MEASURING THE COMPLIANCE COST OF NUTRIENT MANAGEMENT REGULATIONS OF ONTARIO DAIRY FARMS

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KENNETH POON

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ABSTRACT

MEASURING THE COMPLIANCE COST OF NUTRIENT MANAGEMENT REGULATIONS ON ONTARIO DAIRY FARMS

Kenneth Poon
University of Guelph, 2009

Advisor:
Dr. Glenn C. Fox

This thesis investigates of the compliance cost of the current and possible future configurations of the nutrient management regulations on Ontario dairy farms. Three optimization models representing small, medium, and large Ontario dairy farms were solved under regulatory scenarios simulating variations of the current Nutrient Management Act (NMA) and the proposed Clean Water Act (CWA). Under the NMA regulations, small, medium, and large Ontario dairy farms do not incur compliance costs. Under stricter NMA regulations, large farms may face compliance cost up to 24% of net return. Dairy farms with low soil P will not be able to comply with these stricter regulations. Medium and large dairy farms will incur higher compliance costs under the proposed CWA regulations. Manure export and land rental can reduce compliance costs for the CWA regulations. If regulations in the CWA were made stricter, medium and large farms will see an increase in compliance costs.

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Chapter 1 - Introduction

Excess nutrients in agricultural runoff reduce the surface water quality of streams and lakes, damaging the surrounding aquatic ecosystem and reducing the recreational value of these water bodies. Nutrient contamination of groundwater is also a concern, as it is the main source of drinking water for many rural communities in Ontario. Rudolph *et. al.* (1998) reported that 23% of 144 farms surveyed in Ontario have wells with groundwater with nitrate concentration exceeding the safe drinking water standard of 10mg/L set by the Ontario Ministry of Environment (OMOE, 2003).

The province has introduced nutrient management legislation that specifically targets the agricultural sector. The Nutrient Management Act (2002), which aims to protect water of rural areas from nutrient and manure contamination from agricultural operations, requires large livestock operations to document the disposal and usage of manure and commercial fertilizers. Large livestock operations, in the context of the Nutrient Management Act (2002), are defined as operations that generate over 300 nutrient units. For the dairy sector, a Holstein milking herd of 170 head with 170 replacement heifers will generate 300 nutrient units. Farms of any size constructing new buildings and retrofitting existing buildings are also regulated under the Nutrient Management Act (2002). Specifically, the Nutrient Management Act (2002) contains regulations that limit the application of phosphorous (P) to 390kg/ha above the amount of P removed through crop harvest over a 5-year period.

Recent proposals within the Clean Water Act (2007) may also play a role in the future of nutrient management. With the aim to protect drinking water quality for both rural and urban communities, the Clean Water Act (2007) considers nutrient application within what the regulation defines as groundwater protection areas and surface water intake protection zones to be a possible threat to drinking water quality. Groundwater protection zones are areas where significant groundwater recharge takes place or areas around wellheads (Lake Erie Source Protection Region, 2008). Intake protection zones are the areas of land upstream of a town's surface water intake, such as a drinking water treatment facility (Lake Erie Source Protection Region, 2008). Specifically, under the Clean Water Act (2007), nitrogen (N) and P applied per hectare 15% above the amount of N and P the crops require for production are considered to be significant threats to drinking water. Since the Clean Water Act (2007) prohibits activities that are identified as significant threats to drinking water quality, these threats translate into regulatory limits for N and P application in these protection zones. The size and location of the surface water intake protection zones and groundwater protection zones are still being determined, and it is unclear how much agricultural land will be regulated under these regulations.

The main difference between the Nutrient Management Act (2002) and the Clean Water Act (2007), aside from the regulatory triggers, is in how the nutrient application limits are calculated. Nutrient Management Act (2002) regulations limit nutrient application based on crop removal, which is very different from the proposed Clean Water Act (2007) regulations that limit nutrient applications based on crop requirement. Because nutrient removal and nutrient requirements for crops are calculated differently, these regulatory limits may have very different implications for the regulated farms.

