increase in marginal cost and a 16% increase in the average cost. A change in sediment emission reduction from 40% to 50% results in a 48% increase in marginal cost and a 22% increase in average cost. This is explained by the substitution of corn with hay. Hay was the only crop that can be grown in order to satisfy an increasingly severe emission constraint. But, it presents the lowest net margin per hectare and, in order to fulfill the animal needs in energy and protein, inputs have to be purchased from outside of the farm. This contributes to a further OFV reduction. From Figure 4.1, it can be seen that the OFV decreases at an increasing rate. Average and marginal costs of phosphorus, nitrogen, e-coli, and pesticide behave in a similar manner.

Figure 4. 7 : Average and marginal cost as a function of sediment emission reductions.

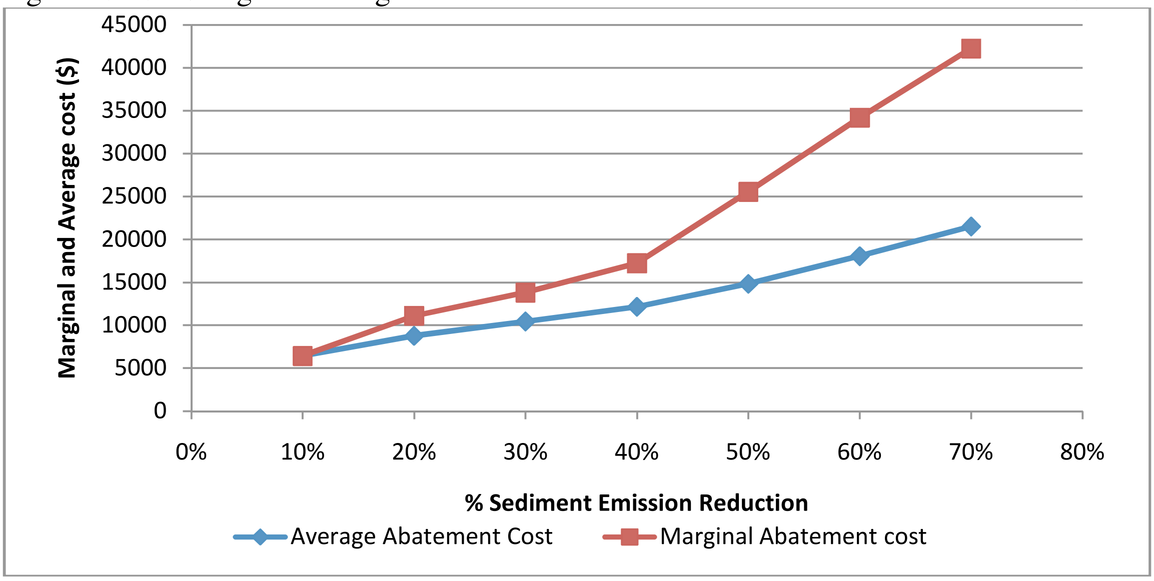


Figure 4. 8 : Average and marginal cost as a function of phosphorus emission reductions.

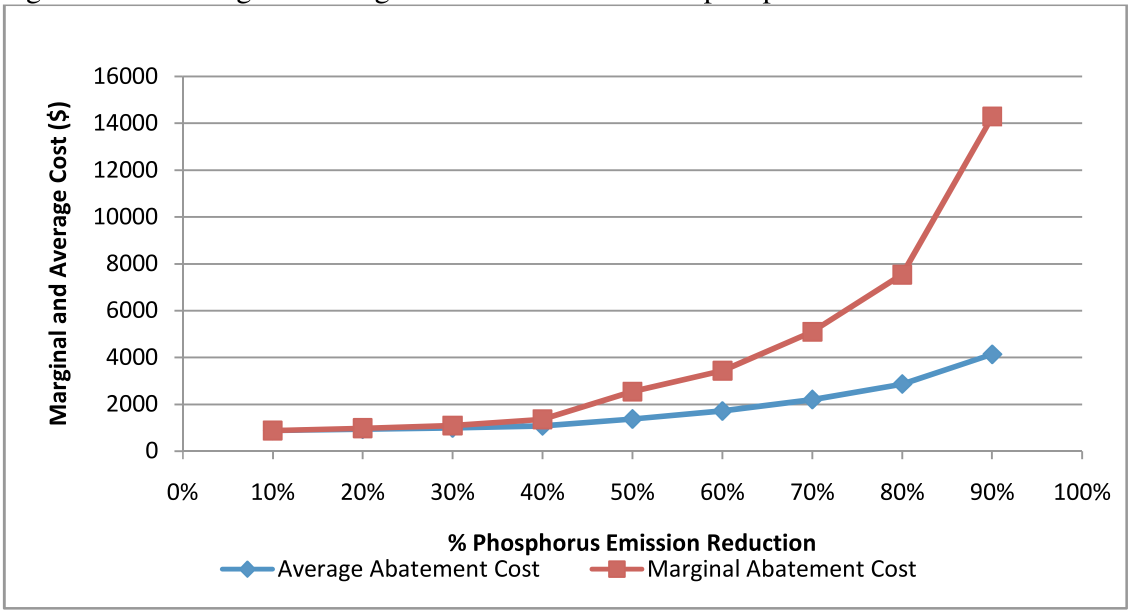


Figure 4. 9 : Average and marginal cost as a function of nitrogen emission reductions.

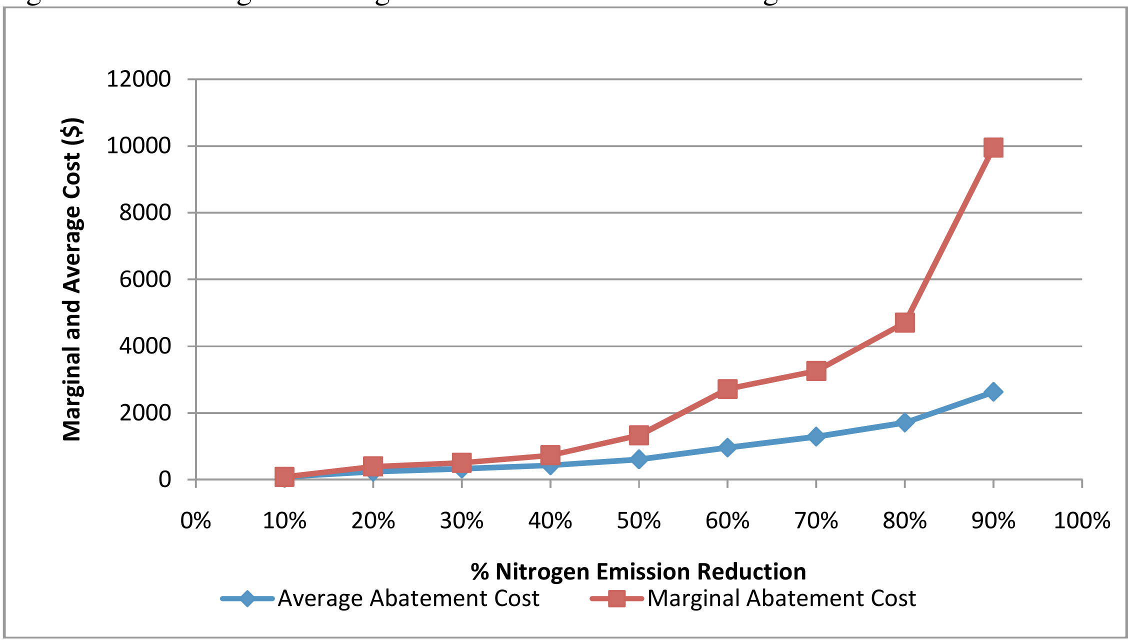


Figure 4. 10 : Average and marginal cost as a function of e-coli emission reductions.

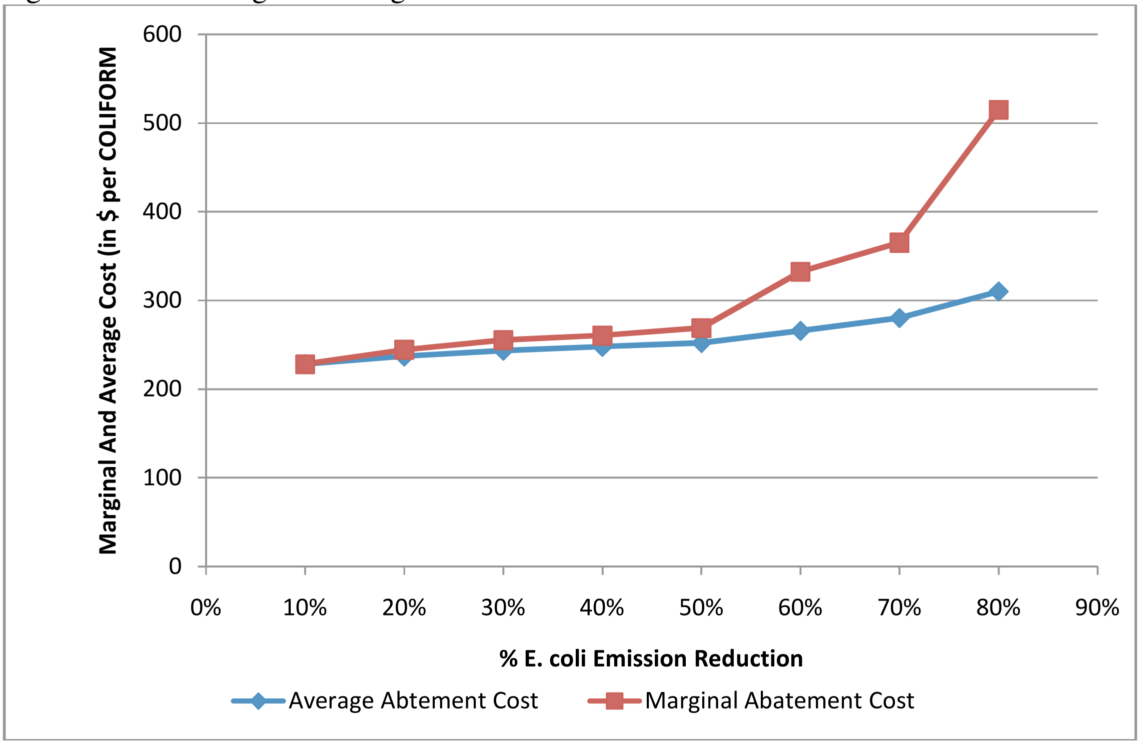


Figure 4. 11 : Average and marginal cost as a function of pesticide emission reductions.

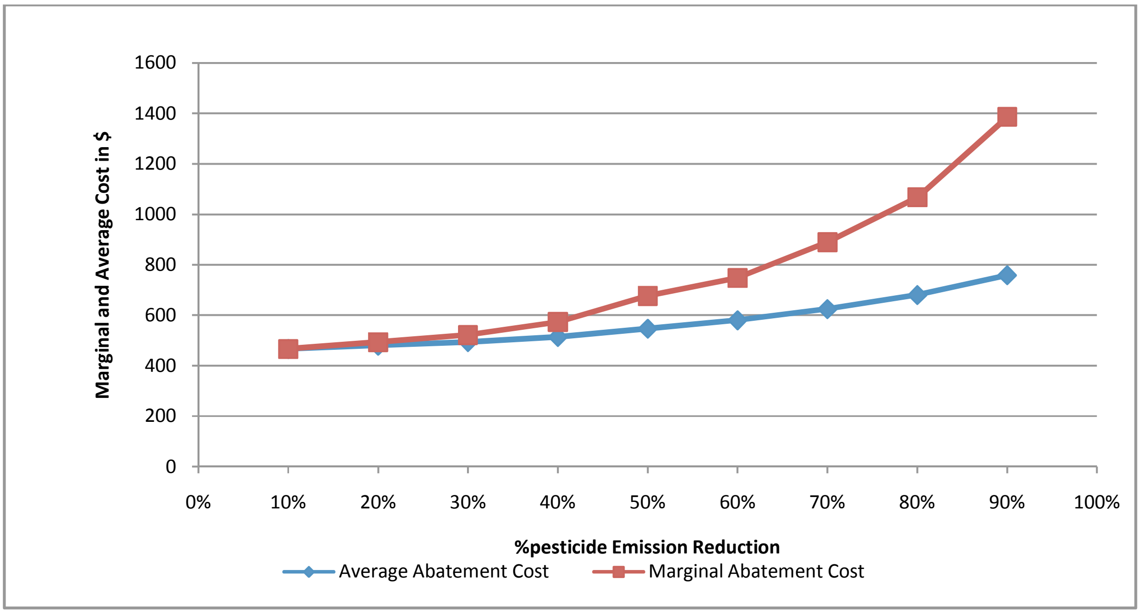


Table 4.8 shows the abatement cost for each environmental parameter when constrained at the watershed scale. Note that the units of output of the average cost in Table 4.8 are in terms of ton of sediment, kg of phosphorus, kg of nitrogen, 1*10E9 NCF of e-coli, and kg of pesticide. For example, the average abatement cost per ton of sediment measured at the 10% emission reduction was $6,439 (sediment column). As seen in Figures 4.8 to 4.11 the average costs were always non-negative and increase at an increasing rate as the emission reduction was increased.

Table 4. 8 : Average abatement cost of every environmental parameter as a function of an emission reduction constraint at the watershed.

Emission Reduction	Average abatement cost ($)				
	Sediment (t)	Phophorous (kg)	Nitrogen (kg)	E. coli (1*10E9 NCF)	Pesticide (kg)
0%					
10%	6439	873	84	228	467
20%	8771	923	238	237	480
30%	10452	977	327	243	494
40%	12147	1071	428	248	514
50%	14828	1365	608	252	547
60%	18055	1709	959	266	580
70%	21511	2192	1287	280	624
80%	n/a	2860	1714	310	680
90%	n/a	4131	2629	n/a	758

Table 4.9 shows the marginal abatement cost of each environmental parameter when constrained at the watershed scale. Note that the unit of output of the marginal cost in Table 4.9 is in terms of dollars per ton of sediment, kg of phosphorus, kg of nitrogen, 1*10E9 NCF of e-coli, and kg of pesticide. For example, the interpretation of the cost is $6,439 for an additional ton of sediment reduction when measured at the 10% level. As shown in Tables 4.8 to 4.11 the marginal costs were always non-negative and increased at an increasing rate as the pollutant emission reduction increased.

Table 4. 9 : Marginal abatement cost of every environmental parameter as a function of an emission reduction constraint.

Emission Reduction	Marginal abatement cost ($)				
	Sediment (t)	Phophorous (kg)	Nitrogen (kg)	Ecoli (1*10E9 NCF)	Pesticide (kg)
0%					
10%	6439	873	84	228	467
20%	11104	972	393	244	493
30%	13812	1086	504	255	522
40%	17234	1354	731	260	574
50%	25550	2538	1329	269	677
60%	34190	3431	2714	332	748
70%	42245	5091	3256	365	890
80%	n/a	7537	4703	515	1068
90%	n/a	14293	9951	n/a	1386

Finally, note that in Figures 4.7 to 4.11 and in Tables 4.8 and 4.9, the marginal abatement costs were always equal or higher than the average abatement costs. This holds for every environmental parameter. Furthermore, the marginal cost for the first unit of output equals the average cost. This occurs because the average and marginal costs are similar for the first unit (%) of reduction. After this point, the average costs are rising because of the increased environmental constraint then it must be the case that the marginal costs are increasing at a greater rate. It is the higher marginal costs that are pushing the average costs up. Therefore, this result is as expected from economic theory.

4.3.5 Watershed vs farm scale emission reduction constraint.

The environmental constraint was modified in order to analyze the impact at the farm scale as opposed to the watershed scale. This allows for an estimate to be determined for the impact on the individual farm OFV of an emission reduction set at the farm scale. See equation 17 for this modification.

Figures 4.12 to 4.15 present the average abatement cost curves of sediment, phosphorus, nitrogen, and pesticide at the farm and at the watershed scale. The figures indicate that the average abatement cost at the watershed scale were lower than at the farm scale with the exception of pesticide. In other words, it was less expensive to constrain pollution emissions at the watershed scale than at the farm scale. Similarly, for a given average abatement cost more sediment will be abated with a watershed constraint than with a farm constraint. This was expected from economic theory since the emission reduction at the watershed scale provides greater flexibility and more reductions will come from the least cost area. Sediment, phosphorous, and nitrogen have similar behaviour when comparing farm and watershed average abatement costs. Data limitations did not allow for a comparison of e-coli reductions at the farm and at the watershed scale for abatement costs. The model did not reduce animal numbers or adopt dribble bar applications of manure. The model simply selected the fields with coliform pollution and gradually put them out of production as the emission reduction increased. This occurred because the e-coli pollution coefficients did not change by type of production and therefore all crop production had the same pollution coefficients within a given RHHU. The model is confronted with the choice to decrease the # of animals or to buy feed from outside the farm. Since animal production is more profitable than crop production the model eliminated crops but not animals. Note that dairy and poultry animal are assumed to be fixed. Only hog and beef animal can vary. This explains why the model eliminated crops but did not decrease animal numbers.

Figure 4.15 indicates that the cost of reducing pesticide at the watershed scale was higher than reducing it at the farm scale. This occurred because of how the scenario was designed and data limitations. When the model was constrained to its base case level of pollution emission, i.e. when the RHS of the environmental constraints equals the base case level of pollution emissions, the watershed model produces more corn than in the base case while still respecting the environmental constraint. That is, at the watershed scale, the model can reallocate crop production throughout the watershed. As a result, more corn was produced but on less environmentally sensitive fields.

However, with the farm scale simulation there was little or no movement of corn production between fields on the farm. In the farm scale simulation, the model could move corn around the farm and expand hectarage if one field was less environmentally sensitive. However, this is probably minimal. If a farm did not grow corn in the base case it would have a 0 pesticide constraint, then the farm could not grow corn. Therefore, the corn production pattern is very similar to the current practice on the farm. As a result, there would be corn grown on pesticide sensitive fields. Since there was more corn hectares grown in the watershed model than in the farm model, reducing pesticide emission represents a greater cost for the watershed model than for the farm model. This is a limitation of having only one production using pesticide.

Figure 4. 12 : Sediment average abatement cost for watershed and farm simulations.

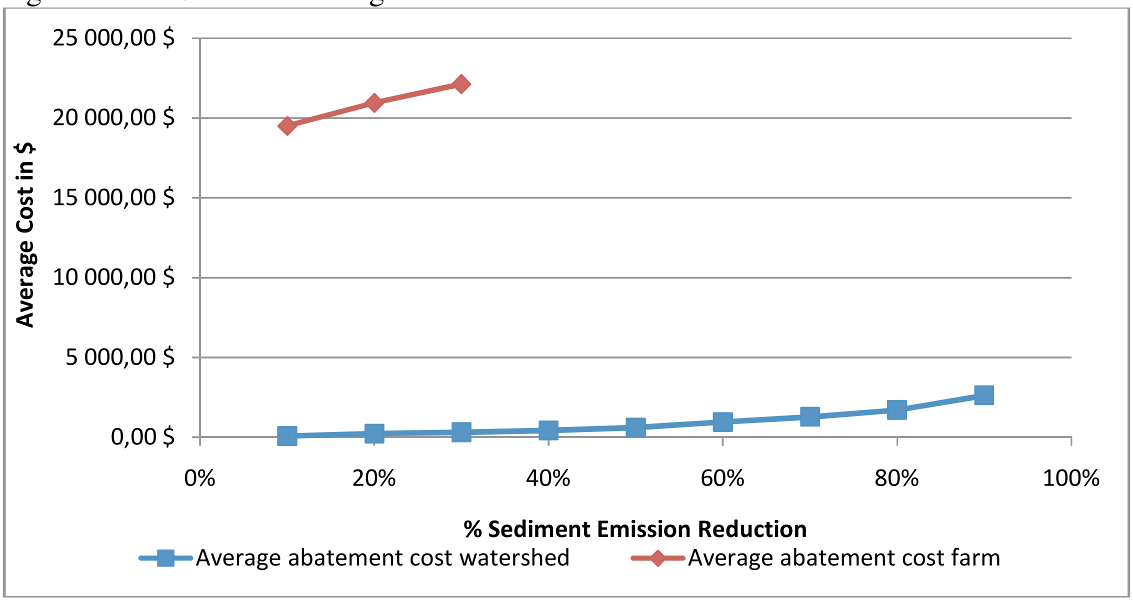


Figure 4. 13: Phosphorus average abatement cost for watershed and farm simulations.

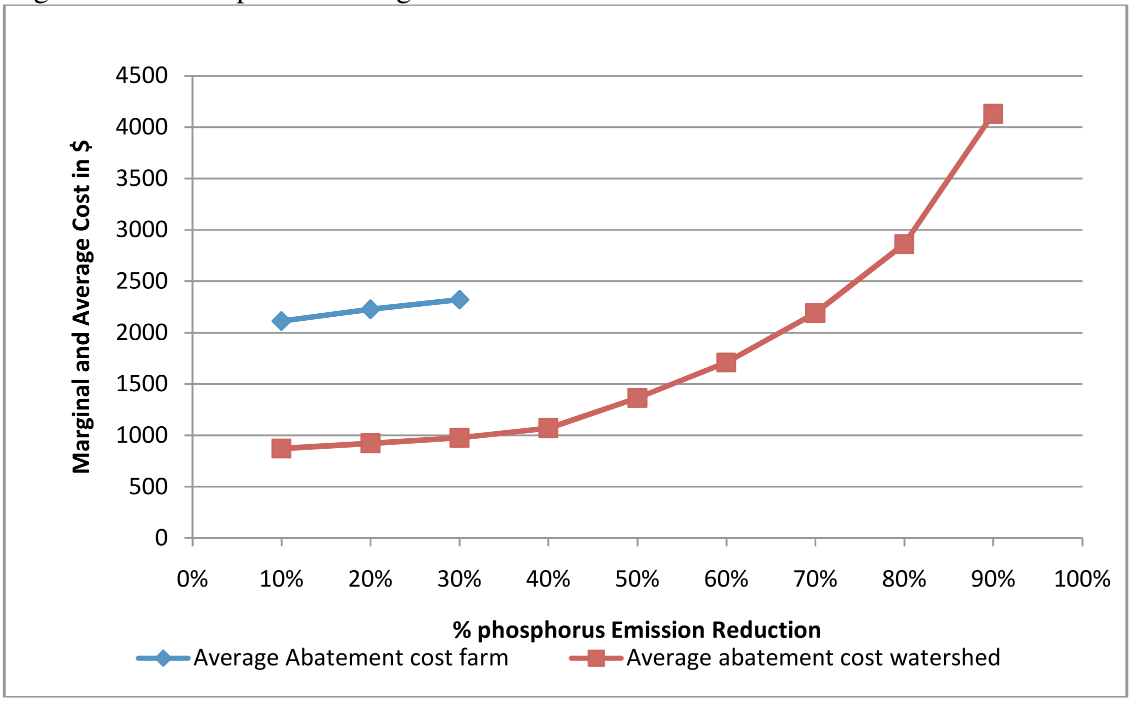


Figure 4. 14 : Nitrogen average abatement cost for watershed and farm simulations.