Economic Problem

The economic problem is the lack of information on the compliance costs of the Nutrient Management Act (2002) and the Clean Water Act (2007) for Ontario Diary farms, in terms of the cost of compliance and changes in production practices in order to reach compliance. Understanding compliance of the current and possible future regulatory regime is important for both regulators and the Ontario dairy sector. For regulators, it is important to understand whether current and possible future regulations are effective in reducing excess nutrient application, and if the regulations have any unintended consequences. It will also aid agricultural policy makers to assess the sector-specific economic impacts of nutrient management policies. Understanding compliance is also important for the dairy industry to estimate the industry wide impact of these regulations, and is important to dairy farmers in evaluating how to best manage their farms with minimal compliance costs. Currently, most dairy farms are too small to be regulated under the Nutrient Management Act (2002). Figure 1.1 shows the number of small, medium, and large Ontario dairy farms from 1998 to 2005. Small dairy farms are represented by the light grey bars and include farms with herd sizes smaller than 45 head of milking age cows, medium dairy farms are represented by the dark grey bars and include farms with herd sizes between 45 and 75 head of milking age cows, and large dairy farms are represented by the black bars and include farms with herd sizes greater than 75 head of milking age cows. Although small dairy farms make up the majority of the dairy sector, the numbers are rapidly decreasing. While the number of medium sized farms remain the same, the number of large farms have doubled in this period. Furthermore, the small number of large dairy