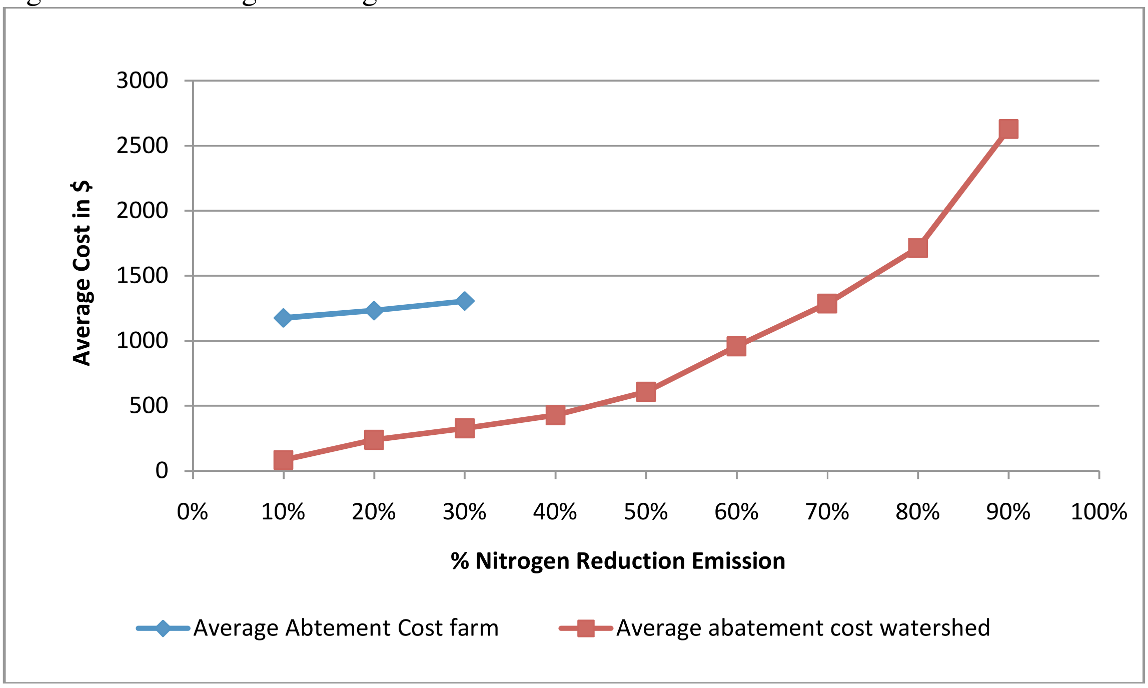


Figure 4. 15 : Pesticide average abatement cost for watershed and farm simulations.

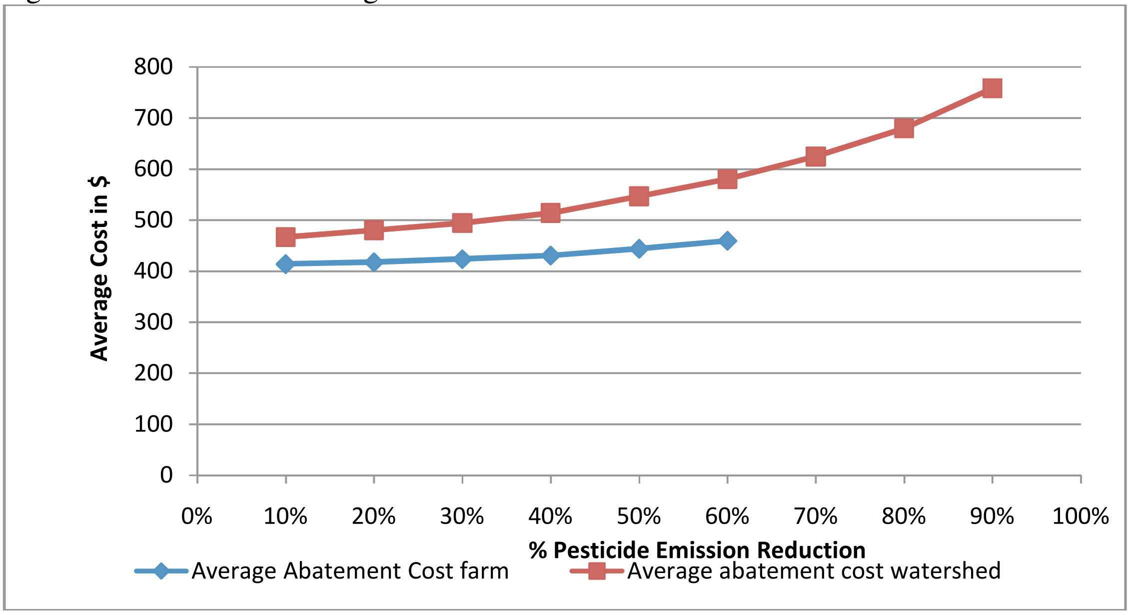


Table 4.10 shows the abatement cost of each environmental parameter when constrained at the farm scale. The unit of output of the average cost were in terms of tons of sediment, kg of phosphorus, kg of nitrogen, 1*10E9 NCF of e-coli, and kg of pesticide. For example, the interpretation of the $19,509 in the sediment column is the average abatement cost per ton of sediment measured at the 10% of emission reduction level. As illustrated in Figures 4.12 to 4.15 the average costs were always non-negative and increasing as the pollutant emission was reduced. Given the limited number of solutions at the farm scale, it was not possible to conclude that the farm scale average abatement costs were increasing at an increasing rate.

Table 4. 10 : Average abatement cost for every environmental parameter as a function of pollutant reduction constraint at the farm scale.

Emission Reduction	Average abatement cost				
	Sediment (t)	Phophorous (kg)	Nitrogen (kg)	Ecoli (1*10E9 NCF)	Pesticide (kg)
0%					
10%	$19 509	$2 114	$1 176	n/a	$414
20%	$20 952	$2 228	$1 233	n/a	$418
30%	$22 134	$2 322	$1 306	n/a	$424
40%	n/a	n/a	n/a	n/a	$431
50%	n/a	n/a	n/a	n/a	$444
60%	n/a	n/a	n/a	n/a	$460
70%	n/a	n/a	n/a	n/a	n/a
80%	n/a	n/a	n/a	n/a	n/a
90%	n/a	n/a	n/a	n/a	n/a

Figures 4.16 to 4.19 present the marginal abatement cost of sediment, phosphorus, nitrogen, and pesticide at the farm and at the watershed scales. From these figures, it can be seen that the marginal abatement cost at the watershed scale was lower than at the farm scale for sediment, phosphorous, and nitrogen. In other words, it was less expensive to constraint an additional unit of pollution emission at the watershed scale than at the farm scale. Sediment, phosphorous, and nitrogen have similar behaviour when comparing farm and watershed marginal abatement cost. With regard to e-coli, data limitations did not allow for any comparison between the marginal abatement cost at the farm and at the watershed scale.

Figure 4.19 shows that the cost of reducing an additional unit of pesticide emission at the watershed scale was higher than reducing it at the farm scale. With the farm scale simulation there was little or no movement of corn production on fields on the farm. In the farm scale simulation, the model could not move corn around the farm and expand hectarage if one field was less environmentally sensitive. If a farm did not grow corn in the base case it would have a 0 pesticide constraint, then the farm could not grow corn. Therefore, the corn production pattern is very similar to the current practice on the farm. As a result, there would be corn grown on pesticide sensitive fields. Since there were more corn hectares grown in the watershed model than in the farm model, reducing pesticide emission represents a greater cost for the watershed model than for the farm model. This is a limitation of having only one production using pesticide.

Figure 4. 16 : Sediment marginal abatement cost at the watershed and at the farm scale.

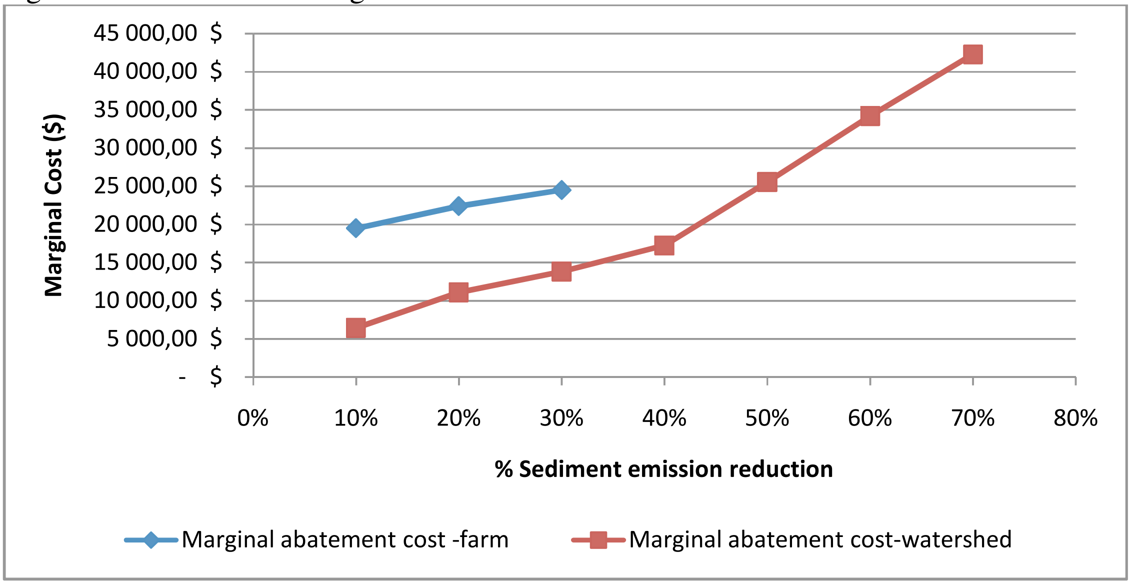


Figure 4. 17 : Phosphorus marginal abatement cost at the watershed and at the farm scale.

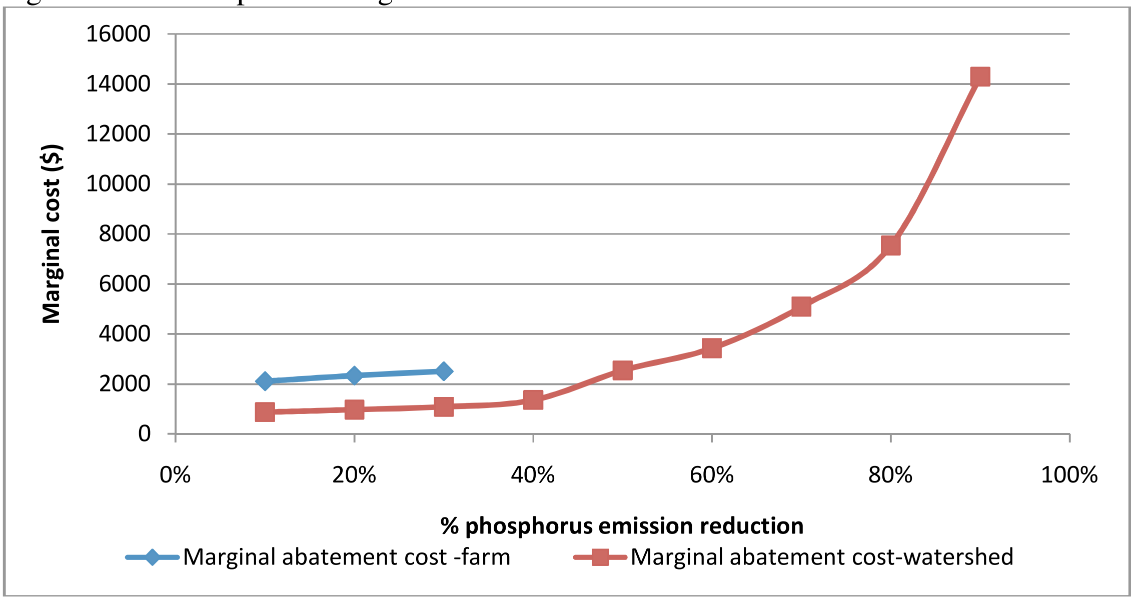


Figure 4. 18 : Nitrogen marginal abatement cost at the watershed and at the farm scale.

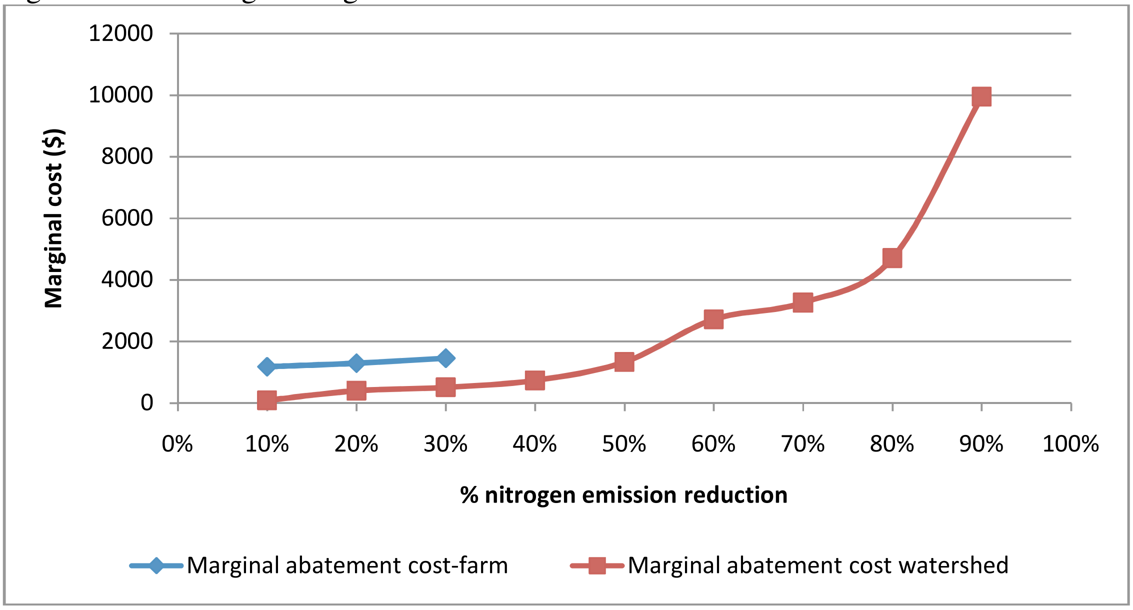


Figure 4. 19 : Pesticide marginal abatement cost at the watershed and at the farm scale.

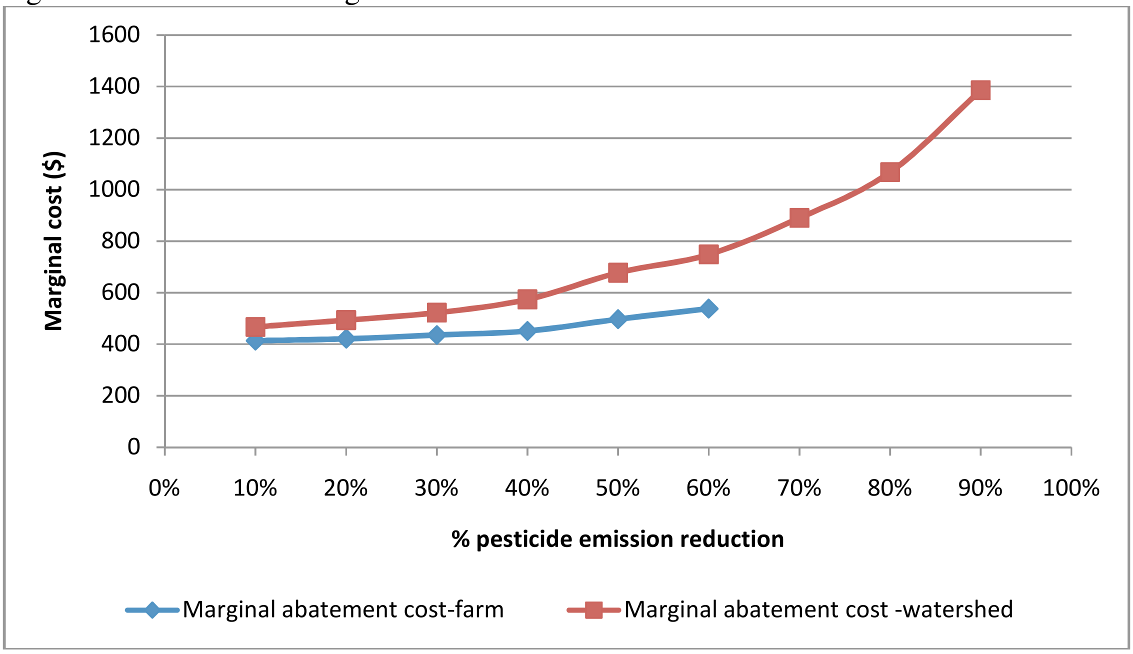


Table 4.11 shows the marginal abatement cost for each environmental parameter when constrained at the farm scale. Note that the unit of output of the marginal cost are tons of sediment, kg of phosphorus, kg of nitrogen, 1*10E9 NCF of e-coli, and kg of

pesticide. For example, the interpretation of the $19,509 in the sediment column is that the cost of abating one additional ton of sediment is $19,509, when measured at the 10% emission reduction level. As show in Figures 4.16 to 4.19 the marginal costs are always non-negative and increasing as the pollutant emission constraint was increased.

Table 4. 11 : Marginal abatement cost for every environmental parameter as a function of pollutant reduction constraint at the farm scale.

Emission Reduction	Marginal abatement cost ($)				
	Sediment (t)	Phophorous (kg)	Nitrogen (kg)	Ecoli (1*10E9 NCF)	Pesticide (kg)
0%					
10%	19509	2114	1176	n/a	414
20%	22393	2342	1289	n/a	421
30%	24494	2510	1452	n/a	436
40%	n/a	n/a	n/a	n/a	451
50%	n/a	n/a	n/a	n/a	497
60%	n/a	n/a	n/a	n/a	538
70%	n/a	n/a	n/a	n/a	n/a
80%	n/a	n/a	n/a	n/a	n/a
90%	n/a	n/a	n/a	n/a	n/a

Finally, note that in Figures 4.16 to 4.19 and in Tables 4.10 and 4.11 the marginal abatement costs are always equal to or higher than the average abatement costs. This holds for every environmental parameter and also for the pollution emission constraint when all pollution was reduced by a given percentage. Furthermore, the marginal cost for the first unit of output equals the average cost. This occurs because the average costs were increasing as a result of the increase in the pollution reduction and as a result the marginal costs increase at a faster rate than the average cost. It was the higher marginal costs that are pushing the average cost up. This result is what was expected from economic theory. Furthermore, higher levels of abatement were available by implementing an environmental constraint at the watershed scale. This has forced the model to account for environmental efficiency as well as economic efficiency.

4.4 Discussion

In chapter 1 (p.11) three hypotheses were presented for testing. None of these hypotheses were rejected. The first hypothesis tests whether implementing a pollutant emission constraint reduces the amount of pollutant generated from agricultural production. This implies that the base case scenario produces an amount pollution that can be decreased. Testing the second hypothesis indicates that implementing an emission constraint forces cropping patterns and farming practices to change. The change in crop mix from the base case scenario and the adoption of BMPs was done in order to satisfy the emission reduction constraint. The test of the third hypothesis indicates that the change in cropping pattern and farming practices reduced profits. From this it can be concluded that implementing a pollution emission constraint reduces both pollution and profits.

Other conclusions can be drawn from this research. First, at the watershed scale, as pollution emission reductions increase both marginal and average costs increase at an increasing rate and profits decrease at an increasing rate. At the farm scale, as pollution emission reductions increase, both marginal and average costs increase and profits decrease. At the farm scale, the curvature of the average and the marginal cost curves were indeterminate. However, it was determined that marginal and average costs at the farm scale were always non-negative and increasing. Second, the increase in marginal and average costs corresponds to an increase in hay production across farms. Third, in the studied watershed, farms would be better off with pollution emission reduction constraints implemented at the watershed scale than at the farm scale. Finally, there were interactions between the environmental parameters and BMPs. Implementing a BMP has an impact on the emission of a number of the environmental parameters. These interactions can be positive or negative.

Substantial costs would be borne by farmers to decrease the pollution emissions that result from agriculture production, while society, as a whole, would benefit from the reduced pollution. The results bring to the forefront a number of interesting policy questions. These include: how much abatement should be supplied? What is the most efficient means of providing the incentives to generate pollution abatement from agriculture producers?

A number of different ways can be used to generate the incentives for agricultural producers to generate pollution abatement. These include the type of economic instrument, (i.e. tax, subsidy, or pollution certificate), and the scale at which the regulation is applied, (i.e. farm or watershed). The choice of economic instrument and scale will have an impact on the efficiency of the abatement supplied and the distribution of costs and benefits to individual producers in the watershed. A tax could be implemented on the amount of pollution generated by a farm. This tax should be set where the marginal abatement cost is equal to the marginal benefit of increased environmental quality. Producers would provide abatement to the point where their marginal abatement cost equals the tax rate and pay the tax on the remaining emissions. In this case the producer pays the total cost of pollution. A potential problem with implementing a tax is the high transaction costs of monitoring and enforcement.

An alternative to the tax would be to implement a subsidy for the establishment of BMPs that increase environmental quality. Government could determine the maximum amount of pollution coming from the watershed and subsidize BMPs until environmental quality improves to that level. In this case the cost of improved environmental quality is borne by the tax payer and producers are compensated for the BMPs that they establish. Transaction costs are lower for the subsidy since it is easier to monitor the implementation of a BMP. However, the nature of non-point source pollution may still result in high transaction costs.

A third policy alternative is to establish a pollution emission trading market. The optimal level of pollution abatement from the watershed should be when the marginal cost of abatement equals the marginal benefit of decreased pollution emissions to society. This study has estimated the marginal abatement cost curves for pollution emission reductions. The values of the marginal benefit could be estimated by conducting a contingency valuation or choice modelling experiment on a broader scale.

As explained by Randall (1987), a government agency would determine the permissible amount of pollution (PAP) in a geographic region. This region could be an individual farm or the watershed. Each polluter would be permitted a certain amount of pollution corresponding to the number of certificates purchased by auction and would face prohibitive penalties for excess pollution. The advantage of the pollution certificate program is that it provides incentives for high cost abaters to purchase pollution certificates from low cost abaters. Low cost abaters have an incentive to supply more abatement. Income derived from the auction may be viewed as compensation to society for non-point source pollution. If the erosion target was set at the farm scale, individual farms could satisfy their target by changing management practices; i.e. adopt BMPs or change cropping patterns, decrease production or purchase pollution certificates from other producers in the watershed. The increased cost to the producer is the result of the social cost of pollution. The results indicate that it is cost effective to set constraints at the watershed scale as compared to the farm scale. That is the lost profit for an individual farm is greater when the pollution target is set at the farm scale than when it is set at the watershed scale. To achieve these cost savings, producers with high abatement costs would purchase certificates from lower cost abatement producers. In this situation, producers would benefit from the gains from trade to satisfy the regulation requirement. Each farm would be better off from this way of achieving the PAP.

One last technical issue is that pollution abatement costs estimated are for the farms selected in this watershed. This is, because the abatement cost curves are based on field physical characteristics and farmer cropping decisions that generate a unique combination of environmental economic data for this watershed, they are not necessarily transferable to other watersheds. Hence, since every watershed is different and the associated pollution abatement costs are different, legislators could not implement a national or a provincial policy base on these estimates. One approach may be to identify an average abatement cost curve for all farmers and from this establish how much abatement would be required (Turvey and Weersink, 1991). Or following the discussion on pollution certificates, the government could set a per hectare soil loss standard and let either the watershed or the individual farms comply with this standard. More generally, to induce enhanced stewardship and sustainability on Canadian farms, “policies should be prescribed on a targeted basis, so that differences among farmers in terms of conservation needs and effort can be accounted for, and so that pre-specified societal goals, such as more nearly attained” (Stonehouse 1996, p.116).

Chapter 5: Conclusion

5.1 Summary and conclusions

The Chaudière Watershed has one of the highest concentrations of animal production in Quebec and nearly two-thirds of its land is under crop production (AAFC, 2007a). Over time, the surface water quality in the Bras d'Henri sub-watershed has declined and agricultural non-point source pollution has been identified as being the main source of this decrease in water quality (AAFC, 2007b). This study addresses the issue of non-point source agricultural pollution in the Bras d'Henri sub-watershed. It estimates the economic impact of an increase in the environmental constraint on the farm scale and watershed scale. The environmental and economic impacts of adopting Best Management Practices (BMPs) were evaluated to satisfy the environmental constraint.