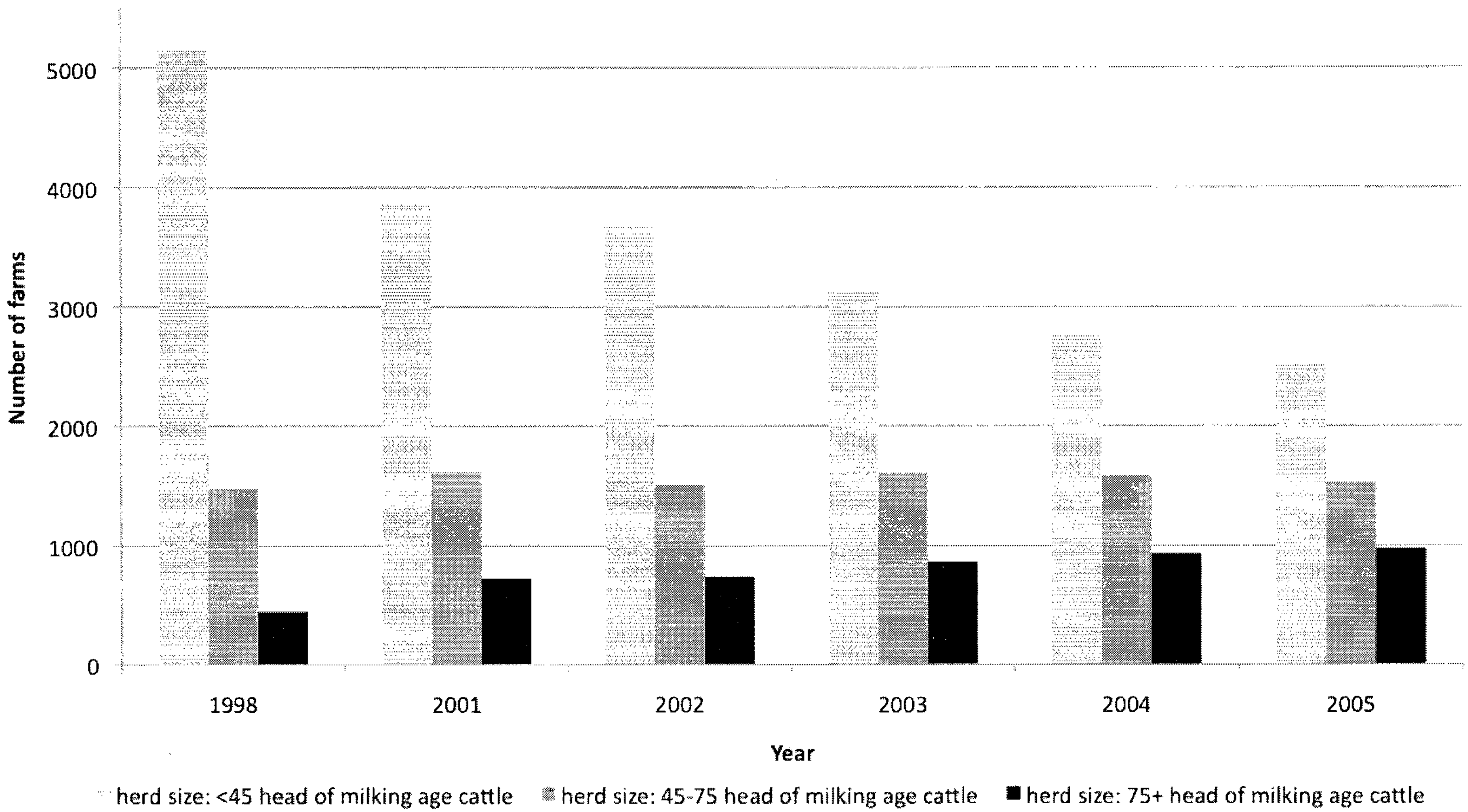

Figure 1.1 – Number of small, medium, and large dairy farms in Ontario between 1998 and 2005.

Source: Calculated from data provided by DFO (2007) Statistical Handbook.

farm contribute to a large percentage of total milk production in Ontario. Figure 1.2 shows the estimated percentage of total milk output by small, medium, and large farms between 1998 and 2005. In 2005, the large farms produced over 46% of dairy production in Ontario. It is uncertain how farms in each size category are impacted by the regulations under the current Nutrient Management Act (2002), as well as the proposed regulations under the Clean Water Act (2007). However, even if only the large dairy farms are negatively impacted by these regulations, it could have a large impact on the Ontario dairy industry.

Economic Research Problem

The economic research problem addressed by this study is that the compliance costs of the current and future configurations of nutrient management regulations for Ontario dairy farms are unknown. This research builds on a large body of research assessing farm-level compliance costs of nutrient management regulations, with little consensus on the costs of these regulations. Using a farm-level optimization model, Fleming, Babcock, and Wang (1998) compared the compliance costs of a P-requirement based application limit to a N-requirement based application limit for the Iowa pork farms under different production systems. They found that the cost of P-requirement regulations are lower for farms that apply manure as a nutrient source. Whereas Feinerman, Bosch and Pease (2004) found that using a regional mode of Virginia livestock operations allowing for sales and purchases of manure between counties, nitrogen based manure application standards reduced welfare of the livestock sector by 5 percent. P-based manure application standard, however, reduced welfare by 15 percent. Weersink, deVos, and Stonehouse (2004) measured the cost of compliance to N

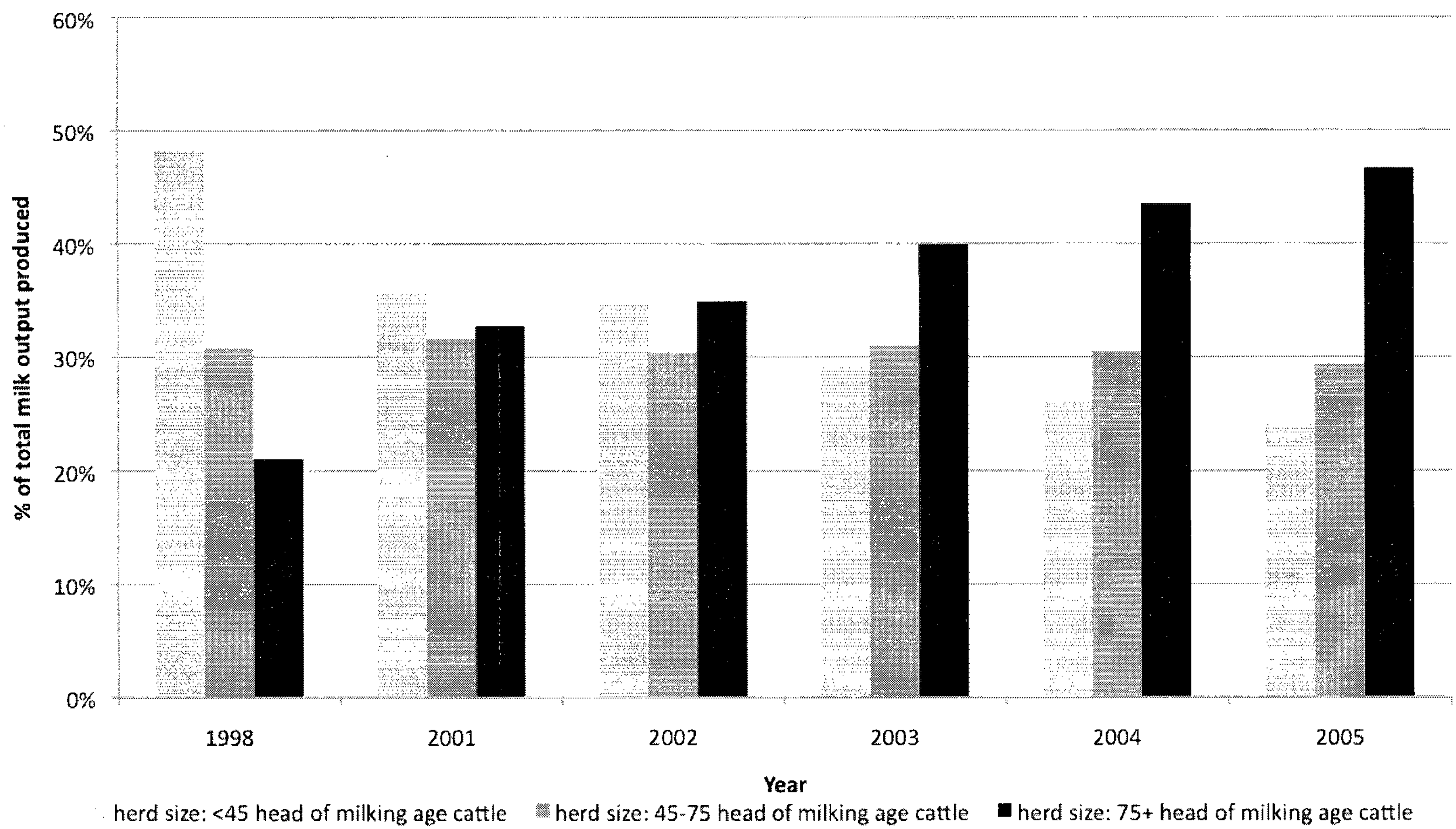

Figure 1.2 – Estimated percent of total milk output produced by small, medium, and large dairy farms in Ontario between 1998 and 2005.

Source: Calculated from data provided by DFO (2007) Statistical Handbook.

and P requirement based application limits for the Southern Ontario Hog sector with different manure storage systems under limited land availability. They found that hog operations with high levels of manure output will incur significant compliance costs, especially in situations where additional land available for manure disposal is scarce and farms are forced to reduce herd size. These studies, however, did not consider the differences in compliance between a requirement based application limit and a removal based application limit, or the differences in compliance cost for farms in different size categories. Furthermore, it is difficult for the Ontario dairy sector to draw conclusions from these studies since herd sizes and nutrient profiles of hog manure are very different from dairy operations in Ontario. This research contributes to the literature by examining the different consequences in compliances with removal-based P application limits and requirement-based N and P application limits in terms of cost and changes in farm production activities for dairy farms of different sizes.

Purpose and Objective

The purpose of this study is to measure the farm level compliance costs of the current and possible future configurations of nutrient management regulations for Ontario dairy. The objectives of this study are:

1. To understand the environmental policies and regulations imposed on dairy farmers in Ontario by reviewing current nutrient management policies and regulations in Ontario pertinent to livestock operations.
2. To understand the economic theories used for analyzing environmental compliance costs for livestock operations by compiling a literature review on the economics of environmental compliance in agriculture.
3. Develop an analytical framework that combines farm level economic analysis with an appropriate biophysical simulation model

4. Measure the compliance cost of current and possible future configurations of nutrient management regulations on Ontario dairy farms.

5. Make policy recommendations to regulators on consequences of current and possible future nutrient management regulations, and to farmers on the costs of these regulations as well as management practices that may reduce these costs.

Chapter Outline

Chapter 2: Review of nutrient management and water protection policies

This chapter provides an overview of federal, provincial, and municipal roles in water quality protection and nutrient management. This chapter also pinpoints the nutrient management regulations relevant to Ontario dairy farmers.

Chapter 3: Review of literature on the economics of environmental compliance

This chapter provides a review of economic theories applicable to measuring compliance costs for nutrient management regulations, as well as critique methods previously employed to study economic effects of nutrient management.

Chapter 4: Conceptual Framework

This chapter will provide the theoretical motivation behind the empirical model, as well as discuss the theoretical framework in detail.

Chapter 5: Empirical Framework

This chapter will present the sources of data used in the empirical framework, the calibration of the empirical model, as well as the validation of the model.

Chapter 6: Model Results and Discussion

This chapter will provide a detailed analysis of the results of the model, and discuss the implications of the results.