The literature review identified some important relationships. First, agricultural land management has an impact on water quality. It was recognized that best management farming practices are a major tool in addressing non-point source pollution problems in agriculture. Factors that are important for the adoption of BMPs are asymmetric information, risk perception, and the farm economic context. Second, it is recognized that site-specific information is important when conducting economic ecological modelling. Finally, different environmental control regulations in Quebec/ Canada and U.S. in agriculture were identified. The importance of the concept of sustainability as a policy was outlined.

A Linear Programming (LP) model was used to assess the costs of implementing an erosion constraint at the farm and at the watershed scales. The LP model took into account the spatial relationship in the watershed based on a GIS model of the sub-watershed. The model was based on three types of data: crop and animal budgets, animal nutrient requirements, and environmental coefficients. This study was conducted in the Chaudière River Basin and addresses the issues of agricultural non-point source pollution in the Bras d'Henri sub-watershed. The objectives of the study were to quantify at the farm and at the watershed scale the relative economic impact of an environmental target when relying on BMPs to mitigate conditions such as sediment, phosphorus, nitrogen, e-coli, and pesticide pollution.

The farm data originated from an on-farm survey where the spatial location of each field on each farm and the farm characteristics were collected. Crop and animal budgets were estimated from CRAAQ data. These budgets were estimated for the Beauce region, i.e. taking in account the regional statistics such as the production yields, number of animals per farm, etc. The animal nutrient data were estimated from published sources. These estimates should be taken as approximations only. The estimated nutrient requirement for a farm was depended on the type of animal production, but in general included energy, protein, calcium, and phosphorus. Finally, nutritional values of crops grown on-farm were estimated from published sources. The environmental coefficients were estimated using a Relative Homogenous Hydrologic Unit (RHHU). These units consist of similar bio-physical properties. In order to permit the farm analysis, each field was attributed to only one RHHU or a weighted average of the RHHU values depending on whether the field was lying on only one RHHU or several. The environmental coefficients were estimated for five environmental parameters: (1) Pesticide, (2) Nitrogen, (3) Phosphorus, (4) Sediment, and (5) coliform. A base case scenario, which took into account current crop and animal production, was used to estimate the pollution emissions from the farms and the watershed. A series of environmental constraints were introduced that decreased the amount of base case pollution by certain percentages. The following BMPs could be used to decrease pollution emissions: (1) 1m wide buffer strip, (2) 3m wide buffer strip, (3) 5m wide buffer strip, (4) reduced use of pesticide, and (5) a dribble bar. The objective function maximized the sum of field net margins subject to five sets of constraints: (1) farm characteristics, (2) best management practices (3) animal nutrient requirements, (4) environmental constraints, and (5) crop mix constraints.

None of the hypotheses presented for testing were rejected. Implementing a pollutant emission constraint reduces the amount of pollutant generated from agricultural production. Further, implementing an emission constraint forces the cropping patterns and farming practices to change and the change in cropping pattern and farming practices reduced profits. From this it can be concluded that implementing a pollution emission constraint reduces both pollution and profits.

Other conclusions were drawn from this research. First, at the watershed scale, as pollution emission reductions increase both marginal and average costs increase at an increasing rate and profits decrease at an increasing rate. At the farm scale, as pollution emission reductions increase, both marginal and average costs increase and profits decrease. Second, the increase in marginal and average costs correspond to an increase in hay production across farms. Third, in the studied watershed, farms would be better off with a pollution emission reduction constraint implemented at the watershed scale than at the farm scale. Finally, there are interactions between the environmental parameters and BMPs and these interactions can be positive or negative.

Substantial costs would be borne by farmers to decrease the pollution emissions that result from agriculture production, while society, as a whole, would benefit from the reduced pollution. A number of different ways have been identified to generate the incentives for agricultural producers to generate pollution abatement. These include different economic instruments, (i.e. tax, subsidy, or pollution certificate), and the scale at which the regulation is applied, (i.e. farm or watershed). A tax could be implemented on the amount of pollution generated by a farm. This tax should be set where the marginal abatement cost is equal to the marginal benefit of increased environmental quality. Producers would provide abatement to the point where their marginal abatement cost equals the tax rate and pay the tax on the remaining emissions. An alternative to the tax would be to implement a subsidy for the establishment of BMPs that increase environmental quality. Government could determine the maximum amount of pollution coming from the watershed and subsidize BMPs until environmental quality improves to that level. In this case the cost of improved environmental quality is borne by the tax payer and producers are compensated for the BMPs that they establish.

A third policy alternative is to establish a pollution emission trading market. The optimal level of pollution abatement from the watershed should be when the marginal cost of abatement equals the marginal benefit of decreased pollution emissions to society. The values of the marginal benefit could be estimated by conducting a contingency valuation or choice modelling experiment on the broader society.

If the erosion target was set at the farm scale, individual farms could satisfy their target by changing management practices, (i.e. adopt BMPs or change cropping patterns, decrease production or purchase pollution certificates from other producers in the watershed). The increase in cost to the producer is the result of the social cost of pollution. These results indicate that it is cost effective to set the environmental constraint at the watershed scale as compared to the farm scale. That is the lost profit for individual farms is greater when the pollution target is set at the farm scale than when it is set at the watershed scale. Because the abatement cost curves are based on physical field characteristics and farmer cropping decisions that generate a unique combination of environmental economic data for this watershed and since every watershed is different, i.e. the associated pollution abatement costs are different, legislators should not use the value estimates to implement a National or Provincial policy. However, the results concerning the farm and watershed scale policies should hold. Similarly, the shapes of the average and marginal abatement cost curves should be similar.

There are several contributions of this study. First, it used data extracted from a survey, which was transferred into a GIS database and recombined at the field level in order to estimate field level environmental coefficients. Second, a LP model was built to study the effect of an increasing pollution emission constraint on farm profitability at both the farm and watershed scale and the distributional issues associated with policy at the farm and at the watershed scale were investigated. Third, animal nutrient requirements were taken into account. Finally, even though different methods were used, results were comparable to other studies that found that reducing pollution emissions from agriculture production could only be satisfied by increasing costs to farmers.

5.1 Limitations of the study and recommendations for future research.

The model was a linear programming model. This LP model could be expanded to include integer components in crops and BMP selections. Simple modification to the model would be required in order to incorporate integer components; however the model would then have to be run by powerful computers in order to generate results in a reasonable time length. With respect to distributional issues, limitation of this study was that off-farm benefits of reducing pollution emissions were not taken into account. Therefore, it is hard to provide quantitative estimates of environmental off-farm benefits of reduced pollution. Also, the consequence of having spatial autocorrelation patterns (M.I.: 0.2) in the pollution data have a moderate impact on the results. First, the Moran Index indicates a significant but a relative low value describing weak autocorrelation pattern. Second, the lack of variation in the sediment coefficient for hay may explain part of this autocorrelation patterns. As a result, data collection should be refined to correct for autocorrelation patterns when present. Note that no spatial autocorrelation patterns across farm characteristics have been identified.

Finally, this study has several data and model limitations that potentially could be solved with further research. Data collection should be refined in order to be more specific and incorporate all the heterogeneity of a watershed into the model such as crop specific environmental coefficients, farm size, and specific watershed environmental coefficients that are at the mouth of the watershed to take into account the transportation of pollution in the sub-watershed. In addition, the exclusion of the large farms in the survey procedure implies biased model estimations that mist the impact of the agricultural practices on the environment of the studied region. Further, a macro model that would allow the geographical representation of the results and the illustration of the change in crop mix patterns and in management practices would be beneficial on a WEB's II project in order to better analyze changes in management practices. Other improvements to the model would include: first, adding a complete manure export trading block between farmers in the watershed, and between farmer and the rest of the world. Second, a complete crop trading block could be added that included transportation costs. Finally, a more accurate spatially referenced database would be beneficial.

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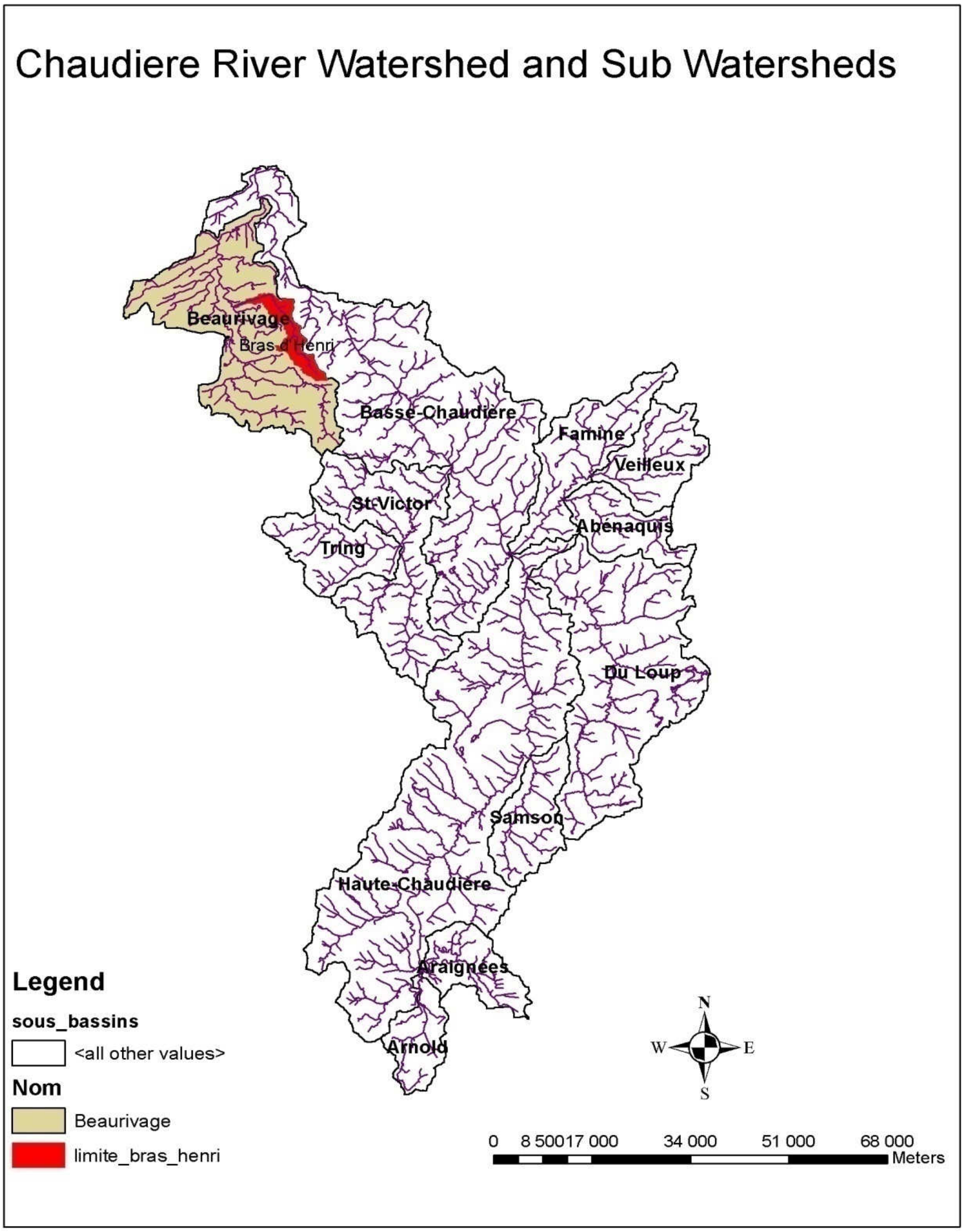
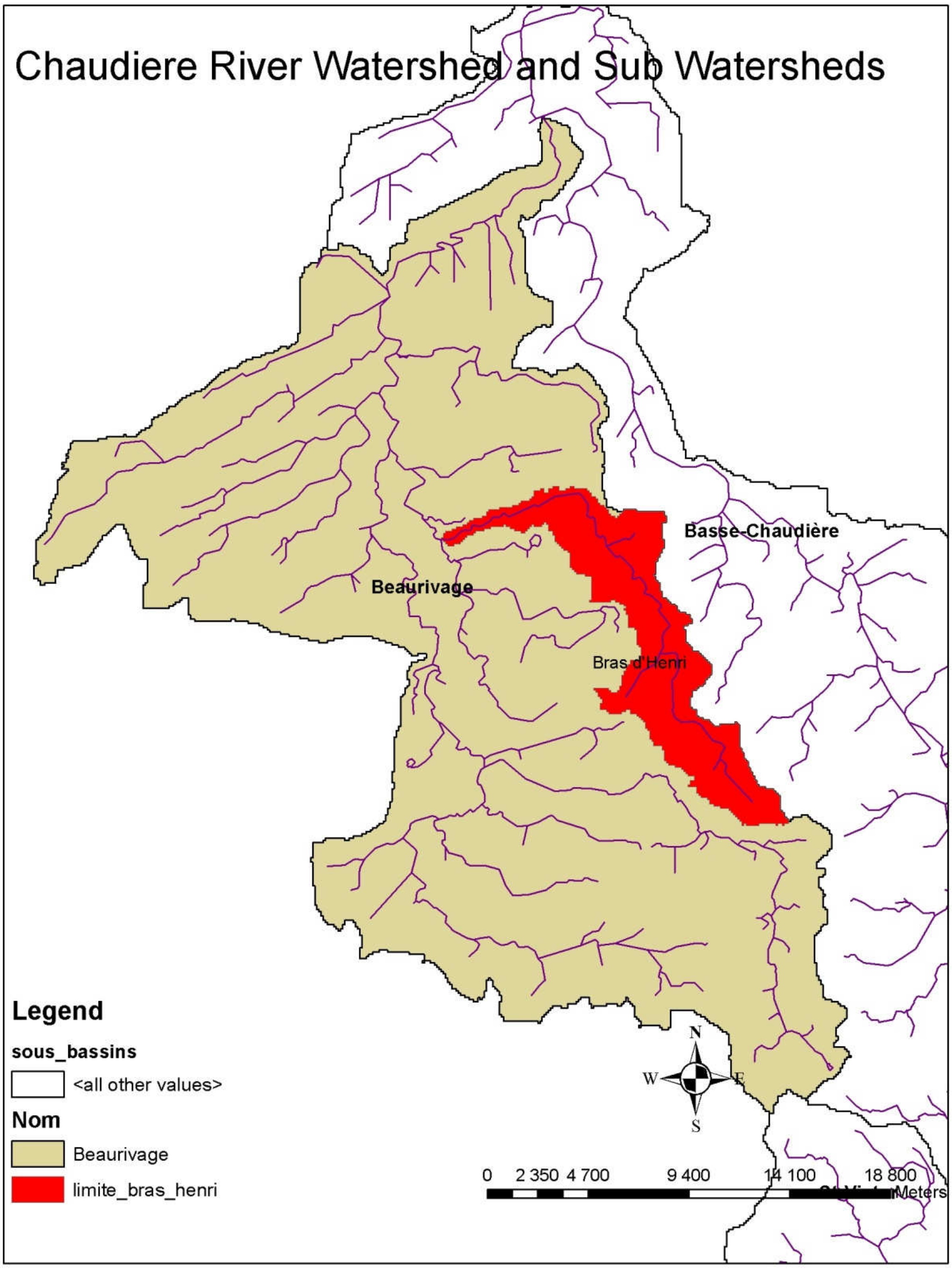
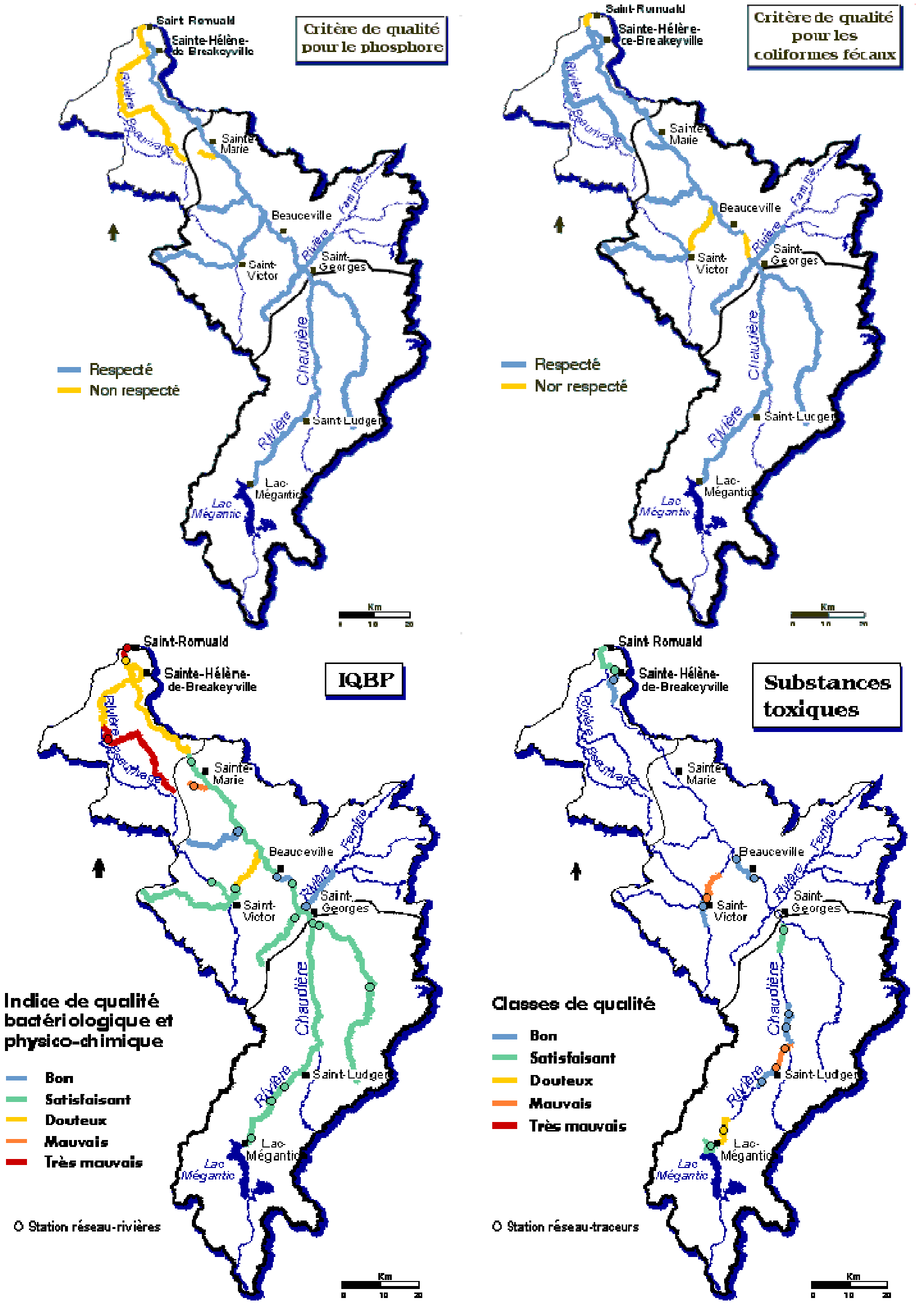
Appendix 1. Map of the Chaudière River Sub-watersheds



Appendix 2. Map of the Beaurivage Sub-watershed and its Bras d'Henri Sub-watershed.



Appendix 3. Watershed environmental situation for phosphorous, E-Coli, IQBP, and toxicity.



Source : MDDEP, 2007d.

Appendix 4 Farm Survey.

Numéro de la ferme:_____________ Date:________ Heure:______________________

Adresse du répondant :

1) Type de ferme et pourcentage de chaque production :

Laitier (%):____
Bovin (%):____
Porcin (%) :____
Autre (%) :____(spécifiez)

2) Combien d'animaux avez-vous sur votre ferme?

	Nombre d'animal
Bovin laitier/Bovin de boucherie	
Vache laitière ou Vache à bœuf.	
Veau (0-6 months)	
Génisse (7-15 months)	
Taure (>15 months)	
Taureaux	
Autre	
Engraissement/ Maternité/ Pouponnière	
Engraissement	
Maternité	
Pouponnière	
Verrat	
Poultry Producer	
Coq	
Poule	

3) Identifiez sur la carte les champs dont vous êtes le gestionnaire (propriétaire ou locataire).

3-a) Tracez le contour de votre ferme.

3-b) Indiquez sur la carte quelle était la culture sur chaque champ en 2006.

(A-Avoine, O-orge, M-Maïs, S-Soya, B-Blé, F-Foin, ME-Maïs Ensilage, paturage, X-Aucune production, AU-Autre (spécifiez) :______________

3-c) Indiquez le nombre d'ha et leur production qui n'on pas été identifié sur les cartes.____

3) Indiquez si vous appliquez actuellement des pratiques de gestions bénéfiques. Si applicable, indiquez sur la carte ou ils sont appliqués.

Bande Riveraine (Si oui :_______m)	Oui	Non
Épandeur à rampe basse	Oui	Non
Application réduite de pesticides	Oui	Non
Sur :_________________________ha____________________		
Sur :_________________________ha____________________		
Rotation des cultures	Oui	Non

4) Existe t-il une raison pour laquelle vous n'appliqueriez pas un PGB sur votre ferme (incluant des terres en location)?

____

____

____

____

5) Indiquez si vous utilisez la totalité de votre fumier sur votre ferme (incluant les terres louées). Oui :_______NON :________.