Chapter 7: Conclusion

This chapter will summarize the method used in this study, highlight the principal findings of the study, as well as discuss the implications of the empirical results for regulators and the Ontario dairy farm sector. Suggestions for future research will also be provided.

Chapter 2 – Review of Water Quality and Nutrient Management Policies

In Canada, environmental quality is the responsibility of all levels of government. The federal, provincial, and municipal governments have all enacted acts, policies, regulations and by-laws regulating water quality. Some of these regulations are specific in protecting water quality, while others include water quality protection as part of the objective in achieving environmental protection. Agricultural operations with a risk of water contamination may also be targeted by sector-specific policies: some designed to specifically control pollution by agricultural activities, while others help protect farmers from liability suits. All of these factors may affect nutrient management decisions by Ontario farmers in varying degrees. Each level of government has had varying success in regulating the impact of agricultural production on water quality. Through the introduction of new legislations and the revision of old policies, the relative importance of each regulatory body has also changed over time. This also changes the standards, guidelines, and rules farmers need to follow to comply to avoid persecution.

In order to understand the compliance cost of the current nutrient management regulatory regime for Ontario dairy farmers, it is important to first recognize the regulations and standards farmers need to follow when managing nutrient output of their operations. The purpose of this chapter is to provide a review on the policies, regulations, acts, and guidelines affecting nutrient management decisions for Ontario dairy farmers. This chapter will identify important components of environmental regulations as they relate to agricultural nutrient management, interactions of these regulations, as well as the ability for each level of government in enforcing nutrient management of agricultural operations.

Role of Federal Governments

Federal policies, acts, and regulations relating to water quality

The federal government has no direct control over most water quality issues, as the management of natural resources falls under provincial jurisdiction. In terms of water resources, the federal government only has control over those that crosses borders, which includes international and inter-provincial water bodies. Examples are coastal waters, the Great Lakes, rivers crossing provincial boarders, as well as those that flow into and out of the United States. Having jurisdiction of these water bodies translates to the federal government having control with all uses of these water bodies and the resources within (such as fisheries and off-shore oil reserves). The protection of federal water resources has led to the development of some early water quality policies, with the very first being the Canada Water Act.

Canada Water Act

First passed in the 1970s, the purpose of the Clean Water Act is to "provide for the management of the water resources of Canada, which included research and the planning and implementation of programs relating to the conservation, development and utilization of water resources." The act includes provisions for setting up federal-provincial arrangements that are seminal in carrying out most of the objectives set out by the act. Federal-provincial arrangements are responsible for consultation on water resource matters, for prioritizing research, planning, conservation, development and utilization of those resources, advice on the formulation of water policies and programs, as well as to facilitate the coordination and implementation of water policies and programs.

The Canada Water Act also calls for comprehensive water resource management programs, the purpose of which is to inventory water resources, gather data, research, formulate plans and design projects relating to water resource management. This is done through joint commissions or boards to supervise and coordinate those programs. Lastly, the Canada Water Act calls for water quality management through federal-provincial agreements. However, these management programs only apply to federal waters, unless the quality of a non-federal water has become a national concern.

Fisheries Act

Another policy designed to protect federally controlled resources is the Fisheries Act, enacted in 1985. The act includes a section titled ‘Fish Habitat Protection and Pollution Prevention’ which prevents activities that degrade water quality for all surface waters inhabited by fish. However, the scope of the Act is only limited to surface water and focuses mainly on regulation of toxic substances entering the water. Groundwater quality and nutrient pollution remains outside the power of the Fisheries Act.

Federal Water Policy

The federal government has also been able to influence water quality regulations beyond its jurisdictional control through two important pieces of policies. The first of these policies is the Federal Water Policy. Enacted in 1987, the Federal Water Policy is “a statement of the federal government’s philosophy and goals for the nation’s freshwater resources and of the proposed ways of achieving them”. The policy has two goals: to protect and enhance the quality of the water resource, and to promote the wise and efficient management and use of water. It also outlined five strategies to reach those goals: through realistic pricing, science leadership, integrated planning, legislation, as well as public awareness. Specifically, the legislative strategy includes the modernization of the legislative base for a more anticipatory and comprehensive approach, the establishment of water quality standards and guidelines, and well as the provision of appropriate enforcement and compliance measures.