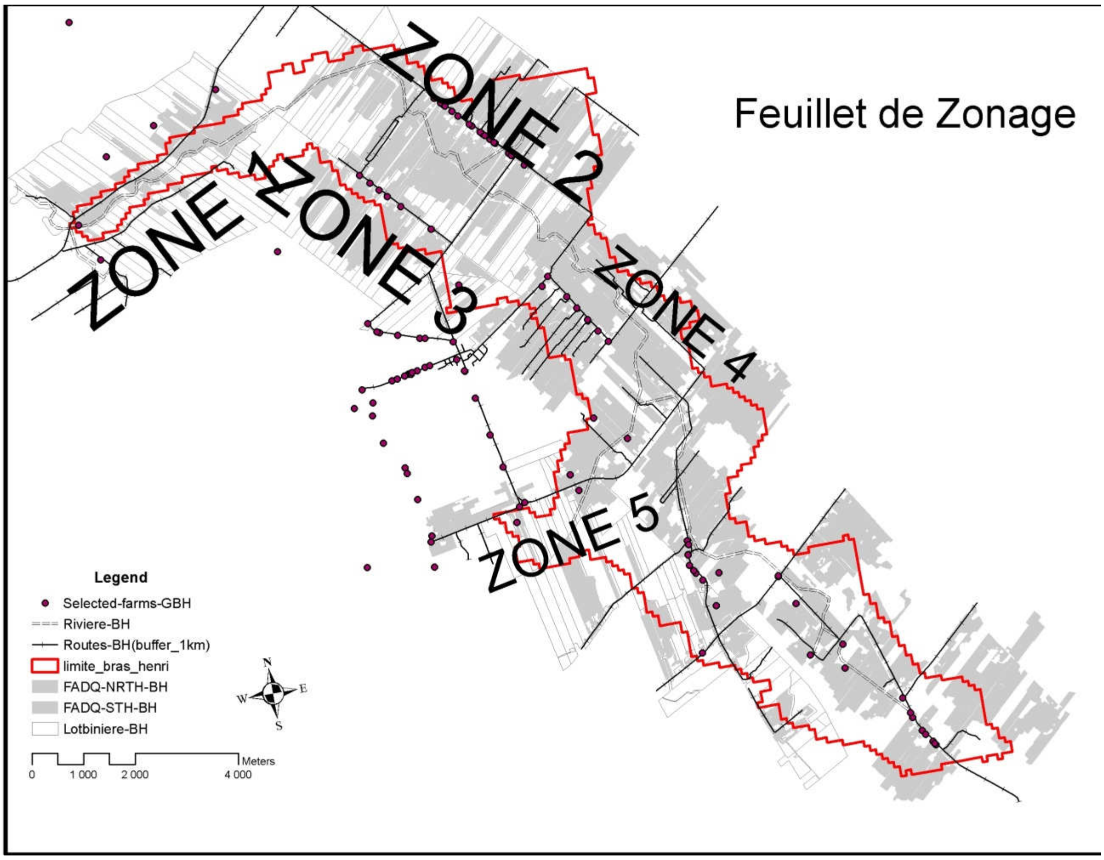
Si oui, indiquez si vous utilisez ou pourriez utiliser plus de fumier, combien et de quel type?
Oui :_______NON :________Combien : (spécifiez unité de mesure)_______
____

Si non, indiquez si votre fumier est épandu à l'extérieur ou l'intérieur des limites de la zone Bras d'Henri (voir carte). Oui :_______NON :__________
Combien : (spécifiez unité de mesure)________________________________
____

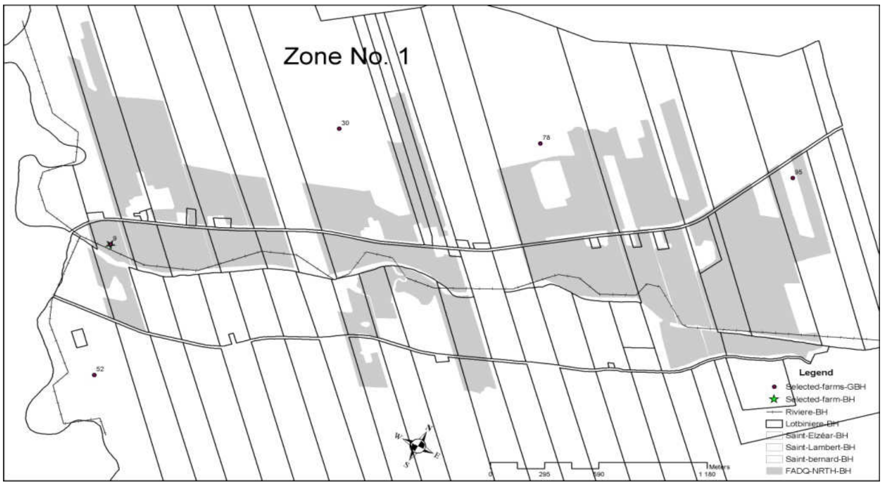
6) Indiquez si vous louez des terres uniquement afin de disposer de votre fumier. Oui :_______NON :________.

7) Discussion sur les pratiques culturales :
Semi direct, irrigation, rotation des cultures, commentaires généraux.____

Appendix 5 Zonage division of the survey area.

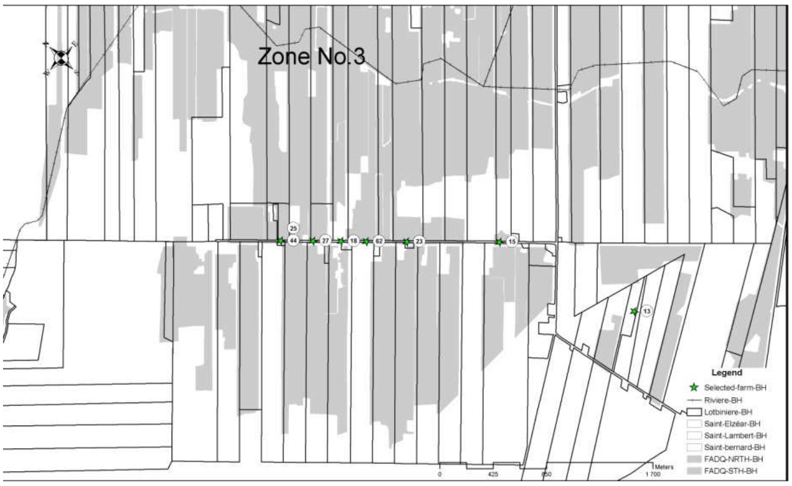


Appendix 6 Zonage map no.1 of the survey.

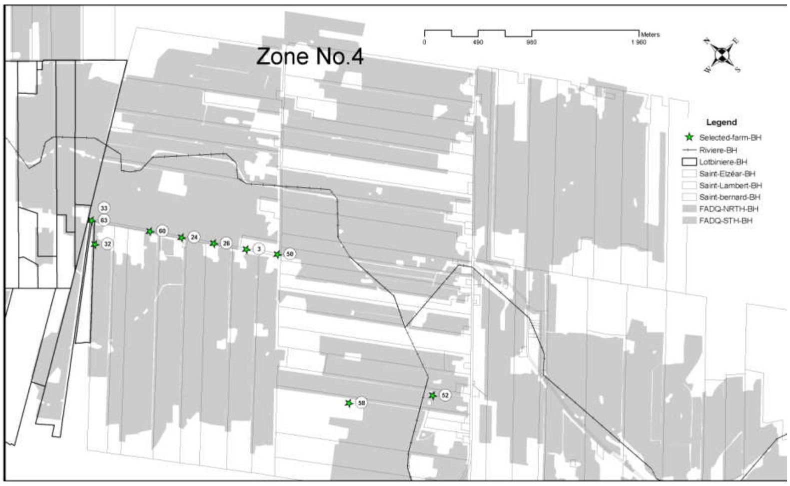


Appendix 7 Zonage map no.2 of the survey.

Appendix 8 Zonage map no.3 of the survey.



Appendix 9 Zonage map no.4 of the survey.



Appendix 10 Zonage map no.5 of the survey.

Appendix 11. RHHU descriptions and details.

	Quantity of liquid manure sprayed	Hay and pasture, Cereal, and Corn in production			Maximal Buffer strip length		
RHHU	Lisier (L)	hay and pasture (ha)	Cereal (ha)	Corn (ha)	hay and pasture (m)	Cereal (m)	Corn (m)
445	2399934	26.24	11.88	18.24	920	880	140
454	2416770.75	28.92	25.72	18.64	1540	0	0
455	13571098	126.32	101.56	50.32	6040	5120	3760
456	6868680.5	25.96	20.12	5.96	100	160	360
457	1110522	8.00	4.48	0.16	840	0	0
458	18132796	57.20	41.96	50.56	1220	640	1680
459	6880255	17.92	1.44	56.04	940	40	3100
460	10827063	73.88	6.92	42.44	1240	0	1040
462	20199504	78.52	47.20	104.20	960	1980	1320
463	6033860	41.64	3.64	23.40	1640	140	1820
464	9569220	47.00	32.16	29.76	200	0	2680
465	31568.84961	0.32	0.04	0.00	160	20	0
466	14540261	76.76	20.88	27.40	4180	360	320
467	13536724	59.88	17.76	1.04	2480	1460	0
468	16057670	25.48	28.60	0.00	2080	1220	0
469	20628840	35.40	24.00	8.32	1000	0	0
470	59450104	116.00	20.48	58.68	3340	560	220
471	3134786.75	20.52	8.28	6.88	1000	680	240
472	8723175	38.00	20.28	13.08	740	1260	0
473	9971898	58.12	41.28	2.36	1600	1440	0
474	24127720	63.76	21.16	24.40	1320	740	0
475	69767512	200.52	15.48	66.20	3980	240	3740
476	36140368	69.56	16.80	32.28	3140	360	680
478	16409838	29.56	16.24	9.92	1160	0	0
480	36834884	48.56	26.28	46.08	1200	0	0
481	22785694	18.68	4.28	51.84	1820	640	2340
483	39943012	84.92	47.12	34.80	4000	1900	940
486	9950501	52.60	18.36	43.64	140	740	3680
487	1667186	10.12	0.24	8.84	480	0	0
488	24625806	52.56	26.72	1.56	280	0	0
489	18179798	25.84	8.48	25.36	2440	280	420
490	39405992	100.32	8.16	20.88	5180	340	1700
491	27196564	53.20	18.24	17.84	1740	2420	720
492	29167162	55.96	16.60	23.36	2880	20	620
493	5209562	36.16	4.68	19.16	400	120	400
494	3017982.25	16.32	3.20	15.24	40	0	0
495	54813344	92.00	36.84	54.96	3480	1880	2100
496	9638320	11.72	3.32	16.60	600	80	420
498	13683693	26.56	7.76	10.60	0	880	1260
499	13652124	7.48	0.28	43.92	0	160	1840
500	31912246	75.84	5.84	23.08	920	220	1760
501	21291084	56.08	5.76	8.88	220	0	0
502	8103373	7.72	5.32	14.32	1140	40	1060
503	11927062	29.00	0.20	15.12	880	0	260
504	30350292	34.24	13.80	60.40	1500	220	2260
505	15912454	45.20	6.16	5.96	480	860	0
506	42840684	123.60	21.68	9.04	4780	1100	200
507	18922018	45.68	14.80	7.68	960	560	0
508	12803273	27.36	17.12	1.64	820	400	0
509	18533370	52.76	16.12	21.36	80	0	0
517	1976560.75	33.24	15.84	10.52	1860	940	0
522	1778027.625	19.04	1.20	0.00	500	60	0
523	1096491.375	6.72	5.76	0.00	160	180	0
524	7059847	40.80	19.64	19.92	1620	260	0
532	20723196	124.68	52.40	58.80	4120	1700	1520
533	1627198.875	14.12	4.40	0.00	1240	340	0
534	7896421.5	34.48	29.48	25.92	300	3680	380
551	17222912	134.36	45.04	16.64	2960	1620	1880
554	29434444	71.60	7.92	17.96	1400	0	0
555	32760048	100.64	10.64	38.76	3840	1020	1880
579	5515078	91.76	51.56	21.52	7380	2980	1960

Source: (INRS-ETE, 2007)

Appendix 12. Pollution and abatement coefficients for pesticide.

Management scenario Unit RHHU	Base case kg per ha on corn	1m buffer strip kg per m on corn	3m buffer strip kg per m on corn	5m buffer strip kg per m on corn	Pest. Resuction kg per ha on corn	Dribble bars kg per m3 on corn
445	1.986E-04	-8.783E-06	-1.214E-05	-1.413E-05	-5.837E-05	0.000E+00
454	1.312E-04	#DIV/0!	#DIV/0!	#DIV/0!	-3.857E-05	0.000E+00
455	1.756E-04	-5.800E-07	-7.992E-07	-9.280E-07	-5.140E-05	-2.063E-11
456	3.311E-04	-1.587E-06	-2.209E-06	-2.567E-06	-9.693E-05	0.000E+00
457	9.681E-05	#DIV/0!	#DIV/0!	#DIV/0!	-3.738E-05	0.000E+00
458	7.256E-05	-6.321E-07	-8.757E-07	-1.016E-06	-2.123E-05	1.489E-11
459	2.461E-04	-1.595E-06	-2.209E-06	-2.569E-06	-7.201E-05	2.369E-10
460	3.429E-04	-5.100E-06	-7.055E-06	-8.203E-06	-1.004E-04	0.000E+00
462	1.976E-04	-4.980E-06	-7.296E-06	-8.652E-06	-4.807E-05	7.049E-08
463	7.991E-05	-3.395E-07	-4.824E-07	-5.659E-07	-2.199E-05	9.006E-09
464	2.576E-05	-8.213E-08	-1.128E-07	-1.325E-07	-7.734E-06	0.000E+00
465	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	0.000E+00
466	5.930E-05	-1.667E-06	-2.314E-06	-2.679E-06	-1.749E-05	0.000E+00
467	2.704E-04	#DIV/0!	#DIV/0!	#DIV/0!	-8.283E-05	0.000E+00
468	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	0.000E+00
469	1.039E-04	#DIV/0!	#DIV/0!	#DIV/0!	-3.067E-05	0.000E+00
470	3.185E-04	-2.964E-05	-4.132E-05	-4.816E-05	-9.130E-05	2.532E-09
471	2.275E-05	-2.140E-07	-2.865E-07	-3.487E-07	-7.346E-06	0.000E+00
472	2.473E-04	#DIV/0!	#DIV/0!	#DIV/0!	-7.275E-05	0.000E+00
473	2.448E-04	#DIV/0!	#DIV/0!	#DIV/0!	-5.803E-05	5.068E-09
474	5.277E-05	#DIV/0!	#DIV/0!	#DIV/0!	-1.005E-05	7.850E-09
475	4.597E-05	-1.855E-07	-2.551E-07	-2.956E-07	-1.349E-05	0.000E+00
476	6.076E-05	-8.380E-07	-1.156E-06	-1.346E-06	-1.801E-05	7.471E-12
478	3.334E-05	#DIV/0!	#DIV/0!	#DIV/0!	-1.022E-05	0.000E+00
480	2.415E-05	#DIV/0!	#DIV/0!	#DIV/0!	-7.171E-06	0.000E+00
481	3.093E-05	-1.393E-09	-1.859E-09	-2.205E-09	-9.131E-06	0.000E+00
483	8.668E-05	-1.149E-06	-1.576E-06	-1.823E-06	-2.555E-05	-2.028E-11
486	6.487E-05	-2.644E-07	-3.643E-07	-4.219E-07	-1.906E-05	0.000E+00
487	2.459E-05	#DIV/0!	#DIV/0!	#DIV/0!	-7.900E-06	0.000E+00
488	5.609E-05	#DIV/0!	#DIV/0!	#DIV/0!	-2.038E-05	0.000E+00
489	1.806E-04	-3.639E-06	-5.027E-06	-5.852E-06	-5.310E-05	0.000E+00
490	7.656E-05	-2.254E-07	-3.083E-07	-3.581E-07	-2.251E-05	6.852E-12
491	3.653E-05	-1.163E-07	-1.627E-07	-1.872E-07	-1.085E-05	0.000E+00
492	3.717E-05	-2.117E-07	-2.919E-07	-3.419E-07	-1.134E-05	-9.600E-12
493	6.026E-05	-8.947E-07	-1.202E-06	-1.381E-06	-1.784E-05	0.000E+00
494	1.135E-04	#DIV/0!	#DIV/0!	#DIV/0!	-3.334E-05	1.789E-10
495	1.140E-04	-1.063E-06	-1.444E-06	-1.659E-06	-3.325E-05	9.414E-11
496	2.361E-04	-2.794E-06	-3.856E-06	-4.475E-06	-6.908E-05	-5.706E-11
498	2.640E-04	-7.613E-07	-1.049E-06	-1.222E-06	-7.765E-05	0.000E+00
499	1.665E-04	-1.481E-06	-2.026E-06	-2.337E-06	-4.872E-05	-7.984E-11
500	8.881E-05	-3.560E-07	-4.918E-07	-5.707E-07	-2.650E-05	1.692E-11
501	9.642E-05	#DIV/0!	#DIV/0!	#DIV/0!	-2.840E-05	0.000E+00
502	1.834E-04	-8.057E-07	-1.103E-06	-1.277E-06	-5.387E-05	0.000E+00
503	6.628E-05	-7.055E-07	-9.553E-07	-1.097E-06	-1.957E-05	-2.264E-11
504	1.361E-04	-1.299E-06	-1.770E-06	-2.040E-06	-3.978E-05	2.702E-11
505	1.958E-04	#DIV/0!	#DIV/0!	#DIV/0!	-5.754E-05	1.697E-11
506	2.255E-04	-3.799E-06	-5.173E-06	-5.965E-06	-6.604E-05	1.260E-11
507	2.419E-04	#DIV/0!	#DIV/0!	#DIV/0!	-7.147E-05	1.427E-11
508	1.909E-04	#DIV/0!	#DIV/0!	#DIV/0!	-5.683E-05	0.000E+00
509	2.939E-05	#DIV/0!	#DIV/0!	#DIV/0!	-8.854E-06	0.000E+00
517	1.302E-04	#DIV/0!	#DIV/0!	#DIV/0!	-3.841E-05	-1.366E-10
522	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	0.000E+00
523	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	0.000E+00
524	1.494E-04	#DIV/0!	#DIV/0!	#DIV/0!	-4.388E-05	-3.824E-11
532	9.534E-05	-1.084E-06	-1.492E-06	-1.729E-06	-2.784E-05	1.303E-11
533	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	0.000E+00
534	1.883E-05	-1.280E-07	-1.781E-07	-2.045E-07	-5.703E-06	0.000E+00
551	5.631E-05	-1.496E-07	-2.041E-07	-2.375E-07	-1.680E-05	0.000E+00
554	3.351E-05	#DIV/0!	#DIV/0!	#DIV/0!	-1.012E-05	-2.752E-11
555	6.008E-05	-3.453E-07	-4.761E-07	-5.500E-07	-1.764E-05	0.000E+00
579	1.342E-04	-2.749E-07	-3.770E-07	-4.366E-07	-3.955E-05	0.000E+00

Source: (INRS-ETE, 2007)

Appendix 13. Pollution and abatement coefficients for sediment.

Management Scenario.	Scenario de Base			1m wide Buffer Strip			3m wide Buffer Strip			5 m wide Buffer Strip			Pest. Reduction	Dribble bars		
Unit	t per ha	t per ha	t per ha	t per m	t per m	t per m	t per m	t per m	t per m	t per m	t per m	t per m	t per ha	t per m3	t per m3	t per m3
RHHU	on hay	on cereal	on corn	on hay	on cereal	on corn	on hay	on cereal	on corn	on hay	on cereal	on corn	on corn	on hay	on cereal	on corn
445	8.93E-04	6.71E-04	3.13E-03	-9.33E-06	-3.32E-06	-1.49E-04	-1.29E-05	-4.60E-06	-2.07E-04	-1.51E-05	-5.35E-06	-2.41E-04	2.32E-06	1.03E-14	3.77E-15	1.77E-14
454	2.68E-04	8.61E-05	4.08E-04	-1.85E-06	#DIV/0!	#DIV/0!	-2.56E-06	#DIV/0!	#DIV/0!	-2.98E-06	#DIV/0!	#DIV/0!	-1.95E-07	-1.97E-15	-4.92E-16	-1.50E-15
455	9.26E-04	1.32E-03	2.11E-03	-7.11E-06	-9.64E-06	-1.04E-05	-9.85E-06	-1.33E-05	-1.44E-05	-1.15E-05	-1.55E-05	-1.67E-05	-7.27E-08	-2.77E-16	-3.34E-16	-2.70E-16
456	1.39E-04	2.72E-04	4.32E-04	-1.33E-05	-1.26E-05	-2.62E-06	-1.84E-05	-1.74E-05	-3.63E-06	-2.14E-05	-2.02E-05	-4.23E-06	-6.71E-08	-7.28E-17	-1.12E-16	-5.82E-17
457	2.30E-04	4.05E-04	7.94E-04	-8.06E-07	#DIV/0!	#DIV/0!	-1.12E-06	#DIV/0!	#DIV/0!	-1.30E-06	#DIV/0!	#DIV/0!	-9.38E-07	-1.50E-15	-1.58E-15	-1.35E-16
458	2.59E-04	3.37E-04	4.88E-04	-4.46E-06	-8.10E-06	-5.39E-06	-6.17E-06	-1.12E-05	-7.47E-06	-7.19E-06	-1.31E-05	-8.69E-06	-2.02E-08	-3.25E-17	-3.03E-17	-5.63E-17
459	4.79E-04	1.60E-04	1.48E-03	-3.32E-06	-2.10E-06	-9.69E-06	-4.62E-06	-2.92E-06	-1.35E-05	-5.38E-06	-3.40E-06	-1.57E-05	1.05E-05	6.59E-15	1.32E-16	8.58E-14
460	8.15E-04	5.62E-04	1.43E-03	-1.78E-05	#DIV/0!	-2.14E-05	-2.46E-05	#DIV/0!	-2.97E-05	-2.87E-05	#DIV/0!	-3.46E-05	2.20E-06	1.08E-14	5.38E-16	8.64E-15
462	5.60E-04	5.10E-04	1.92E-03	-1.75E-05	-4.64E-06	-5.72E-05	-2.38E-05	-6.32E-06	-7.84E-05	-2.75E-05	-7.31E-06	-9.08E-05	-2.95E-05	-5.15E-14	-2.88E-14	-1.52E-13
463	1.99E-04	8.30E-05	4.49E-04	-1.73E-06	-7.43E-07	-1.97E-06	-2.47E-06	-1.06E-06	-2.82E-06	-2.91E-06	-1.24E-06	-3.32E-06	1.89E-05	5.35E-14	1.79E-15	7.33E-14
464	1.51E-04	1.28E-04	1.47E-04	-1.31E-05	#DIV/0!	-5.99E-07	-1.81E-05	#DIV/0!	-8.30E-07	-2.10E-05	#DIV/0!	-9.66E-07	-4.70E-09	-8.88E-17	-5.85E-17	-1.46E-17
465	7.19E-07	5.00E-07	#DIV/0!	-5.00E-10	-5.00E-10	#DIV/0!	-7.50E-10	-5.00E-10	#DIV/0!	-8.75E-10	-5.00E-10	#DIV/0!	#DIV/0!	0.00E+00	0.00E+00	0.00E+00
466	4.00E-04	3.55E-04	4.91E-04	-2.69E-06	-7.56E-06	-1.54E-05	-3.73E-06	-1.05E-05	-2.14E-05	-4.34E-06	-1.22E-05	-2.49E-05	-6.46E-08	-2.83E-16	-6.74E-17	-1.22E-16
467	8.06E-04	5.41E-04	3.82E-05	-7.15E-06	-2.42E-06	#DIV/0!	-9.90E-06	-3.35E-06	#DIV/0!	-1.15E-05	-3.90E-06	#DIV/0!	0.00E+00	-6.20E-16	-1.34E-16	0.00E+00
468	2.42E-04	2.43E-04	#DIV/0!	-1.09E-06	-2.09E-06	#DIV/0!	-1.51E-06	-2.89E-06	#DIV/0!	-1.75E-06	-3.36E-06	#DIV/0!	#DIV/0!	9.59E-17	9.90E-17	0.00E+00
469	3.32E-04	3.03E-04	4.30E-04	-4.31E-06	#DIV/0!	#DIV/0!	-5.98E-06	#DIV/0!	#DIV/0!	-6.95E-06	#DIV/0!	#DIV/0!	8.41E-09	2.38E-17	1.26E-17	3.39E-18
470	8.89E-04	7.00E-04	9.89E-04	-1.10E-05	-9.22E-06	-9.54E-05	-1.55E-05	-1.29E-05	-1.33E-04	-1.81E-05	-1.50E-05	-1.55E-04	8.44E-06	2.58E-14	2.58E-15	8.33E-15
471	1.38E-04	1.80E-04	5.35E-04	-1.04E-06	-8.06E-07	-5.63E-06	-1.44E-06	-1.12E-06	-7.80E-06	-1.68E-06	-1.30E-06	-9.08E-06	-1.26E-07	-2.14E-16	-1.72E-16	-2.78E-16
472	4.62E-04	4.16E-04	1.06E-03	-8.71E-06	-2.46E-06	#DIV/0!	-1.21E-05	-3.40E-06	#DIV/0!	-1.40E-05	-3.96E-06	#DIV/0!	-9.02E-08	-2.51E-16	-1.10E-16	-1.35E-16
473	7.59E-04	8.76E-04	1.74E-03	-9.89E-06	-9.01E-06	#DIV/0!	-1.38E-05	-1.26E-05	#DIV/0!	-1.62E-05	-1.47E-05	#DIV/0!	1.71E-05	5.98E-14	4.77E-14	4.04E-15
474	2.02E-04	1.85E-04	4.55E-04	-3.38E-06	-1.83E-06	#DIV/0!	-4.80E-06	-2.61E-06	#DIV/0!	-5.64E-06	-3.06E-06	#DIV/0!	1.48E-05	1.72E-14	5.11E-15	1.50E-14
475	4.08E-04	6.74E-04	8.95E-04	-7.54E-06	-1.59E-05	-5.81E-06	-1.05E-05	-2.21E-05	-8.05E-06	-1.22E-05	-2.57E-05	-9.37E-06	-7.55E-10	-7.17E-19	-1.43E-19	-7.17E-19
476	2.91E-04	2.67E-04	5.63E-04	-2.36E-06	-4.57E-06	-9.81E-06	-3.27E-06	-6.33E-06	-1.36E-05	-3.81E-06	-7.36E-06	-1.58E-05	-9.70E-08	-1.18E-16	-2.66E-17	-8.66E-17
478	7.20E-05	1.13E-04	2.62E-04	-6.73E-07	#DIV/0!	#DIV/0!	-9.33E-07	#DIV/0!	#DIV/0!	-1.09E-06	#DIV/0!	#DIV/0!	0.00E+00	0.00E+00	0.00E+00	0.00E+00
480	1.89E-05	2.15E-05	3.72E-05	-2.80E-07	#DIV/0!	#DIV/0!	-3.88E-07	#DIV/0!	#DIV/0!	-4.51E-07	#DIV/0!	#DIV/0!	0.00E+00	0.00E+00	0.00E+00	0.00E+00
481	1.63E-05	1.64E-05	3.62E-05	-6.14E-08	-4.03E-08	-2.94E-07	-8.50E-08	-5.59E-08	-4.08E-07	-9.89E-08	-6.50E-08	-4.75E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
483	1.39E-03	1.17E-03	3.32E-03	-1.08E-05	-1.07E-05	-4.51E-05	-1.50E-05	-1.48E-05	-6.25E-05	-1.74E-05	-1.72E-05	-7.27E-05	-1.56E-07	-1.02E-16	-7.64E-17	-1.36E-16
486	9.37E-04	4.43E-04	1.22E-03	-1.29E-04	-4.03E-06	-5.30E-06	-1.79E-04	-5.59E-06	-7.34E-06	-2.08E-04	-6.50E-06	-8.54E-06	-6.87E-10	-3.01E-18	-1.00E-18	-3.01E-18
487	7.02E-06	3.38E-06	1.16E-05	-5.43E-08	#DIV/0!	#DIV/0!	-7.52E-08	#DIV/0!	#DIV/0!	-8.75E-08	#DIV/0!	#DIV/0!	0.00E+00	0.00E+00	0.00E+00	0.00E+00
488	3.47E-04	3.99E-04	1.58E-04	-2.39E-05	#DIV/0!	#DIV/0!	-3.32E-05	#DIV/0!	#DIV/0!	-3.86E-05	#DIV/0!	#DIV/0!	0.00E+00	4.06E-19	0.00E+00	0.00E+00
489	1.02E-03	8.75E-04	1.14E-03	-3.94E-06	-9.71E-06	-2.53E-05	-5.46E-06	-1.35E-05	-3.51E-05	-6.36E-06	-1.57E-05	-4.08E-05	7.08E-07	9.26E-16	2.83E-16	9.88E-16
490	2.11E-03	1.54E-03	1.18E-03	-1.50E-05	-1.36E-05	-5.33E-06	-2.08E-05	-1.88E-05	-7.39E-06	-2.42E-05	-2.19E-05	-8.60E-06	1.23E-06	5.77E-15	4.60E-16	6.54E-16
491	2.98E-04	5.27E-04	6.96E-04	-3.35E-06	-1.46E-06	-6.33E-06	-4.64E-06	-2.02E-06	-8.77E-06	-5.39E-06	-2.35E-06	-1.02E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
492	1.84E-04	3.14E-04	2.47E-04	-1.31E-06	-9.56E-05	-3.41E-06	-1.82E-06	-1.33E-04	-4.73E-06	-2.12E-06	-1.54E-04	-5.50E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
493	2.39E-03	8.81E-04	3.37E-03	-7.95E-05	-1.26E-05	-5.93E-05	-1.10E-04	-1.75E-05	-8.21E-05	-1.28E-04	-2.03E-05	-9.55E-05	-1.67E-06	-8.81E-15	-4.34E-16	-6.13E-15
494	4.25E-03	7.23E-03	1.47E-02	-6.35E-04	#DIV/0!	#DIV/0!	-8.81E-04	#DIV/0!	#DIV/0!	-1.03E-03	#DIV/0!	#DIV/0!	2.73E-05	4.64E-14	1.63E-14	1.38E-13
495	4.56E-03	4.07E-03	1.05E-02	-4.40E-05	-2.92E-05	-1.00E-04	-6.11E-05	-4.05E-05	-1.39E-04	-7.12E-05	-4.71E-05	-1.62E-04	2.21E-05	1.89E-14	7.82E-15	2.21E-14
496	2.58E-03	2.17E-03	5.11E-03	-1.85E-05	-3.30E-05	-7.42E-05	-2.56E-05	-4.57E-05	-1.03E-04	-2.98E-05	-5.32E-05	-1.20E-04	-1.14E-07	-8.40E-17	-1.87E-17	-1.96E-16
498	5.38E-03	6.11E-03	5.32E-03	#DIV/0!	-1.98E-05	-1.64E-05	#DIV/0!	-2.74E-05	-2.27E-05	#DIV/0!	-3.19E-05	-2.65E-05	-1.42E-06	-2.86E-15	-1.05E-15	-1.10E-15
499	3.08E-03	4.52E-03	1.47E-02	#DIV/0!	-2.90E-06	-1.29E-04	#DIV/0!	-4.02E-06	-1.79E-04	#DIV/0!	-4.68E-06	-2.08E-04	-9.26E-07	-1.61E-16	-1.25E-17	-2.98E-15
500	3.55E-03	1.39E-03	2.68E-03	-1.07E-04	-1.35E-05	-1.29E-05	-1.49E-04	-1.87E-05	-1.79E-05	-1.73E-04	-2.18E-05	-2.08E-05	2.12E-07	6.75E-16	4.29E-17	1.53E-16
501	4.30E-03	3.73E-03	1.24E-02	-4.02E-04	#DIV/0!	#DIV/0!	-5.57E-04	#DIV/0!	#DIV/0!	-6.48E-04	#DIV/0!	#DIV/0!	-3.78E-06	-6.26E-15	-5.32E-16	-1.58E-15
502	2.34E-03	6.24E-03	5.58E-03	-5.83E-06	-3.05E-04	-2.77E-05	-8.07E-06	-4.22E-04	-3.84E-05	-9.40E-06	-4.91E-04	-4.46E-05	-3.65E-07	-2.69E-16	-4.70E-16	-6.45E-16
503	2.49E-03	5.40E-03	3.97E-03	-3.01E-05	#DIV/0!	-8.46E-05	-4.16E-05	#DIV/0!	-1.17E-04	-4.85E-05	#DIV/0!	-1.36E-04	-6.75E-08	-1.08E-16	6.79E-17	-8.55E-17
504	5.13E-03	5.49E-03	1.68E-02	-4.30E-05	-1.26E-04	-1.64E-04	-5.95E-05	-1.75E-04	-2.28E-04	-6.93E-05	-2.04E-04	-2.65E-04	1.26E-06	1.30E-15	8.39E-16	2.52E-15
505	9.07E-03	5.52E-03	6.12E-03	-3.13E-04	-1.45E-05	#DIV/0!	-4.34E-04	-2.01E-05	#DIV/0!	-5.05E-04	-2.34E-05	#DIV/0!	2.56E-06	7.22E-15	1.04E-15	9.57E-16
506	1.20E-02	7.26E-03	1.80E-02	-1.14E-04	-5.25E-05	-2.99E-04	-1.58E-04	-7.27E-05	-4.15E-04	-1.83E-04	-8.46E-05	-4.82E-04	6.45E-06	9.40E-15	1.53E-15	1.36E-15
507	1.69E-02	1.57E-02	2.63E-02	-2.95E-04	-1.52E-04	#DIV/0!	-4.08E-04	-2.11E-04	#DIV/0!	-4.75E-04	-2.45E-04	#DIV/0!	-4.79E-06	-6.80E-15	-2.88E-15	-1.94E-15
508	1.00E-02	5.69E-03	6.03E-03	-1.23E-04	-8.94E-05	#DIV/0!	-1.70E-04	-1.24E-04	#DIV/0!	-1.98E-04	-1.44E-04	#DIV/0!	3.74E-06	1.08E-14	4.08E-15	4.80E-16
509	3.35E-04	7.02E-04	8.18E-04	-8.12E-05	#DIV/0!	#DIV/0!	-1.12E-04	#DIV/0!	#DIV/0!	-1.31E-04	#DIV/0!	#DIV/0!	1.08E-08	1.29E-17	9.17E-18	1.24E-17
517	8.62E-04	6.71E-04	4.17E-04	-5.66E-06	-4.15E-06	#DIV/0!	-7.83E-06	-5.75E-06	#DIV/0!	-9.12E-06	-6.69E-06	#DIV/0!	1.90E-09	6.58E-17	2.53E-17	1.01E-17
522	3.01E-04	8.78E-05	#DIV/0!	-4.21E-06	-6.44E-07	#DIV/0!	-5.83E-06	-8.93E-07	#DIV/0!	-6.78E-06	-1.04E-06	#DIV/0!	#DIV/0!	4.61E-16	1.12E-17	0.00E+00
523	6.35E-04	1.06E-03	#DIV/0!	-9.78E-06	-1.25E-05	#DIV/0!	-1.35E-05	-1.73E-05	#DIV/0!	-1.58E-05	-2.01E-05	#DIV/0!	#DIV/0!	-1.82E-17	-1.82E-17	0.00E+00
524	3.08E-04	1.07E-03	1.82E-03	-2.85E-06	-2.96E-05	#DIV/0!	-3.95E-06	-4.10E-05	#DIV/0!	-4.59E-06	-4.77E-05	#DIV/0!	-7.12E-07	-7.00E-16	-1.28E-15	-2.01E-15
532	7.34E-04	6.54E-04	1.82E-03	-8.15E-06	-7.40E-06	-2.58E-05	-1.13E-05	-1.02E-05	-3.57E-05	-1.31E-05	-1.19E-05	-4.16E-05	1.29E-07	4.21E-16	2.00E-16	3.65E-16
533	2.98E-03	1.40E-03	#DIV/0!	-1.25E-05	-6.65E-06	#DIV/0!	-1.73E-05	-9.22E-06	#DIV/0!	-2.01E-05	-1.07E-05	#DIV/0!	#DIV/0!	-5.30E-15	-8.11E-16	0.00E+00
534	2.31E-04	1.35E-04	3.72E-04	-9.74E-06	-3.98E-07	-9.30E-06	-1.35E-05	-5.51E-07	-1.29E-05	-1.57E-05	-6.41E-07	-1.50E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
551	4.49E-04	4.58E-04	8.99E-04	-7.48E-06	-4.68E-06	-2.92E-06	-1.04E-05	-6.48E-06	-4.05E-06	-1.21E-05	-7.54E-06	-4.71E-06	5.95E-08	2.07E-16	8.19E-17	5.75E-17
554	2.66E-04	1.97E-04	6.29E-04	-5.28E-06	#DIV/0!	#DIV/0!	-7.14E-06	#DIV/0!	#DIV/0!	-8.24E-06	#DIV/0!	#DIV/0!	-1.95E-05	-2.19E-14	-1.66E-15	-1.19E-14
555	1.02E-03	8.09E-04	1.53E-03	-9.80E-06	-3.10E-06	-1.16E-05	-1.36E-05	-4.29E-06	-1.60E-05	-1.58E-05	-4.99E-06	-1.86E-05	-3.10E-09	-1.62E-17	2.14E-18	-3.66E-18
579	7.23E-04	7.10E-04	9.23E-04	-3.30E-06	-4.51E-06	-3.72E-06	-4.57E-06	-6.24E-06	-5.15E-06	-5.32E-06	-7.26E-06	-6.00E-06	7.43E-08	1.13E-15	7.07E-16	2.90E-16

Source: INRS-ETE, 2007

Appendix 14. Pollution and abatement coefficients for phosphorus.

Scenario de Base	Base case scenario			1m wide Buffer Strip			3m wide Buffer Strip			5m wide Buffer Strip			Pest. reduction	Dribble bar		
Nitrogen RHHU	on hay kg per ha	on cereal kg per ha	on corn kg per ha	on hay kg per ha	on cereal kg per ha	on corn kg per ha	on hay kg per ha	on cereal kg per ha	on corn kg per ha	on hay Hay per BS	on cereal Cereal per BS	on corn Corn per BS	kg per ha Corn per ha	kg per m3 hay per m3	kg per m3 cereal per m3	kg per m3 corn per m3
445	5.74E-03	5.48E-03	1.75E-02	-4.69E-05	-2.14E-05	-6.34E-04	-6.70E-05	-3.06E-05	-9.11E-04	-7.95E-05	-3.63E-05	-1.08E-03	2.14E-05	1.07E-13	5.68E-14	1.63E-13
454	2.42E-03	1.10E-03	3.74E-03	-1.35E-05	#DIV/0!	#DIV/0!	-1.92E-05	#DIV/0!	#DIV/0!	-2.28E-05	#DIV/0!	#DIV/0!	-1.24E-06	-2.36E-14	-6.74E-15	-9.44E-15
455	6.55E-03	1.03E-02	1.54E-02	-3.95E-05	-5.87E-05	-5.87E-05	-5.63E-05	-8.37E-05	-8.38E-05	-6.68E-05	-9.92E-05	-9.95E-05	-2.32E-07	-9.21E-16	-8.61E-16	-8.81E-16
456	1.82E-03	4.53E-03	6.88E-03	-1.53E-04	-1.77E-04	-3.88E-05	-2.21E-04	-2.55E-04	-5.54E-05	-2.61E-04	-3.03E-04	-6.53E-05	-2.28E-06	-9.51E-16	-3.28E-15	-1.98E-15
457	1.88E-03	3.73E-03	3.96E-03	-5.71E-06	#DIV/0!	#DIV/0!	-8.10E-06	#DIV/0!	#DIV/0!	-9.55E-06	#DIV/0!	#DIV/0!	0.00E+00	-1.22E-14	-2.81E-14	0.00E+00
458	3.23E-03	5.64E-03	8.41E-03	-4.45E-05	-1.09E-04	-7.39E-05	-6.36E-05	-1.56E-04	-1.05E-04	-7.53E-05	-1.85E-04	-1.25E-04	-1.34E-07	-4.47E-17	-1.84E-15	-2.70E-16
459	4.60E-03	1.23E-03	1.50E-02	-2.57E-05	-2.22E-05	-7.66E-05	-3.68E-05	-3.01E-05	-1.10E-04	-4.37E-05	-3.49E-05	-1.31E-04	9.54E-05	6.01E-14	1.70E-15	7.77E-13
460	7.87E-03	7.50E-03	1.70E-02	-1.35E-04	#DIV/0!	-1.98E-04	-1.92E-04	#DIV/0!	-2.84E-04	-2.28E-04	#DIV/0!	-3.37E-04	2.86E-05	9.16E-14	8.43E-15	1.12E-13
462	5.16E-03	5.97E-03	1.77E-02	-1.31E-04	-4.49E-05	-4.20E-04	-1.82E-04	-6.22E-05	-5.88E-04	-2.13E-04	-7.29E-05	-6.92E-04	-3.86E-04	-5.13E-13	-4.31E-13	-1.99E-12
463	1.82E-03	1.05E-03	4.69E-03	-1.21E-05	-8.72E-06	-1.54E-05	-1.81E-05	-1.26E-05	-2.32E-05	-2.18E-05	-1.49E-05	-2.81E-05	2.39E-04	5.78E-13	2.33E-14	9.28E-13
464	1.47E-03	1.59E-03	1.76E-03	-1.05E-04	#DIV/0!	-5.90E-06	-1.50E-04	#DIV/0!	-8.36E-06	-1.78E-04	#DIV/0!	-9.89E-06	0.00E+00	-1.93E-15	0.00E+00	2.82E-17
465	0.00E+00	0.00E+00	#DIV/0!	0.00E+00	0.00E+00	#DIV/0!	0.00E+00	0.00E+00	#DIV/0!	0.00E+00	0.00E+00	#DIV/0!	#DIV/0!	0.00E+00	0.00E+00	0.00E+00
466	4.23E-03	5.56E-03	7.67E-03	-2.26E-05	-9.67E-05	-1.93E-04	-3.22E-05	-1.38E-04	-2.76E-04	-3.81E-05	-1.64E-04	-3.28E-04	-1.41E-06	-3.68E-15	-1.23E-15	-2.49E-15
467	7.68E-03	8.81E-03	3.44E-04	-5.35E-05	-3.20E-05	#DIV/0!	-7.63E-05	-4.57E-05	#DIV/0!	-9.05E-05	-5.43E-05	#DIV/0!	0.00E+00	-8.85E-15	-2.63E-15	0.00E+00
468	2.29E-03	4.15E-03	#DIV/0!	-8.18E-06	-2.87E-05	#DIV/0!	-1.18E-05	-4.12E-05	#DIV/0!	-1.39E-05	-4.87E-05	#DIV/0!	#DIV/0!	1.93E-15	5.82E-15	0.00E+00
469	4.04E-03	7.20E-03	1.27E-02	-4.22E-05	#DIV/0!	#DIV/0!	-6.03E-05	#DIV/0!	#DIV/0!	-7.17E-05	#DIV/0!	#DIV/0!	2.48E-06	6.59E-17	1.90E-15	1.07E-15
470	9.38E-03	1.52E-02	2.36E-02	-9.03E-05	-1.60E-04	-1.79E-03	-1.31E-04	-2.32E-04	-2.58E-03	-1.56E-04	-2.76E-04	-3.07E-03	2.28E-04	2.97E-13	5.55E-14	2.25E-13
471	1.41E-03	2.21E-03	5.66E-03	-8.65E-06	-8.43E-06	-4.76E-05	-1.24E-05	-1.20E-05	-6.84E-05	-1.46E-05	-1.42E-05	-8.12E-05	-6.31E-07	-2.86E-15	-3.47E-15	-1.38E-15
472	5.15E-03	6.63E-03	1.54E-02	-7.73E-05	-3.21E-05	#DIV/0!	-1.10E-04	-4.59E-05	#DIV/0!	-1.31E-04	-5.46E-05	#DIV/0!	-1.87E-06	-2.71E-15	-1.09E-15	-2.49E-15
473	6.47E-03	9.39E-03	1.83E-02	-6.52E-05	-7.51E-05	#DIV/0!	-9.44E-05	-1.09E-04	#DIV/0!	-1.13E-04	-1.30E-04	#DIV/0!	2.23E-04	5.74E-13	5.60E-13	5.29E-14
474	1.93E-03	2.88E-03	7.23E-03	-2.45E-05	-2.20E-05	#DIV/0!	-3.64E-05	-3.26E-05	#DIV/0!	-4.38E-05	-3.92E-05	#DIV/0!	3.11E-04	1.87E-13	8.87E-14	3.14E-13
475	4.11E-03	1.16E-02	1.79E-02	-5.99E-05	-2.19E-04	-9.19E-05	-8.54E-05	-3.12E-04	-1.31E-04	-1.01E-04	-3.70E-04	-1.55E-04	8.16E-09	-1.18E-17	1.16E-17	3.04E-16
476	2.44E-03	4.01E-03	9.31E-03	-1.57E-05	-5.47E-05	-1.28E-04	-2.23E-05	-7.77E-05	-1.83E-04	-2.64E-05	-9.19E-05	-2.16E-04	-2.85E-06	-2.41E-15	-1.01E-15	-2.23E-15
478	6.58E-04	1.54E-03	4.15E-03	-4.91E-06	#DIV/0!	#DIV/0!	-6.96E-06	#DIV/0!	#DIV/0!	-8.28E-06	#DIV/0!	#DIV/0!	0.00E+00	0.00E+00	0.00E+00	1.16E-16
480	1.15E-04	2.90E-04	6.09E-04	-1.36E-06	#DIV/0!	#DIV/0!	-1.94E-06	#DIV/0!	#DIV/0!	-2.29E-06	#DIV/0!	#DIV/0!	0.00E+00	0.00E+00	0.00E+00	0.00E+00
481	8.19E-05	1.79E-04	4.63E-04	-2.45E-07	-3.50E-07	-2.99E-06	-3.48E-07	-4.99E-07	-4.25E-06	-4.13E-07	-5.96E-07	-5.03E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
483	1.04E-02	1.57E-02	4.60E-02	-6.31E-05	-1.14E-04	-4.88E-04	-9.00E-05	-1.62E-04	-6.96E-04	-1.07E-04	-1.92E-04	-8.26E-04	-1.47E-06	-1.07E-15	-2.11E-16	-4.42E-16
486	7.77E-03	5.78E-03	1.39E-02	-8.52E-04	-4.30E-05	-4.82E-05	-1.21E-03	-6.13E-05	-6.85E-05	-1.44E-03	-7.29E-05	-8.12E-05	-1.88E-08	-3.28E-16	0.00E+00	1.91E-16
487	5.00E-05	0.00E+00	1.16E-04	-3.07E-07	#DIV/0!	#DIV/0!	-4.36E-07	#DIV/0!	#DIV/0!	-5.24E-07	#DIV/0!	#DIV/0!	0.00E+00	0.00E+00	0.00E+00	0.00E+00
488	3.67E-03	8.19E-03	2.80E-03	-2.01E-04	#DIV/0!	#DIV/0!	-2.87E-04	#DIV/0!	#DIV/0!	-3.40E-04	#DIV/0!	#DIV/0!	0.00E+00	-1.14E-17	0.00E+00	0.00E+00
489	8.30E-03	1.45E-02	2.23E-02	-2.54E-05	-1.33E-04	-3.92E-04	-3.63E-05	-1.89E-04	-5.59E-04	-4.31E-05	-2.24E-04	-6.62E-04	1.96E-05	8.86E-15	5.62E-15	2.85E-14
490	1.46E-02	2.37E-02	2.36E-02	-7.97E-05	-1.67E-04	-8.47E-05	-1.14E-04	-2.39E-04	-1.21E-04	-1.36E-04	-2.83E-04	-1.43E-04	2.79E-05	4.50E-14	8.90E-15	1.50E-14
491	2.93E-03	9.76E-03	1.57E-02	-2.61E-05	-2.17E-05	-1.14E-04	-3.72E-05	-3.09E-05	-1.63E-04	-4.42E-05	-3.68E-05	-1.93E-04	1.51E-08	-3.02E-17	-1.99E-17	4.01E-17
492	1.80E-03	5.86E-03	5.99E-03	-1.03E-05	-1.48E-03	-6.84E-05	-1.47E-05	-2.10E-03	-9.72E-05	-1.75E-05	-2.49E-03	-1.16E-04	-2.35E-08	9.26E-18	-9.26E-18	9.33E-17
493	1.45E-02	8.84E-03	2.75E-02	-3.74E-04	-1.06E-04	-3.78E-04	-5.33E-04	-1.52E-04	-5.39E-04	-6.33E-04	-1.80E-04	-6.40E-04	-1.68E-05	-6.04E-14	-5.74E-15	-6.10E-14
494	2.31E-02	4.61E-02	8.22E-02	-2.63E-03	#DIV/0!	#DIV/0!	-3.78E-03	#DIV/0!	#DIV/0!	-4.50E-03	#DIV/0!	#DIV/0!	1.80E-04	2.74E-13	1.12E-13	9.13E-13
495	2.47E-02	4.71E-02	1.17E-01	-1.80E-04	-2.62E-04	-8.53E-04	-2.59E-04	-3.76E-04	-1.23E-03	-3.08E-04	-4.47E-04	-1.46E-03	3.24E-04	1.22E-13	1.02E-13	3.28E-13
496	1.49E-02	2.38E-02	5.82E-02	-8.19E-05	-2.86E-04	-6.51E-04	-1.17E-04	-4.07E-04	-9.31E-04	-1.39E-04	-4.84E-04	-1.11E-03	1.72E-06	-6.20E-16	-7.90E-16	5.72E-15
498	3.01E-02	6.53E-02	7.64E-02	#DIV/0!	-1.64E-04	-1.84E-04	#DIV/0!	-2.35E-04	-2.62E-04	#DIV/0!	-2.79E-04	-3.12E-04	-2.34E-05	-2.11E-14	-1.07E-14	-1.69E-14
499	1.99E-02	4.46E-02	1.40E-01	#DIV/0!	-2.75E-05	-9.15E-04	#DIV/0!	-3.97E-05	-1.32E-03	#DIV/0!	-4.70E-05	-1.57E-03	-1.23E-05	-1.11E-15	1.59E-16	-2.80E-14
500	1.83E-02	1.72E-02	3.65E-02	-4.19E-04	-1.33E-04	-1.37E-04	-6.01E-04	-1.90E-04	-1.96E-04	-7.15E-04	-2.25E-04	-2.32E-04	4.98E-06	1.22E-14	8.69E-16	4.35E-15
501	2.24E-02	4.05E-02	1.19E-01	-1.59E-03	#DIV/0!	#DIV/0!	-2.28E-03	#DIV/0!	#DIV/0!	-2.71E-03	#DIV/0!	#DIV/0!	-5.46E-05	-3.57E-14	-7.27E-15	-2.12E-14
502	1.61E-02	6.38E-02	7.61E-02	-3.14E-05	-2.43E-03	-2.93E-04	-4.48E-05	-3.47E-03	-4.18E-04	-5.32E-05	-4.13E-03	-4.97E-04	-1.72E-05	-8.15E-15	-2.09E-14	-2.82E-14
503	1.14E-02	3.72E-02	3.61E-02	-1.05E-04	#DIV/0!	-5.95E-04	-1.50E-04	#DIV/0!	-8.50E-04	-1.78E-04	#DIV/0!	-1.01E-03	-1.08E-06	-8.43E-16	7.29E-16	-4.10E-16
504	2.68E-02	5.21E-02	1.33E-01	-1.69E-04	-9.27E-04	-9.62E-04	-2.43E-04	-1.33E-03	-1.39E-03	-2.89E-04	-1.58E-03	-1.66E-03	2.07E-05	9.43E-15	9.33E-15	4.72E-14
505	4.21E-02	5.67E-02	7.74E-02	-1.06E-03	-1.16E-04	#DIV/0!	-1.54E-03	-1.66E-04	#DIV/0!	-1.84E-03	-1.97E-04	#DIV/0!	4.76E-05	4.19E-14	1.29E-14	1.83E-14
506	4.86E-02	6.72E-02	1.61E-01	-3.29E-04	-3.74E-04	-1.99E-03	-4.77E-04	-5.35E-04	-2.87E-03	-5.71E-04	-6.36E-04	-3.42E-03	1.01E-04	8.03E-14	2.35E-14	2.20E-14
507	5.90E-02	1.07E-01	1.94E-01	-7.25E-04	-7.77E-04	#DIV/0!	-1.05E-03	-1.12E-03	#DIV/0!	-1.26E-03	-1.33E-03	#DIV/0!	-6.36E-05	-4.24E-14	-3.16E-14	-2.46E-14
508	4.08E-02	5.08E-02	6.80E-02	-3.62E-04	-6.14E-04	#DIV/0!	-5.23E-04	-8.79E-04	#DIV/0!	-6.26E-04	-1.04E-03	#DIV/0!	4.87E-05	5.58E-14	4.80E-14	6.47E-15
509	3.07E-03	9.99E-03	1.32E-02	-5.88E-04	#DIV/0!	#DIV/0!	-8.38E-04	#DIV/0!	#DIV/0!	-9.96E-04	#DIV/0!	#DIV/0!	4.07E-07	6.30E-16	-1.47E-16	6.01E-16
517	7.07E-03	6.84E-03	4.71E-03	-3.67E-05	-3.44E-05	#DIV/0!	-5.23E-05	-4.92E-05	#DIV/0!	-6.21E-05	-5.84E-05	#DIV/0!	0.00E+00	-4.10E-16	0.00E+00	0.00E+00
522	2.95E-03	2.59E-04	#DIV/0!	-3.54E-05	-3.08E-06	#DIV/0!	-5.00E-05	-3.89E-06	#DIV/0!	-5.95E-05	-4.42E-06	#DIV/0!	#DIV/0!	5.65E-15	0.00E+00	0.00E+00
523	4.60E-03	8.57E-03	#DIV/0!	-5.68E-05	-7.92E-05	#DIV/0!	-8.14E-05	-1.13E-04	#DIV/0!	-9.72E-05	-1.35E-04	#DIV/0!	#DIV/0!	-2.46E-16	4.95E-15	0.00E+00
524	3.10E-03	1.06E-02	1.76E-02	-2.33E-05	-2.34E-04	#DIV/0!	-3.32E-05	-3.33E-04	#DIV/0!	-3.94E-05	-3.95E-04	#DIV/0!	-7.31E-06	-7.66E-15	-1.17E-14	-2.01E-14
532	6.73E-03	8.38E-03	1.90E-02	-5.86E-05	-7.51E-05	-2.09E-04	-8.36E-05	-1.07E-04	-2.99E-04	-9.91E-05	-1.27E-04	-3.55E-04	1.16E-06	3.25E-15	1.89E-15	3.84E-15
533	2.00E-02	1.48E-02	#DIV/0!	-6.42E-05	-5.82E-05	#DIV/0!	-9.19E-05	-8.30E-05	#DIV/0!	-1.09E-04	-9.88E-05	#DIV/0!	#DIV/0!	-3.67E-14	-7.35E-15	0.00E+00
534	1.45E-03	1.19E-03	2.91E-03	-4.80E-05	-2.78E-06	-5.71E-05	-6.85E-05	-3.95E-06	-8.14E-05	-8.12E-05	-4.69E-06	-9.65E-05	0.00E+00	0.00E+00	0.00E+00	1.72E-16
551	4.54E-03	6.16E-03	1.14E-02	-5.97E-05	-5.01E-05	-2.94E-05	-8.50E-05	-7.13E-05	-4.20E-05	-1.01E-04	-8.46E-05	-4.99E-05	1.49E-06	1.03E-15	3.03E-15	1.56E-15
554	2.02E-03	2.74E-03	9.59E-03	-3.25E-05	#DIV/0!	#DIV/0!	-4.47E-05	#DIV/0!	#DIV/0!	-5.23E-05	#DIV/0!	#DIV/0!	-4.24E-04	-1.81E-13	-3.09E-14	-2.59E-13
555	7.95E-03	1.17E-02	2.29E-02	-5.96E-05	-3.66E-05	-1.36E-04	-8.51E-05	-5.21E-05	-1.94E-04	-1.01E-04	-6.18E-05	-2.30E-04	-1.68E-07	-6.64E-16	1.50E-16	1.41E-16
579	5.83E-03	6.80E-03	8.37E-03	-2.10E-05	-3.43E-05	-2.68E-05	-2.99E-05	-4.88E-05	-3.83E-05	-3.55E-05	-5.79E-05	-4.55E-05	7.20E-07	1.13E-14	5.57E-15	2.81E-15