Application of the Federal Water Policy would be done through institutional arrangements as well as through the Interdepartmental Water Committee, which assesses the strength and weaknesses of the policy, provides information of the policy to the public, addresses issues as related to water policies through subcommittees, as well as coordinates interdepartmental studies.

The Federal Water Policy is an overarching policy aiming to address a myriad of water resource issues, addressed in 25 specific policy statements. Three of these statements directly address water quality issues: one on water quality management, one on groundwater quality, and the last on safe drinking water. To address all three items, the development of water quality guidelines with provincial governments is vital. The policy statements also stressed the importance of research for the development of those standards, technological research and development for assessment and management of water quality, promotion of public awareness, development of water quality management policies. The policy also stresses the importance of inter-jurisdictional agreements dealing with water quality issues as a way to avoid court processes, which the policy claims to be overly costly and lengthy.

Few goals have been achieved on acting on the five strategies outlined to fulfill the goals set out by the Federal Water Act, as most issues addressed in the policy are contemporary issues faced today. There is one exception, however, as one of the major outcomes of the Federal Water Policy was the development of the Canadian Water Quality Guidelines, which provides the maximum allowable concentration of many organic and inorganic compounds for drinking, recreational use protection of aquatic life, agricultural irrigation use, and industrial use. In the guidelines for drinking water, the specified concentration is mainly the highest concentration before any adverse health effects have been noted my previous studies and health surveys. Following the mandate of the Federal Water Policy, these guidelines are supported by scientific research and professional study. The Canadian Water Quality Guidelines have since been used as part of many water quality policies.

Around the time the Federal Water Policy was introduced, the federal government also introduced the Canadian Environmental Protection Act (CEPA), which later received a major revision in 1999. One of the main purposes of the act is to prevent and manage risks posed by toxic and other harmful substances. The current version of CEPA manages environmental and human health impacts from a wide range of sources. It is designed to compliment other environmental statutes at the federal and provincial level, dealing with water, air, and soil quality as well as protect biodiversity.

Federal policies and their relationship with agricultural nutrient management

Jurisdictional constraints leaves most policies and regulations specific to water quality only limited to federally controlled waters. The federal government can also protect water quality in the spirit of protecting environmental quality, through acts such as CEPA. CEPA handles mainly toxic substances entering surface water, but does not control nutrient pollution or protect groundwater quality. There is room for controlling agriculturally sourced nutrient pollution in CEPA, which is evident in the regulation regarding phosphorous. However, phosphorus regulation in CEPA is specifically targeted towards reducing phosphorous content in detergents and other cleaning agents.

Federal policies and acts able to regulate water quality share some common characteristics that result in limited direct control by the federal government on nutrient management decisions for agricultural operations in Canada. One of the reasons is the jurisdictional constraints faced by the federal government when addressing water quality issues. Specific water quality regulations, such as the Canada Water Act and the Fisheries Act, can only be applied to water bodies under federal control. The federal government can also regulate water quality through overarching environmental protection policies such as CEPA, but shared jurisdiction usually translates to leaving policy implementation in the hands of federal-provincial agreements, giving provincial governments substantial control over policy implementation. Groundwater resources are also not mentioned in federal water quality policies likely because the federal government has no control over it.

The design of many environmental policies and acts relating to water quality at the federal level also tends to be 'hands off' and leaves little detail for implementation. For example, In the Canada Water Act, federal-provincial arrangements were mainly meant to coordinate research, facilitate implementation of management programs, and develop pilot projects. However, the details of those programs were not in the Act, nor were the completion of any of these projects mandatory.

Finally, while monitoring, enforcement, and compliance measures are in place for many of these acts and policies, they are mainly focused on regulating the industrial and resource extraction sector. This is perhaps most apparent with CEPA 1999, which includes specific provisions to regulate nutrient pollution. However, even though nutrients are defined by the act as 'substances that promote the growth of aquatic vegetation,' phosphorous is the only nutrient out of the many substances regulated under the act. CEPA specifically targets one source of the phosphorous pollution: it prohibits the production of laundry detergents with phosphorous pentoxide content over 2.2 percent by weight.