Source: INRS-ETE, 2007

Appendix 15. Pollution and abatement coefficients for E. Coli.

Management scenario RHHU	Base case Scenario no. coliform per ha	1m wide buffer strip no. coliform per m	3 m wide Buffer Strip no. coliform per m	5 m wide Buffer Strip no. coliform per m	Pest. Reduction no. coliform per m3	dribble bar no. coliform per ha
445	8.603E+07	-1.744E+04	-2.482E+04	-2.940E+04	3.477E+03	8.164E+01
454	6.296E+07	-8.443E+03	-1.198E+04	-1.421E+04	-5.114E+02	-1.551E+01
455	8.233E+07	-1.146E+04	-1.628E+04	-1.927E+04	2.017E+00	4.134E-02
456	2.687E+08	-4.780E+04	-6.862E+04	-8.117E+04	-1.458E+03	-1.104E+01
457	1.189E+08	-4.107E+03	-5.802E+03	-6.879E+03	-1.237E+03	-1.408E+01
458	2.291E+08	-3.204E+04	-4.556E+04	-5.400E+04	-1.361E+03	-1.124E+01
459	1.296E+08	-1.178E+04	-1.696E+04	-2.016E+04	2.159E+04	2.366E+02
460	1.193E+08	-5.093E+04	-7.271E+04	-8.622E+04	1.487E+04	1.692E+02
462	1.181E+08	-4.067E+04	-5.553E+04	-6.474E+04	-9.972E+04	-1.135E+03
463	1.163E+08	-4.022E+03	-6.042E+03	-7.300E+03	4.059E+04	4.620E+02
464	1.162E+08	-7.735E+03	-1.095E+04	-1.295E+04	-9.679E+02	-1.102E+01
465	1.167E+08	-8.311E+01	-8.311E+01	-8.311E+01	-4.155E+04	-4.739E+02
466	2.128E+08	-2.330E+04	-3.310E+04	-3.920E+04	6.309E+02	5.426E+00
467	4.067E+08	-6.206E+04	-8.817E+04	-1.044E+05	-2.669E+03	-1.551E+01
468	8.124E+08	-3.036E+04	-4.313E+04	-5.111E+04	3.222E+03	1.085E+01
469	8.470E+08	-2.235E+05	-3.180E+05	-3.779E+05	3.335E+03	1.095E+01
470	8.634E+08	-3.125E+05	-4.647E+05	-5.593E+05	1.039E+06	3.410E+03
471	1.162E+08	-3.470E+03	-4.951E+03	-5.842E+03	-2.024E+01	-2.303E-01
472	2.344E+08	-4.467E+04	-6.348E+04	-7.525E+04	-2.275E+03	-1.861E+01
473	1.527E+08	-3.284E+04	-4.731E+04	-5.628E+04	4.585E+04	4.679E+02
474	5.589E+08	-5.544E+04	-8.218E+04	-9.874E+04	1.532E+05	6.943E+02
475	6.501E+08	-8.930E+04	-1.269E+05	-1.502E+05	2.036E+02	8.234E-01
476	8.402E+08	-6.056E+04	-8.600E+04	-1.018E+05	-3.447E+03	-1.132E+01
478	8.022E+08	-2.487E+04	-3.531E+04	-4.183E+04	-7.753E+02	-2.633E+00
480	8.321E+08	-1.017E+04	-1.445E+04	-1.711E+04	-2.101E+00	-6.896E-03
481	8.305E+08	-1.131E+03	-1.608E+03	-1.905E+03	2.451E+02	8.047E-01
483	6.556E+08	-1.651E+05	-2.346E+05	-2.777E+05	-5.820E+02	-2.431E+00
486	2.349E+08	-4.755E+04	-6.756E+04	-7.999E+04	-5.796E+02	-6.676E+00
487	2.289E+08	-5.471E+02	-7.573E+02	-8.846E+02	-1.196E+03	-1.378E+01
488	8.368E+08	-8.459E+05	-1.202E+06	-1.424E+06	-1.017E+01	-3.338E-02
489	8.605E+08	-1.346E+05	-1.914E+05	-2.266E+05	1.692E+04	5.556E+01
490	8.802E+08	-2.068E+05	-2.943E+05	-3.486E+05	6.322E+04	2.075E+02
491	8.432E+08	-4.117E+04	-5.866E+04	-6.953E+04	-8.993E+02	-2.952E+00
492	8.333E+08	-3.961E+04	-5.651E+04	-6.717E+04	-1.932E+02	-6.352E-01
493	2.444E+08	-2.393E+05	-3.398E+05	-4.022E+05	-6.932E+03	-7.984E+01
494	2.549E+08	-5.178E+06	-7.375E+06	-8.739E+06	4.695E+04	5.408E+02
495	8.942E+08	-5.066E+05	-7.218E+05	-8.554E+05	2.019E+05	6.771E+02
496	8.949E+08	-3.650E+05	-5.186E+05	-6.138E+05	-7.018E+03	-2.304E+01
498	9.432E+08	-5.385E+05	-7.649E+05	-9.054E+05	-3.162E+04	-1.038E+02
499	7.902E+08	-3.831E+05	-5.442E+05	-6.445E+05	-3.276E+03	-1.240E+01
500	9.052E+08	-5.742E+05	-8.159E+05	-9.659E+05	3.063E+03	1.006E+01
501	8.681E+08	-5.661E+06	-8.041E+06	-9.516E+06	-2.301E+04	-7.644E+01
502	7.822E+08	-1.427E+05	-2.028E+05	-2.399E+05	8.020E+02	2.708E+00
503	6.907E+08	-2.885E+05	-4.099E+05	-4.852E+05	-1.001E+03	-3.721E+00
504	5.758E+08	-3.826E+05	-5.437E+05	-6.437E+05	1.602E+04	5.725E+01
505	5.781E+08	-9.285E+05	-1.320E+06	-1.563E+06	3.110E+04	1.120E+02
506	5.936E+08	-6.582E+05	-9.355E+05	-1.108E+06	3.161E+04	1.139E+02
507	6.233E+08	-1.441E+06	-2.047E+06	-2.423E+06	-2.414E+04	-8.697E+01
508	5.796E+08	-8.041E+05	-1.143E+06	-1.353E+06	3.450E+04	1.243E+02
509	5.728E+08	-1.902E+06	-2.706E+06	-3.203E+06	1.297E+03	6.314E+00
517	6.437E+07	-1.074E+04	-1.527E+04	-1.808E+04	-1.108E+02	-3.342E+00
522	1.203E+08	-1.548E+04	-2.195E+04	-2.596E+04	-1.163E+03	-1.324E+01
523	1.198E+08	-2.172E+04	-3.095E+04	-3.671E+04	7.123E+01	8.108E-01
524	1.197E+08	-1.781E+04	-2.531E+04	-3.007E+04	1.782E+02	2.029E+00
532	1.198E+08	-2.664E+04	-3.785E+04	-4.480E+04	-8.030E+01	-9.140E-01
533	1.282E+08	-2.980E+04	-4.237E+04	-5.016E+04	-1.367E+03	-1.555E+01
534	1.163E+08	-4.054E+03	-5.757E+03	-6.813E+03	-3.307E+02	-3.764E+00
551	1.171E+08	-1.656E+04	-2.354E+04	-2.786E+04	3.805E+02	4.331E+00
554	8.283E+08	-1.323E+05	-1.809E+05	-2.111E+05	-2.395E+05	-7.932E+02
555	5.646E+08	-1.000E+05	-1.421E+05	-1.683E+05	-1.424E+03	-6.523E+00
579	6.485E+07	-5.584E+03	-7.935E+03	-9.398E+03	1.678E+02	5.015E+00

Source: INRS-ETE, 2007

Appendix 16. Pollution and abatement coefficients for nitrogen.

Management Scenario	Base case scenario			1m wide buffer strip			3m wide buffer strip			5m wide buffer strip			Pest. Reduction	Dribble bar		
Production	on hay	on cereal	on corn	on hay	on cereal	on corn	on hay	on cereal	on corn	on hay	on cereal	on corn	on corn	on hay	on cereal	on corn
RHHU	kg per ha	kg per ha	kg per ha	kg per m	kg per m	kg per m	kg per m	kg per m	kg per m	kg per m	kg per m	kg per m	kg per ha	kg per m3	kg per m3	kg per m3
445	1.61E-02	3.01E-02	3.08E-02	-1.95E-04	-2.20E-04	-1.40E-03	-8.68E-03	-1.98E-02	-1.44E-02	-2.75E-04	-2.89E-04	-2.16E-03	3.04E-05	7.03E-07	7.45E-03	8.29E-02
454	8.48E-03	1.24E-02	8.14E-03	-3.71E-05	#DIV/0!	#DIV/0!	-2.61E-03	-3.90E-03	-3.28E-03	-5.58E-05	#DIV/0!	#DIV/0!	-1.91E-06	3.77E-08	1.70E-03	8.17E-03
455	1.61E-02	3.24E-02	2.60E-02	-1.01E-04	-2.28E-04	-1.06E-04	-6.45E-03	-1.47E-02	-1.10E-02	-1.54E-04	-3.23E-04	-1.71E-04	-3.35E-07	2.01E-07	1.39E-02	2.78E-02
456	1.26E-02	3.77E-02	1.47E-02	-1.54E-03	-2.52E-03	-1.04E-04	-7.24E-03	-2.41E-02	-8.18E-03	-2.03E-03	-3.25E-03	-1.52E-04	-4.15E-06	3.12E-07	2.58E-02	2.20E-02
457	9.54E-03	2.71E-02	9.05E-03	-3.32E-05	#DIV/0!	#DIV/0!	-4.34E-03	-1.43E-02	-5.49E-03	-4.53E-05	#DIV/0!	#DIV/0!	0.00E+00	2.24E-07	3.27E-02	7.48E-04
458	9.26E-03	1.95E-02	1.27E-02	-1.71E-04	-5.96E-04	-1.29E-04	-4.65E-03	-1.13E-02	-5.80E-03	-2.43E-04	-8.08E-04	-2.02E-04	-5.75E-07	1.24E-07	1.57E-02	6.95E-02
459	1.40E-02	1.87E-02	2.31E-02	-1.20E-04	-4.18E-04	-1.34E-04	-7.99E-03	-1.39E-02	-1.03E-02	-1.68E-04	-5.35E-04	-2.16E-04	1.75E-04	3.88E-07	6.18E-03	8.47E-01
460	1.85E-02	2.82E-02	2.54E-02	-4.59E-04	#DIV/0!	-3.38E-04	-9.94E-03	-1.88E-02	-1.14E-02	-6.64E-04	#DIV/0!	-5.42E-04	5.72E-05	5.18E-07	1.65E-02	9.35E-02
462	1.29E-02	2.07E-02	2.60E-02	-4.33E-04	-2.50E-04	-6.61E-04	-6.78E-03	-1.28E-02	-1.15E-02	-6.19E-04	-3.33E-04	-1.05E-03	-4.06E-04	-9.94E-08	-1.20E-01	-4.05E-01
463	5.53E-03	8.27E-03	7.65E-03	-5.41E-05	-1.12E-04	-3.08E-05	-2.75E-03	-5.25E-03	-3.36E-03	-7.81E-05	-1.47E-04	-5.05E-05	3.25E-04	1.47E-06	9.83E-03	2.01E-01
464	4.86E-03	8.00E-03	3.50E-03	-4.54E-04	#DIV/0!	-1.48E-05	-2.44E-03	-4.54E-03	-1.74E-03	-6.35E-04	#DIV/0!	-2.18E-05	1.10E-07	7.97E-08	7.07E-03	9.13E-03
465	9.80E-03	3.34E-02	#DIV/0!	-1.42E-05	-5.06E-05	#DIV/0!	-8.41E-03	-2.99E-02	#DIV/0!	-1.78E-05	-6.32E-05	#DIV/0!	#DIV/0!	1.11E-06	4.32E-03	0.00E+00
466	9.90E-03	1.75E-02	1.13E-02	-7.12E-05	-4.86E-04	-3.30E-04	-5.02E-03	-1.04E-02	-5.26E-03	-1.03E-04	-6.64E-04	-5.21E-04	-2.27E-06	2.02E-07	1.83E-02	2.38E-02
467	2.11E-02	3.67E-02	5.19E-03	-2.38E-04	-2.51E-04	#DIV/0!	-1.24E-02	-2.52E-02	-4.19E-03	-3.31E-04	-3.32E-04	#DIV/0!	-7.88E-07	6.32E-07	5.79E-02	1.15E-03
468	8.00E-03	1.65E-02	#DIV/0!	-4.27E-05	-1.83E-04	#DIV/0!	-4.36E-03	-9.59E-03	#DIV/0!	-5.87E-05	-2.44E-04	#DIV/0!	#DIV/0!	1.11E-07	9.52E-02	0.00E+00
469	1.73E-02	4.29E-02	1.93E-02	-3.31E-04	#DIV/0!	#DIV/0!	-1.15E-02	-3.11E-02	-1.06E-02	-4.40E-04	#DIV/0!	#DIV/0!	4.87E-06	3.38E-07	1.97E-01	6.81E-02
470	3.57E-02	7.80E-02	3.74E-02	-6.64E-04	-1.75E-03	-3.78E-03	-2.37E-02	-5.81E-02	-1.89E-02	-8.98E-04	-2.29E-03	-5.75E-03	6.39E-04	2.62E-06	2.21E-01	6.07E-01
471	4.95E-03	9.95E-03	8.69E-03	-4.31E-05	-5.97E-05	-8.45E-05	-2.64E-03	-6.01E-03	-4.03E-03	-5.95E-05	-7.95E-05	-1.33E-04	-1.22E-06	1.25E-07	7.73E-03	1.12E-02
472	1.64E-02	2.96E-02	2.35E-02	-4.03E-04	-2.67E-04	#DIV/0!	-9.82E-03	-2.03E-02	-1.12E-02	-5.55E-04	-3.53E-04	#DIV/0!	-3.51E-06	4.51E-07	2.83E-02	5.14E-02
473	1.34E-02	2.10E-02	2.60E-02	-1.59E-04	-2.25E-04	#DIV/0!	-5.90E-03	-1.03E-02	-1.12E-02	-2.47E-04	-3.32E-04	#DIV/0!	3.53E-04	1.41E-06	1.52E-01	1.92E-02
474	8.01E-03	1.55E-02	1.17E-02	-1.80E-04	-2.30E-04	#DIV/0!	-4.64E-03	-9.78E-03	-5.60E-03	-2.45E-04	-3.02E-04	#DIV/0!	3.74E-04	6.15E-07	5.75E-02	1.97E-01
475	8.91E-03	2.27E-02	2.20E-02	-1.44E-04	-5.29E-04	-1.15E-04	-3.80E-03	-1.07E-02	-9.12E-03	-2.19E-04	-7.79E-04	-1.90E-04	5.76E-08	1.04E-07	1.12E-02	8.49E-02
476	1.13E-02	2.20E-02	1.50E-02	-1.36E-04	-5.89E-04	-2.81E-04	-7.48E-03	-1.52E-02	-7.76E-03	-1.79E-04	-7.63E-04	-4.16E-04	-5.07E-06	2.44E-07	3.57E-02	9.85E-02
478	3.73E-03	7.90E-03	5.83E-03	-3.10E-05	#DIV/0!	#DIV/0!	-1.50E-03	-3.16E-03	-2.33E-03	-4.18E-05	#DIV/0!	#DIV/0!	-5.44E-08	4.72E-08	1.06E-02	2.41E-02
480	1.80E-03	4.63E-03	1.37E-03	-2.31E-06	#DIV/0!	#DIV/0!	-8.05E-05	-6.42E-04	-2.59E-04	-3.84E-06	#DIV/0!	#DIV/0!	-1.17E-08	1.52E-09	4.60E-03	8.28E-03
481	1.59E-03	3.83E-03	1.15E-03	-3.97E-07	-2.15E-06	-3.08E-06	-5.50E-05	-3.94E-04	-1.98E-04	-6.69E-07	-2.87E-06	-5.20E-06	3.67E-08	7.28E-10	7.87E-04	1.88E-02
483	2.39E-02	4.32E-02	5.65E-02	-2.20E-04	-5.46E-04	-6.61E-04	-1.33E-02	-2.74E-02	-2.48E-02	-3.15E-04	-7.46E-04	-1.07E-03	5.46E-06	3.54E-07	1.26E-01	2.83E-01
486	1.38E-02	1.29E-02	2.04E-02	-1.61E-03	-1.31E-04	-7.25E-05	-5.94E-03	-6.86E-03	-8.63E-03	-2.61E-03	-1.92E-04	-1.21E-04	0.00E+00	8.47E-08	5.10E-03	9.05E-02
487	1.29E-03	2.22E-03	5.88E-04	-5.50E-07	#DIV/0!	#DIV/0!	-3.63E-05	-1.66E-04	-6.22E-05	-9.07E-07	#DIV/0!	#DIV/0!	-6.11E-08	4.92E-10	3.82E-06	5.91E-04
488	8.35E-03	1.95E-02	4.53E-03	-5.56E-04	#DIV/0!	#DIV/0!	-3.89E-03	-1.05E-02	-2.81E-03	-8.27E-04	#DIV/0!	#DIV/0!	0.00E+00	8.49E-08	6.72E-02	1.72E-03
489	2.44E-02	5.69E-02	3.31E-02	-1.25E-04	-9.86E-04	-7.44E-04	-1.48E-02	-3.97E-02	-1.64E-02	-1.73E-04	-1.30E-03	-1.13E-03	2.35E-05	3.42E-07	1.07E-01	4.79E-01
490	3.16E-02	5.47E-02	3.17E-02	-2.47E-04	-5.97E-04	-1.29E-04	-1.65E-02	-3.15E-02	-1.44E-02	-3.60E-04	-8.35E-04	-2.06E-04	3.85E-05	6.49E-07	3.84E-02	9.79E-02
491	6.67E-03	1.91E-02	1.80E-02	-6.01E-05	-4.66E-05	-1.30E-04	-2.63E-03	-8.14E-03	-7.43E-03	-9.22E-05	-6.98E-05	-2.18E-04	3.35E-07	4.85E-08	2.12E-02	7.97E-02
492	4.70E-03	1.30E-02	7.72E-03	-2.74E-05	-3.76E-03	-8.79E-05	-1.86E-03	-5.87E-03	-3.26E-03	-4.12E-05	-5.49E-03	-1.45E-04	-5.82E-08	3.69E-08	1.64E-02	4.09E-02
493	2.47E-02	1.96E-02	3.91E-02	-6.36E-04	-2.62E-04	-5.36E-04	-9.89E-03	-8.91E-03	-1.59E-02	-1.05E-03	-3.96E-04	-9.01E-04	-2.37E-05	4.08E-08	2.92E-03	9.76E-02
494	4.03E-02	7.97E-02	1.14E-01	-4.82E-03	#DIV/0!	#DIV/0!	-1.65E-02	-3.46E-02	-4.36E-02	-7.91E-03	#DIV/0!	#DIV/0!	2.47E-04	7.04E-07	1.71E-02	8.46E-01
495	4.63E-02	8.58E-02	1.36E-01	-4.38E-04	-7.03E-04	-1.03E-03	-2.22E-02	-4.64E-02	-5.56E-02	-6.70E-04	-1.02E-03	-1.72E-03	3.60E-04	5.95E-07	2.14E-01	1.36E+00
496	4.19E-02	7.72E-02	7.63E-02	-4.01E-04	-1.75E-03	-1.00E-03	-2.57E-02	-5.16E-02	-3.46E-02	-5.53E-04	-2.33E-03	-1.59E-03	2.64E-06	5.30E-07	5.30E-02	1.54E+00
498	7.18E-02	1.52E-01	1.00E-01	#DIV/0!	-6.64E-04	-2.88E-04	-4.14E-02	-9.43E-02	-4.65E-02	#DIV/0!	-9.16E-04	-4.53E-04	-3.23E-05	1.21E-06	1.51E-01	5.53E-01
499	5.21E-02	1.17E-01	1.71E-01	#DIV/0!	-1.10E-04	-1.20E-03	-3.09E-02	-7.91E-02	-7.06E-02	#DIV/0!	-1.52E-04	-1.99E-03	-2.19E-05	2.45E-07	6.15E-03	1.36E+01
500	4.49E-02	6.52E-02	5.08E-02	-1.68E-03	-9.78E-04	-2.38E-04	-2.59E-02	-4.50E-02	-2.44E-02	-2.37E-03	-1.29E-03	-3.67E-04	4.59E-06	1.01E-06	3.11E-02	2.19E-01
501	5.35E-02	1.05E-01	1.44E-01	-6.03E-03	#DIV/0!	#DIV/0!	-3.02E-02	-6.52E-02	-6.01E-02	-8.56E-03	#DIV/0!	#DIV/0!	-4.77E-05	1.17E-06	7.63E-02	3.03E-01
502	4.24E-02	1.31E-01	9.47E-02	-1.31E-04	-7.69E-03	-4.05E-04	-2.44E-02	-7.38E-02	-4.14E-02	-1.84E-04	-1.09E-02	-6.54E-04	-2.45E-05	3.03E-07	1.71E-01	2.18E+00
503	2.46E-02	6.49E-02	4.52E-02	-2.95E-04	#DIV/0!	-7.69E-04	-1.17E-02	-3.02E-02	-1.86E-02	-4.38E-04	#DIV/0!	-1.27E-03	-1.82E-06	3.44E-07	1.41E-03	2.71E-01
504	6.05E-02	1.20E-01	1.61E-01	-5.86E-04	-3.59E-03	-1.23E-03	-3.30E-02	-7.20E-02	-6.49E-02	-8.44E-04	-4.99E-03	-2.05E-03	2.31E-05	4.37E-07	1.22E-01	3.02E+00
505	8.79E-02	1.52E-01	1.01E-01	-3.31E-03	-5.58E-04	#DIV/0!	-4.58E-02	-9.69E-02	-4.59E-02	-4.86E-03	-7.60E-04	#DIV/0!	5.28E-05	1.36E-06	1.23E-01	1.35E-01
506	9.48E-02	1.60E-01	1.95E-01	-9.16E-04	-1.52E-03	-2.56E-03	-4.67E-02	-9.71E-02	-7.98E-02	-1.37E-03	-2.11E-03	-4.26E-03	1.08E-04	1.45E-06	1.59E-01	1.49E-01
507	1.11E-01	2.14E-01	2.34E-01	-1.83E-03	-2.42E-03	#DIV/0!	-5.14E-02	-1.17E-01	-9.40E-02	-2.80E-03	-3.46E-03	#DIV/0!	-6.16E-05	1.05E-06	2.23E-01	3.86E-01
508	8.14E-02	1.34E-01	9.00E-02	-1.02E-03	-2.82E-03	#DIV/0!	-4.01E-02	-8.22E-02	-4.03E-02	-1.52E-03	-3.86E-03	#DIV/0!	4.97E-05	9.00E-07	3.13E-01	5.40E-02
509	7.31E-03	2.12E-02	1.77E-02	-1.22E-03	#DIV/0!	#DIV/0!	-2.53E-03	-7.69E-03	-7.00E-03	-1.94E-03	#DIV/0!	#DIV/0!	4.71E-07	4.77E-08	1.78E-02	7.48E-02
517	1.60E-02	2.28E-02	9.58E-03	-7.12E-05	-1.05E-04	#DIV/0!	-5.50E-03	-8.13E-03	-3.91E-03	-1.15E-04	-1.55E-04	#DIV/0!	5.23E-08	1.36E-07	2.07E-03	5.60E-03
522	1.65E-02	4.01E-02	#DIV/0!	-3.24E-04	-5.13E-04	#DIV/0!	-1.04E-02	-3.03E-02	#DIV/0!	-4.28E-04	-6.41E-04	#DIV/0!	#DIV/0!	9.01E-07	2.45E-03	0.00E+00
523	1.26E-02	2.82E-02	#DIV/0!	-1.69E-04	-3.25E-04	#DIV/0!	-5.26E-03	-1.29E-02	#DIV/0!	-2.50E-04	-4.57E-04	#DIV/0!	#DIV/0!	1.77E-07	3.49E-02	0.00E+00
524	1.28E-02	3.82E-02	2.82E-02	-1.26E-04	-1.24E-03	#DIV/0!	-6.27E-03	-2.04E-02	-1.27E-02	-1.73E-04	-1.69E-03	#DIV/0!	-8.14E-06	2.31E-07	1.71E-02	4.84E-02
532	1.44E-02	2.43E-02	2.71E-02	-1.47E-04	-3.14E-04	-3.17E-04	-6.45E-03	-1.28E-02	-1.14E-02	-2.22E-04	-4.37E-04	-5.19E-04	1.27E-06	1.80E-07	1.58E-02	4.99E-02
533	4.12E-02	6.63E-02	#DIV/0!	-1.75E-04	-4.66E-04	#DIV/0!	-2.02E-02	-4.40E-02	#DIV/0!	-2.61E-04	-6.17E-04	#DIV/0!	#DIV/0!	8.14E-07	3.70E-02	0.00E+00
534	4.14E-03	5.84E-03	4.65E-03	-1.26E-04	-1.32E-05	-9.03E-05	-1.45E-03	-2.07E-03	-1.84E-03	-1.89E-04	-1.82E-05	-1.46E-04	2.62E-07	3.17E-08	3.74E-03	1.21E-02
551	9.12E-03	1.46E-02	1.61E-02	-1.32E-04	-1.54E-04	-4.31E-05	-3.91E-03	-7.14E-03	-6.85E-03	-2.04E-04	-2.23E-04	-7.13E-05	2.20E-06	1.13E-07	9.25E-03	7.62E-03
554	7.11E-03	1.19E-02	1.29E-02	-1.53E-04	#DIV/0!	#DIV/0!	-3.70E-03	-6.29E-03	-5.87E-03	-2.08E-04	#DIV/0!	#DIV/0!	-4.97E-04	-1.46E-07	-3.08E-03	-8.33E-02
555	1.75E-02	3.05E-02	2.95E-02	-1.79E-04	-1.46E-04	-1.93E-04	-8.87E-03	-1.76E-02	-1.30E-02	-2.62E-04	-2.03E-04	-3.12E-04	-1.05E-06	2.90E-07	1.58E-02	1.27E-01
579	1.41E-02	2.29E-02	1.53E-02	-4.47E-05	-1.11E-04	-4.97E-05	-4.90E-03	-8.33E-03	-6.25E-03	-7.05E-05	-1.62E-04	-8.03E-05	1.15E-06	1.68E-07	4.73E-03	7.36E-03

Source: INRS-ETE, 2007

Appendix 17. Animal productions characteristics for each farm.

	Production (%)				Beef		Dairy					Hog				Poultry
Farm ID	Dairy	Beef	Hog	Poultry	Cow Calf	Fat. Beef	Dairy cows	Calf (0-6)	Heifer (7-15)	Heifer (>15)	Bull	Fat. Hog	Sow	Piglet	Boar	Broiler
F1					46		0	0	0	163	2	0	0	0	0	0
F2	40		60				55	45	26	54		2170	300	500	2	0
F3			100									1600	217	650	7	
F4			100									750	120	300	2	
F5	100						30	10	10	20						
F6		50	50			2200						2500				
F7		10	90		100							2000	500	1700	1	
F8			100									800	120	200	2	
F9	100						7	10	15	10						
F10			100									1500	220	550	1	
F11			100									1400	230	400	1	
F12	50		50				6	9	9	7	1	360	70	200	1	
F13			100									1026	150	350	2	
F14	80			20			14	5	8	12						13600
F15																
F16	100						53	12	12	12	1					
F17	100						35	6	6	12	3					
F18	100						17			15						
F19			100									750				
F20			100									450	95	225	1	
F21	65		35				30	3	7	7	2	145	37	90	2	
F22	100						69	19	18	42	3					
F23			100									300	225	500	2	
F24	100						46	9	15	10	0					
F25			100									2000	630	700	6	
F26	100						55	15	20	20	0					
F27			100									500				
F28			100									900	125	450	1	
F29			100										170	250		
F30			40	60								1100	200	700	0	0
F31			100									1000	160	450		
F32		15	85		35					24	1	800	200	0	2	
F33	100						35	8	50	25						
F34	60		30	10			23	7	8	17		300				9000
F35	40		60				46	25	25	20		1600	250	500		
F36			100									1200	160	320	2	
F37	100						25	25	70	60						
F38			100										415			
F39		60	40			1600						2000	450			
F40				100												
F41			100									225	115	115		
F42	80		20				46	10	15	15		800				
F43		50	50		1115					120		650				
F44			100										400	450		
F45			100									950	150	460	2	
F46	100						50	4	30	20						
F47	100						24	10	10	10						
F48		20	80		175					175		1600	580	2000		
F49			85	15								500	85	150	1	
F50	60		40				47						80	150	1	
F51			100									800	140		1	
F52	70		30				16	13	13	16		450				
F53	85		15				16	10	10	10				250		
F54	50		50				12	20	20	20	2	600	90	180	3	
F55		30	70		30						2		100			
F56	50		50				33	20	20	25		1100	150	100	3	
F57			100										500		1	
F58	100						15	28	46	26						
F59	100						1	10	10	10						
F60																
F61																
F62	55		45				21	22	12	9		650				
F63			100									1250	318	630	6	
F64			100									1195	200	350	2	
F65	100						76	26	40							
F66			100									3662	430	1266		
F67			100									805	130	260		
F68	100						23	15	20	25						
F69			100									800	165	300		
F70							32	12	6	6						
F71	70		30				13	15	15	20		600				
F72		100			66					50						
F73		5	95			300						11000	2200	7000		
…																
WATERSHED	2455	370	3870	205	1567	4100	970	423	566	1087	17	54788	10877	22696	55	22600

Retrieved from the Farm Survey, 2007.

Appendix 18. Field characteristics by farm .

Farm-Fields nombers	Field superficy in the Bras d'Henri	RHHU	Meterof Buffer strip
F1-1	22	555	0
F2-2	12	554	
F2-3	9.6	554	
F2-4	24	554	
F2-5	20.1	551	
F2-6	5.6	551	
F2-7	6.3	460	500
F2-8	14.5	463	
F2-9	10.2	462	
F2-10	7	462	
F2-11	13.8	471	
F2-12	7.5	473	250
F2-13	5.53	464	
F2-14	15.39	468	
F2-15	5.14	466	
F3-1	1.5	475	0
F3-2	6.8	554	0
F3-3	22.07	554/223	0
F3-4	16.85	476/120	
F4-1	0.8	455/92	
F4-2	3.7	455/92	178
F4-3	8.5	455/92	258
F4-4	8.7	455/92	472
F4-5	2	517/174	
F4-6	6.5	455/92	
F5-1	3.8	455/92	
F5-2	0.7	579/255	
F5-3	12.9	455/92	820
F5-4	3.1	455/92	310
F5-5	7	445/79	182
F5-6	1.8	455/92	265
F6-1	11.3	455/92	846
F6-2	19.86	475/118	1386
F6-3	20.3	475/118	896
F7-1	0.5	454/91	
F7-2	5.5	455/92	207
F7-3	4.9	455/92	173
F7-4	11.7	455/92	391
F8-1	13.3	455/92	836
F8-2	8.3	455/92	205
F9-1	0	525/184	
F9-2	2.6	524/183	
F9-3	2.6	522/180	
F10-1	6.2	462/101	
F10-2	2.6	524/183	
F10-3	1.5	462/101	
F10-4	12.1	532/193	
F10-5	11	462/101	
F11-1	1.9	524/183	
F11-2	4	524/183	
F11-3	0.5	524/183	
F11-4	4.5	462/101	
F12-1	2.7	524/183	
F12-2	1.6	462/101	
F12-3	3.49	523/182	
F12-4	4.2	462/101	
F12-7	3	532/101	
F12-8	5.66	462/101	
F12-9	3	464/104	
F13-1	4.7	462/101	
F14-1	4.73	464/104	
F14-2	3	532/104	
F14-3	0.9	464/104	
F14-4	5.9	464/104	
F14-5	3.36	532/193	
F14-6	2.2	532/193	
F14-8	5.2	464/104	
F16-1	7.4	467/108	
F16-2	16	466/106	
F16-3	27.5	467/108	1144
F16-4	9.8	466/106	570
F16-5	11.6	471/113	300
F17-1	9.13	466/106	
F17-2	9.13	473/116	366
F17-3	9.13	472/114	

F18-1	23.97	473/116	366
F18-1	3.3	472/114	
F18-2	8.78	472/114	
F19-1	17.3	476/120	
F20-1	7	472/114	
F20-2	22.08	473/116	336
F20-3	3.3	472/114	
F21-1	2.5	460/98	
F21-2	4.9	460/98	
F21-3	4.15	459/97	
F21-4	4.15	462/101	
F21-5	3.2	456/93	
F21-6	11.9	524/183	
F21-7	5	459/97	
F21-8	1.7	457/95	
F21-9	4.2	524/183	
F21-10	6.3	457/95	440
F21-11	8.7	524/183	
F21-12	2.7	457/95	
F21-13	7.5	455/92	400
F21-14	13.35	455/92	1724
F22-1	4.4	458/96	430
F22-2	18.83	455/92	
F22-3	0.7	458/96	
F23-1	9.41	462/101	
F23-2	4.63	101/462	
F23-3	10.5	98/460	N/A
F23-4	2.5	102/463	
F23-5	14.4	101/462	600
F23-6	4.7	92/455	145
F23-7	5	92/455	
F24-1	11	102/463	460
F24-2	13.8	104/464	N/A
F25-1	4.6	96/458	N/A
F25-2	18.27	98/460	
F25-3	1.71	106/466	300
F25-4	7	106/466	380
F25-5	8.8	104/464	214
F26-1	23.8	116/473	345
F26-2	10.4	114/472	
F29-1	16.38	129/483	180
F30-1	33.3	129/483	846
F30-2	16	122/478	
F30-3	22.8	129/483	840
F30-4	8.7	122/478	
F31-1	41	135/488	646
F32-1	19.42	141/492	896
F32-2	9	141/492	
F33-1	13.3	163/509	
F33-2	2.7	163/509	
F33-3	15.5	141/492	
F33-4	12.7	141/492	
F33-5	22.5	145/495	900
F33-6	4.5	139/491	
F33-7	22.5	153/501	
F33-8	3.8	153/501	
F33-9	0.6	149/498	
F34-1	28.8	125/480	1124
F34-2	21.52	145/495	1000
F34-3	6	145/495	
F34-4	12.2	141/492	
F36-1	15.8	133/486	
F37-1	7.2	134/487	
F37-2	1.1	133/486	
F37-3	17.2	142/493	
F38-1	8.22	145/495	454
F39-1	19.5	143/494	
F39-2	6.2	143/494	
F39-3	3.6	163/509	
F39-4	11.5	163/509	
F39-5	10.3	150/499	
F39-6	4.5	145/495	
F39-7	5.3	150/499	
F39-8	5.8	163/509	
F39-9	50	150/499	532
F39-10	8.3	145/495	426
F39-11	13.4	145/495	
F39-13	19.2	142/493	
F41-1	7.7	145/495	
F41-2	4.5	145/495	
F41-3	54.47	145/495	814
F43-1	26	158/505	
F43-2	43	159/506	702
F43-3	18.9	157/504	
F44-1	8.2	158/505	
F44-2	6.7	157/504	
F44-3	14.7	157/504	254
F46-1	6.83	159/506	878

F46-2	44.36	159/506	
F47-1	29.1	159/506	
F47-2	4.1	151/500	
F48-1	3.56	159/506	
F49-1	13.07	120/476	247
F49-2	4.9	126/481	247
F49-3	7	135/488	
F50-1	5.3	120/476	
F50-2	5.3	126/481	366
F50-3	5.3	137/489	146
F50-4	5.3	135/488	
F51-1	11.1	138/490	
F52-1	20.8	138/490	
F53-1	20.8	138/490	
F54-1	15.6	138/490	
F55-1	13.35	153/501	
F55-2	8.35	151/500	
F56-1	29	163/509	
F56-2	14.6	151/500	908
F56-3	32.6	163/509	
F56-4	25.77	153/501	
F56-5	0	153/501	
F57-1	22.94	155/503	
F58-1	17.6	158/505	
F59-1	4	160/507	
F61-1	7.9	255/579	
F61-3	8.43	92/455	1250
F62-1	6.2	159/506	
F62-2	23.4	160/507	
F63-1	10.5	126/481	320
F63-2	7.3	137/489	
F63-3	4.2	120/476	
F63-4	4.2	126/481	
F63-5	2.3	137/489	294
F63-6	13.5	120/476	562
F63-7	9.3	129/483	
F64-1	5.7	163/509	
F65-1	28.83	118/475	714
F65-2	57.77	118/475	
F66-1	21.5	106/466	710
F66-2	6.1	104/464	
F66-3	7	114/472	
F66-4	6.9	116/473	
F66-5	6.35	110/469	
F66-6	9.45	117/474	
F66-7	35.9	125/480	
F67-1	4.6	138/490	
F68-1	15.9	98/460	
F68-3	13.75	108/467	
F68-4	14.5	109/468	
F69-1	4.4	154/202	342
F69-2	0.37	151/500	
F69-3	12.1	159/506	370
F69-4	24.34	159/506	
F70-1	28.45	112/470	
F71-1	21.71	112/470	
F72-1	13.2	162/508	
F72-2	3.6	162/508	
F72-3	22.7	162/508	
F72-4	5	162/508	
F72-5	6	160/507	
F73-1	46	145/495	920
F73-2	6.9	141/492	
F73-3	5.9	149/498	
F73-4	7.8	146/496	
F73-5	30.6	151/500	948
F73-6	66	126/481	830
F73-7	41.4	118/475	1254
F73-8	5.3	114/472	
…			
Watershed	5146.33		37615

Source: retrieved from the survey, 2007.

Appendix 19: Farm's base case environmental parameters.

F#	SEDIMENT	PHOSPHOR	NITROGEN	E-COLI.	pesticide
F1	9,56E-03	9,03E-02	2,64E-01	1,24E+10	0,00E+00
F2	3,59E-02	4,36E-01	1,26E+00	6,28E+10	4,02E-04
F3	2,56E-02	4,04E-01	6,38E-01	3,07E+10	1,83E-03
F4	4,40E-02	3,35E-01	8,64E-01	2,47E+09	1,49E-03
F5	3,50E-02	2,61E-01	5,59E-01	2,45E+09	2,27E-03
F6	2,61E-02	4,43E-01	6,93E-01	1,55E+10	9,33E-04
F7	1,82E-02	1,41E-01	3,32E-01	1,78E+09	1,10E-03
F8	1,59E-02	1,28E-01	4,14E-01	1,78E+09	0,00E+00
F9	6,32E-04	7,08E-03	6,28E-02	6,24E+08	0,00E+00
F10	6,02E-02	5,81E-01	9,05E-01	3,97E+09	5,10E-03
F11	1,71E-02	1,61E-01	2,85E-01	1,36E+09	1,55E-03
F12	5,14E-03	5,52E-02	2,06E-01	2,80E+09	0,00E+00
F13	1,15E-03	1,28E-02	4,38E-02	5,55E+08	0,00E+00
F14	5,46E-03	6,61E-02	2,35E-01	2,98E+09	0,00E+00
F16	1,83E-02	2,33E-01	9,23E-01	2,10E+10	0,00E+00
F17	6,28E-03	7,28E-02	2,55E-01	5,48E+09	0,00E+00
F18	7,75E-03	7,91E-02	2,06E-01	3,66E+09	0,00E+00
F19	2,31E-03	2,98E-02	1,50E-01	2,83E+09	0,00E+00
F20	2,02E-03	2,01E-02	1,65E-01	1,45E+10	0,00E+00
F21	9,85E-03	1,12E-01	3,74E-01	5,79E+09	0,00E+00
F22	3,88E-02	3,51E-01	1,25E+00	9,58E+09	1,32E-03
F23	7,60E-03	6,85E-02	2,42E-01	2,79E+09	0,00E+00
F24	3,25E-02	3,05E-01	7,60E-01	5,70E+09	1,80E-03
F25	2,99E-03	3,50E-02	9,60E-02	2,88E+09	3,55E-04
F26	1,02E-02	1,29E-01	4,32E-01	6,11E+09	0,00E+00
F27	9,69E-03	1,04E-01	3,34E-01	6,07E+09	0,00E+00
F29	9,20E-03	8,20E-02	2,64E-01	1,07E+10	0,00E+00
F30	1,42E-01	1,97E+00	3,03E+00	5,66E+10	3,42E-03
F32	5,96E-04	7,32E-03	2,28E-02	3,43E+09	0,00E+00
F33	4,22E-03	7,72E-02	1,44E-01	2,37E+10	3,34E-04
F34	3,13E-01	3,42E+00	4,87E+00	8,04E+10	3,69E-03
F35	1,04E-01	9,86E-01	1,53E+00	5,87E+10	6,85E-04
F36	1,92E-02	2,20E-01	3,23E-01	3,71E+09	1,02E-03
F37	1,73E-02	1,28E-01	2,43E-01	6,11E+09	1,77E-04
F38	1,53E-02	1,01E-01	2,33E-01	7,35E+09	0,00E+00
F39	1,40E+00	1,22E+01	1,57E+01	9,87E+10	1,40E-02
F42	1,80E-01	1,56E+00	2,82E+00	5,96E+10	5,13E-04
F43	4,11E-01	2,61E+00	6,46E+00	5,14E+10	0,00E+00
F44	1,19E-01	1,21E+00	2,47E+00	1,71E+10	1,61E-03
F46	3,42E-01	2,22E+00	4,09E+00	3,04E+10	1,54E-03
F47	1,50E-01	7,68E-01	1,94E+00	2,10E+10	0,00E+00
F48	1,76E-02	8,95E-02	2,22E-01	2,11E+09	0,00E+00
F49	1,02E-02	1,79E-01	3,40E-01	2,09E+10	7,94E-04
F50	3,59E-03	3,66E-02	1,85E-01	1,79E+10	0,00E+00
F51	1,32E-02	2,62E-01	3,52E-01	9,77E+09	8,50E-04
F52	1,86E-02	1,55E-01	4,49E-01	1,83E+10	0,00E+00
F53	1,86E-02	1,55E-01	4,49E-01	1,83E+10	0,00E+00
F54	1,40E-02	1,16E-01	3,36E-01	1,37E+10	0,00E+00
F55	3,59E-02	2,25E-01	7,75E-01	1,91E+10	0,00E+00
F56	7,98E-02	5,59E-01	1,81E+00	7,04E+10	0,00E+00
F57	2,32E-02	1,28E-01	3,74E-01	1,58E+10	0,00E+00
F58	6,43E-02	3,66E-01	1,02E+00	1,02E+10	0,00E+00
F59	2,71E-02	1,19E-01	2,79E-01	2,49E+09	0,00E+00
F62	2,70E-01	1,70E+00	2,84E+00	1,83E+10	1,40E-03
F63	2,49E-02	3,89E-01	7,27E-01	4,14E+10	2,72E-03
F64	1,24E-03	1,31E-02	3,49E-02	3,26E+09	0,00E+00
F65	3,67E-02	6,44E-01	9,93E-01	5,63E+10	1,33E-03
F66	1,32E-02	2,03E-01	7,44E-01	5,32E+10	8,67E-04
F67	5,46E-03	1,09E-01	1,46E-01	4,05E+09	3,52E-04
F68	1,15E-02	1,31E-01	5,07E-01	1,93E+10	0,00E+00
F69	1,87E-01	9,86E-01	2,45E+00	2,60E+10	8,88E-05
F70	1,09E-02	1,34E-01	8,44E-01	2,46E+10	0,00E+00
F71	8,29E-03	1,02E-01	6,44E-01	1,87E+10	0,00E+00
F72	2,57E-01	1,81E+00	4,37E+00	2,95E+10	6,87E-04
F73	3,93E-01	5,02E+00	8,17E+00	1,70E+11	1,01E-02
...					
TOTAL	**5,217196008**	**45,87050199**	**85,13320664**	**1,44124E+12**	**0,0643454**

Source: Retrieved from the model, 2007.

Appendix 20. User Guide.

General Description:

The ZORRO MODEL is subdivided into three different excel files.
ZORRO BC
ZORRO EXPANDED
ZORRO EXPANDED FARM

Each of these three files is very similar in term of their structure. Each file contains the following sheets.
SUPERMAN
WATERSHED CONSTRAINT
RESULTS
RESULTS 2
BMP
BMP 2
F1 TO F73 (WITH 5 MISSING FARMS)

General description of each sheet:

Superman sheet:

This sheet has for its objective to collect all the results in every other sheet and regroup it in only one. In this sheet, you will collect data regarding BMPs, environmental parameters, animal mix, crop mix, and manure export and import. The first column of the sheet (A) is the Net Farm Income for your actual run. Columns B to K are where you or the macro procedure enters the RHS of the environmental constraint. Columns B to F are for the farm constraints, and G to K are for the watershed constraints. Columns L to BB are other results from the current run which are pasted automatically by the model. Columns BD to DE are results from previous runs. Note that results WILL NOT automatically be pasted in columns BD to DE. To do this you will have to run the model using the MACRO PROCEDURE described in later section.

Watershed Constraint sheet:

This sheet has the capacity to implement manure export/import constraint, and also to constrain the amount of crops bought outside the farm. However, those characteristics have been deactivated. To activate those constraints you will have to redefine the constraint in L5 and L3 using WHAT'S BEST notation. This being said, this sheet is used to constrain environmental parameters at the watershed scale. Each RHS of the constraint refers to the amount that you or the macro procedure entered in the SUPERMAN sheet in cell G3 to k3. Then, do not use the watershed constraint sheet to enter the RHS of the constraint. Always proceed via the superman sheet. Also, each LHS refer to the RESULTS 2 sheet described below.

Results sheet:

This sheet collects in column B gross revenue from each farm and column C collects the net farm income of each farm. The ZORRO MODEL maximizes net farm income. More precisely, what it is maximized is the summation of the cells C3 to C67. The summation is reported in cell C69 and it is this cell that the model is maximizing.

Results 2 sheet:

This sheet collects pollutant (Sediment, Phosphorus, Nitrogen, Ecoli, and Pesticide) emission from every farm for the current run. In line 71 is the total emission of each farm for each pollutant. We interpret this amount as the total amount of pollutant emitted by the whole watershed. This amount is reported in the sheet watershed constraint as LHS of the watershed constraints.

BMP sheet:

This sheet reports the implemented BMP of every farm for the current run. It collects the number of meters of buffer strip implemented, the cubic meter of liquid manure sprayed with a dribble bar, and the number of ha of corn grown using pesticide reduction management. In addition, this sheet also reports the crop mix of every farm for the current run. The collected crop mix is then used by the crop mix constraints. The crop mix constraints are used to control the amount of ha of a given crop produced. There are six different crop mix constraints in the ZORRO MODEL: 1) wheat, 2) oats, 3) barley, 4) soybean, 5) canola, and 6) the total amount of crop produced under minimum tillage production. Note that the LHS of those constraints are a % of the total ha cultivated in the watershed. This number is in X75 and refers to the total ha cultivated in the watershed in the base case. The RHS are also in % and are user's decision.

BMP 2 sheet:

This sheet reports the animal mix of every farm for the current run. Those numbers are taken directly from sheets F1 to F73.

F1 to F73 sheets:

Those sheets are the farm's sheet. Each sheet is built exactly the same way. There are five farms missing. The reason why they are missing are lack of relevant information regarding crop mix, animal mix, location, management practices, etc.

Field size:

Each farm model (F1 to F73 sheet) is built to have no more than 11 fields. The field sizes are reported automatically in cells D3 to K13 and in BJ3 to BP13. To enter and/or modify a field size go to CG34 to CG44. Using the CG columns, you will be required to enter the size of the field only once. This procedure ensures consistency and minimizes typing error.

The decision variables are reported in lines 15 to 25. The coefficients are between zero and 1 but not binary. This has been done originally to allow for a binary field decision that is 1=produce it or 0=not produce it. However, the binary constraints have been removed due to memory requirement. Those coefficients can be interpreted as factors that indicate what portion of the related field is allowed to such and such production. Note that field decision variable is used only for conventional crop, minimum tillage crop, animal production, buffer strip, pesticide reduction management, and dribble bar. We use a total number with no field distinction for nutrient allocation, buying crop, and selling crop.

The objective function:

The coefficients of the objective function are in line 30 and the decision variables are in line 26. The objective function (NFI) is reported in cell CE29. The associated formula is "=SUMPRODUCT(D26:CD26;D30:CD30)". This result is reported in the result sheet for every farm.

The objective coefficients:

Columns D to K in line 30 report the cost of producing a hectare of a particular crop production. Columns L to Q in line 30 report the cost of buying a kg of the particular nutrient. Columns R to AB in line 30 report the cost of producing a particular animal. (Note that the costs are annual costs meaning that they account for the production cycle of each production). Columns AC to AZ in line 30 report the cost of implementing one linear meter of a particular buffer strip. Columns BA to BB in line 30 report the cost of producing corn and forage corn using pesticide reduction management. Columns BC to BD in line 30 report the cost of spreading a cubic meter of solid manure using conventional practice. Columns BE to BG in line 30 report the cost of spraying a cubic meter of liquid manure using dribble bar on a particular crop. Columns BH to BI in line 30, report the cost of importing and exporting one cubic meter of liquid manure. Columns BJ to BP in line 30 report the cost of producing a ha of the particular minimum tillage crop production. Columns BQ to BX in line 30, report the cost of selling one ton of a particular crop production. Columns BY to CD in line 30, report the cost of buying one ton of a particular crop production.

Gross revenue

Gross revenue for each variable is in line 31. This, multiplied by the objective variables plus the gross revenue from selling crops minus the gross expenses from buying crops result in the total gross revenue reported in cell CG29. The total amount of gross revenue is reported in the result sheet for every farm. Note that the reason why we subtract gross expense from buying crops to obtain gross revenue is because some farms sell and buy, for example corn at the same time. Since corn is bought and sold at the same price there no significant economic impact when treating the NFI. However, when treating the gross revenue we need to subtract gross expense from buying crop in order to avoid model distortion.

Environmental coefficients:

There are two types of environmental coefficient 1) the pollution coefficients, and 2) the abatement coefficient. The pollution coefficients for conventional crops are in D308 to K436 and for minimum tillage crops they are in BJ308 to BP436. The abatement coefficients for buffer strips are in AC440 to AZ502, the abatement coefficients for dribble bar are in BE440 to BG502, and the abatement coefficients for pesticide reduction are in BA440 to BB502. All coefficients are pasted automatically in the farm's model from the budget final file.

ZORRO MODEL

ZORRO BC:

In the ZORRO BC model all the crop mix and the animal mix are fixed following the current practices of each farm.

ZORRO expanded:

In the ZORRO expanded model all crop mix and animal mix are decision variables that are determined according to the model maximization procedure.

ZORRO expanded farm:

In the ZORRO expanded farm model all crop mix and animal mix are decision variables that are determined according to the model maximization procedure. The only thing different with the ZORRO expanded model is in the result 2 sheet. This sheet in the expanded farm model allows for controlling the RHS of the environmental constraint at the farm scale very simplistically. For example, we paste the base case sediment emission in columns I and in columns H we write a % of the base case emission, (i.e. 1*I3, or 0.9*I3). There is no automatic iteration procedure for the farm constraint. That is you will have to manually decrease the amount of % of the base case emission in order to decrease emission (RHS of the constraint). Note that by default the base case emissions are already pasted in the result 2 sheet of the ZORRO EXPANDED FARM model.

Macro procedure

In the ZORRO expanded model, there are 6 basic macros that you can access by clicking on DEVELOPER, then VISUAL BASIC, and on MODULE in the project-vba project box on your left. You will find 6 macros: Coliform, Nitrogen, Pesticide, Phosphorus, Sediment, and Superman.

Here is a script for the coliform macro. Comment in *italic* are explanatory and are not part of the macro.

This is a standard title that treats the macro as a macro loop. It is required for iteration macro procedure.

```
Sub MACROLOOP()
```

This is standard notation that treats every count (iteration) as integer and every cell and row as integer.

```
    Dim Count As Integer
    Dim TableRow As Integer
```

Here the macro selects the sheet superman and paste in their respective cell the RHS of the environmental constraint. This refers to the starting point of the iteration. In J3 the RHS is 1,441E+12

```
    Sheets("SUPERMAN").Select
    Range("B3") = 1E+100
    Range("C3") = 1E+100
    Range("D3") = 1E+100
    Range("E3") = 1E+100
    Range("F3") = 1E+100
    Range("G3") = 1E+100
    Range("H3") = 1E+100
    Range("I3") = 1E+100
    Range("J3") = 1441000000000#
    Range("K3") = 1E+100
```

Here the macro will iterate 10 times. It will change the value J3 reported above by J3-0.1*1.441E+12, solve the model, and report the result in the superman sheet following the indication below. Therefore, the emission increment will be 10%.

```
    For Count = 1 To 10
        Range("J3") = Range("J3") - 0.1 * 1441000000000#
        Application.Run macro:="WBUsers.wbSolve"
        TableRow = Count + 32
        Sheets("SUPERMAN").Select
        Cells(TableRow, 56) = Range("A3")
        Range("A3:BB3").Copy
  Range(Cells(TableRow, 56), Cells(TableRow, 109)).PasteSpecial    Paste:=xlValues
    Cells(TableRow, 56) = Range("A3")
    Cells(TableRow, 57) = Range("B3")
    Cells(TableRow, 58) = Range("C3")
    Cells(TableRow, 59) = Range("D3")
    Cells(TableRow, 60) = Range("E3")
    Cells(TableRow, 61) = Range("F3")
    Cells(TableRow, 62) = Range("G3")
    Cells(TableRow, 63) = Range("H3")
    Cells(TableRow, 64) = Range("I3")
    Cells(TableRow, 65) = Range("J3")
    Cells(TableRow, 66) = Range("K3")
    Cells(TableRow, 67) = Range("L3")
    Cells(TableRow, 68) = Range("M3")
    Cells(TableRow, 69) = Range("N3")
    Cells(TableRow, 70) = Range("O3")
    Cells(TableRow, 71) = Range("P3")
    Cells(TableRow, 72) = Range("Q3")
```

```
    Cells(TableRow, 73) = Range("R3")
    Cells(TableRow, 74) = Range("S3")
    Cells(TableRow, 75) = Range("T3")
    Cells(TableRow, 76) = Range("U3")
    Cells(TableRow, 77) = Range("V3")
    Cells(TableRow, 78) = Range("W3")
    Cells(TableRow, 79) = Range("X3")
    Cells(TableRow, 80) = Range("Y3")
    Cells(TableRow, 81) = Range("Z3")
    Cells(TableRow, 82) = Range("AA3")
    Cells(TableRow, 83) = Range("AB3")
    Cells(TableRow, 84) = Range("AC3")
    Cells(TableRow, 85) = Range("AD3")
    Cells(TableRow, 86) = Range("AE3")
    Cells(TableRow, 87) = Range("AF3")
    Cells(TableRow, 88) = Range("AG3")
    Cells(TableRow, 89) = Range("AH3")
    Cells(TableRow, 90) = Range("AI3")
    Cells(TableRow, 91) = Range("AJ3")
    Cells(TableRow, 92) = Range("AK3")
    Cells(TableRow, 93) = Range("AL3")
    Cells(TableRow, 94) = Range("AM3")
    Cells(TableRow, 95) = Range("AN3")
    Cells(TableRow, 96) = Range("AO3")
    Cells(TableRow, 97) = Range("AP3")
    Cells(TableRow, 98) = Range("AQ3")
    Cells(TableRow, 99) = Range("AR3")
    Cells(TableRow, 100) = Range("AS3")
    Cells(TableRow, 101) = Range("AT3")
    Cells(TableRow, 102) = Range("AU3")
    Cells(TableRow, 103) = Range("AV3")
    Cells(TableRow, 104) = Range("AW3")
    Cells(TableRow, 105) = Range("AX3")
    Cells(TableRow, 106) = Range("AY3")
    Cells(TableRow, 107) = Range("AZ3")
    Cells(TableRow, 108) = Range("BA3")
    Cells(TableRow, 109) = Range("BB3")
 Next Count
 End Sub
```

Macro sediment, macro phosphorus, macro nitrogen, macro coliform, and macro pesticide are built exactly the same way. The only difference is in the RHS of the constraint is located, and also where the result is pasted after the model solved since we don't want subsequent results to be pasted over previous results.

Macro superman simply calls macro sediment, macro phosphorus, macro nitrogen, macro coliform, and macro pesticide and executes them. Here the script of the superman macro.

```
Sub MACROLOOP()
Call VBAProject.SEDIMENT.MACROLOOP
Call VBAProject.PHOSPHORUS.MACROLOOP
Call VBAProject.NITROGEN.MACROLOOP
Call VBAProject.COLIFORM.MACROLOOP
Call VBAProject.PESTICIDE.MACROLOOP
End Sub
```

Normally to run the macros, you are not required to open visual basic. Simply click on DEVELOPER, then on MACRO and select the macro that you need. To interrupt a macro press ESC.
For the ZORRO expanded farm model, there are no macros associated with this model. You will have to run each iteration manually and paste the solution manually also. Select in the superman sheet A3 to BB3 and paste it somewhere useful for you. See running procedure for more detailed information.
For the ZORRO BC model, there are no macros associated with this model. However, no iterations are required since this model is only use to run the base case simulation.

Running the analysis

ZORRO MODEL EXPANDED:
The zorro model expanded is use to generate abatement cost curve for each environmental parameters when we constraint the watershed.
Punctual run:
To run only one simulation using a specific sediment level (or other environmental parameters) uses the following sequence:
In the superman sheet in column G to K, type the pollution level wanted. This will refer as your RHS in your watershed environmental constraint.
Hit the target (run what's best).
Collect your information in column A to BB of the superman sheet.
Check the other associated sheet for detailed results.
Sequence of run:
To run a sequence of simulation using specific starting sediment levels (or other environmental parameters) use the following procedure:
Open visual basic. (Click on DEVELOPER THEN VISUAL BASIC)
Choose the macro that you want to run. Double click on it. The script will appear.
Check and /or adjust the starting point of the iteration. By default the starting point is the base case emission.
Check and /or adjust the increment emission reduction between each iteration. By default the emission increment is 10%
Check the number of iteration. By default the macro will iterate 10 times.
Close visual basic. (No need to save anything).
In (DEVELOPER/MACRO) re-select the macro that you have chosen and run it.
The results will be pasted automatically in the superman sheet in column BD to DE.

ZORRO BC MODEL:

The ZORRO BC model is configured following the base case (current practices) of every farm and therefore the crop mix and the animal mix are predetermined by the current practices of each farm. Each farm model has been built following the survey procedure and the data collected with the farmer's interviews in May 2007.

Base case run:

To run the base case simulation, hit the target. Look at the superman sheet for detailed results in columns A to BB. You may obtain more farm information when looking at the associated sheets described earlier

ZORRO EXPANDED FARM MODEL:

This model is used to generate abatement cost curve for each environmental parameters when we constraint each farm instead of the watershed.

Punctual run:

To run only one simulation using specific sediment levels (or other environmental parameters) use the following sequence:

For sediment simulation,

In the result 2 sheet, in column H, type the % of the base case pollution (in column I) that you want as your RHS and paste your formula to all farms i.e. cells H4 to H68. It's supposed to look like this "=1*I4", or "=0.9*I4".

Hit the target. (Run what's best)

Collect your information in column A to BB of the superman sheet and paste it where it is useful for you.

Check the results sheet for the NFI result, the result 2 sheet for pollution results, the BMP sheet for BMP implementation, and check BMP2 for animal production.

Let say your first run was 100% of the base case emission and as your second run you want to run 90% of the base case emission. Then, go back to the result 2 sheet and type the % of the base case pollution (in column I) that you want as your RHS and paste your formula to all farms i.e. cells H4 to H68. It's supposed to look like this "=0.9*I4".

For phosphorus simulation,

In the result 2 sheet, in column J, type the % of the base case pollution (in column K) that you want as your RHS and paste your formula to all farms i.e. cells J4 to J68. It's supposed to look like this "=1*K4" , or "=0.9*K4".

It the target. (Run what's best)

Collect your information in column A to BB of the superman sheet and paste it where it is useful for you.

Check the results sheet for the NFI result, the result 2 sheet for pollution results, the BMP sheet for BMP implementation, and check BMP2 for animal production.

Let say your first run was 100% of the base case emission and as your second run you want to run 90% of the base case emission. Then, go back to the result 2 sheet and type the % of the base case pollution (in column K) that you want as your RHS and paste your formula to all farms i.e. cells J4 to J68. It's supposed to look like this "=0.9*K4".

For nitrogen simulation,

In the result 2 sheet, in column L, type the % of the base case pollution (in column M) that you want as your RHS and paste your formula to all farms i.e. cells L4 to L68. It's supposed to look like this "=1*M4" , or "=0.9*M4".

It the target. (Run what's best)

Collect your information in column A to BB of the superman sheet and paste it where it is useful for you.

Check the results sheet for the NFI result, the result 2 sheet for pollution results, the BMP sheet for BMP implementation, and check BMP2 for animal production.

Let say your first run was 100% of the base case emission and as your second run you want to run 90% of the base case emission. Then, go back to the result 2 sheet and type the % of the base case pollution (in column M) that you want as your RHS and paste your formula to all farms i.e. cells L4 to L68. It's supposed to look like this "=0.9*M4".

For ecoli simulation,

In the result 2 sheet, in column N, type the % of the base case pollution (in column O) that you want as your RHS and paste your formula to all farms i.e. cells L4 to L68. It's supposed to look like this "=1*O4" , or "=0.9*O4".

It the target. (Run what's best)

Collect your information in column A to BB of the superman sheet and paste it where it is useful for you.

Check the results sheet for the NFI result, the result 2 sheet for pollution results, the BMP sheet for BMP implementation, and check BMP2 for animal production.

Let say your first run was 100% of the base case emission and as your second run you want to run 90% of the base case emission. Then, go back to the result 2 sheet and type the % of the base case pollution (in column M) that you want as your RHS and paste your formula to all farms i.e. cells N4 to N68. It's supposed to look like this "=0.9*O4".

For pesticide simulation,

In the result 2 sheet, in column P, type the % of the base case pollution (in column Q) that you want as your RHS and paste your formula to all farms i.e. cells L4 to L68. It's supposed to look like this "=1*Q4", or "=0.9*Q4".

It the target. (Run what's best)

Collect your information in column A to BB of the superman sheet and paste it where it is useful for you.

Check the results sheet for the NFI result, the result 2 sheet for pollution results, the BMP sheet for BMP implementation, and check BMP2 for animal production.

Let say your first run was 100% of the base case emission and as your second run you want to run 90% of the base case emission. Then, go back to the result 2 sheet and type the % of the base case pollution (in column Q) that you want as your RHS and paste your formula to all farms i.e. cells P4 to P68. It's supposed to look like this "=0.9*Q4".

Constraint Description:
Field Size:
In line 34 to 44, the model control for the available field. The constraint limits the area allocation of a field to its respective size.
No field, no crop:
In line 47 to 57, the model allocates production only if there is field available.
Buffer strip constraint 1:
The model allocate buffer strip on production X only if the field is in production X.
Limit manure application:
The model limits the manure application.
No field, no manure:
The model allocates manure only if there is field under production.
Dribble bar constraint:
The model allocates dribble bar on a crop X only on the field where the crop X is produced.
Manure management constraint:
All the manure (liquid and solid) is disposed either on the farm or exported outside the farm. But there is no admissible inventory.
Pesticide reduction constraint:
The model allocates pesticide reduction management on a crop X i.e. corn or forage corn only on fields where the crop X is produced.
Buffer strip constraint 2:
The model allocates no more buffer than the potential amount available.
Animal constraint:
The dairy, poultry animal are fixed. However, the model allocates an equal or a smaller amount of hog, and beef animal available in the base case.
Environmental constraint:
The model cannot allocate negative amount of pollution and the model emit a equal or a smaller amount of pollution than determined by the RHS of the environmental constraint.