Federal government's influence on nutrient management outside regulations

The federal regulations relating to water quality protection is ineffective in regulating nutrient pollution from agricultural operations. However, the federal government still has an important but indirect influence over nutrient management: through the creation of water quality guidelines. The Canadian Water Quality Guidelines give a scientifically backed reference point to the safety of the water for a number of usages, including consumption, recreation, and ecosystem protection. These standards are developed through a literature review of scientific studies and surveys about the harmful concentrations of each compound. For example, the guideline sets it to 10mg/L of nitrate nitrogen, because that was the concentration below which no health impact has been observed. Although these guidelines are not quality standards and therefore unenforceable, they may be used to determine whether the nutrient output of an agricultural production is harming quality. This may be important in determining whether a farm in over applying nutrients, determining a definition for normal farm practices, or as evidence for or against civil liabilities.

Role of Provincial Government

Water Quality Policies and their relation to agricultural nutrient pollution

The provincial government plays a major role in regulating nutrient management of agricultural operations. The province is responsible for implementation of guidelines, programs, and regulations. They are also responsible for monitoring and enforcement. Ontario has quite a few acts regulating water resources, including the Ontario Safe Drinking Water Act, the Ontario Water Resources Act, and the Clean Water Act (2007).

Ontario Water Resources Act

The Ontario Water Resources Act first came into force in 1990. The purpose of the act is to "provide for the conservation, protection, and management of Ontario's waters and for their efficient and sustainable use, in order to promote Ontario's long-term environmental, social, and economic well-being." A large part of the act deals with regulating water taking permits and water transfers, but also regulating water pollution that may impair water quality. Regulations on water pollution are mainly targeted towards municipal wastewater and sewage treatment facilities, however, individuals may also be persecuted if they were found to place, discharge, or allow to remain any material that the Minister of the Environment deem may impair water quality. The act is important in defining the role of enforcement of provincial officers in monitoring and enforcement for environmental regulations. The act also gives the Minister of Environment the power to file an injunction to the Supreme Court of Justice for an order to prohibit discharges into the water the minister feel may impair water quality. The act gives the minister supervision over all surface and groundwater in Ontario.

Ontario Safe Drinking Water Act

The second piece of water quality legislature from the province, the Ontario Safe Drinking Water Act came in 2002 after the Walkerton incident. The act mainly targets municipal drinking water treatment infrastructure as well as water quality testing standards, with the purpose of protecting human health and preventing drinking water heath hazard. Although both nitrate and nitrite are included in the list of chemicals that may degrade water quality, agricultural sources are not likely to be implicated by the act. This is because the testing ius done to ensure treated water meets drinking water quality guidelines, and is intended to ensure that the municipal treatment systems are working properly. This places most of the liabilities of waterborne illnesses on municipalities for having unsafe drinking water treatment.

The Ontario Drinking Water Act also outlined increased fines for offenses that result in drinking water health hazards compared to earlier environmental regulations. Fines for individuals range from $20,000 per day and one year imprisonment for certain offenses, and upwards of $7 million and a prison term of five years minus a day, depending on the type of offenses and severity. This penalty regime is very different compared to older environmental policies and regulations at all levels of government, for which penalties and fines are not specifically defined, and it is within the discretionary power of the minister in charge of implementing the piece of literature to set those penalties. This also marks a difference in the nature of penalties for non-compliance, where previous transgressions were usually taken to court and the judicial system decides on the penalties.

Clean Water Act (2007)

The newest piece of water quality legislature, the Clean Water Act (2007), came into force in 2006. The act is different from its predecessors in that its purpose is to protect existing and future sources of drinking water. The act focuses on mitigating risk of water contamination through the protection of key areas that may affect drinking water sources. Protection zones include significant groundwater recharge areas, highly vulnerable aquifers, surface water intake protection zones, as well as wellhead protection areas. Source protection committees are responsible for developing the assessment reports evaluating risk of water contamination for regions under their respective jurisdiction, as well as the source protection plans. Source protection committees are appointed by the respective source protection authorities of the area (conservation authority in most cases, appointed by minister of environment in unorganized areas). While the municipalities do not have direct control of the development of the source protection plans, the act requires municipal consultation in the development of the source protection plans. The ministry of environment, the respective conservation authority of the protection area, as well as the respective municipality are all responsible for the implementation and enforcement of source water protection, through the respective enforcement and creation of regulations, resolutions, and zoning by-laws. Specifically, municipalities are required to revise their zoning by-laws and official plans to satisfy the source protection plan. The Clean Water Act (2007) holds enforcement bodies responsible for the implementation of these source protection plans, and individuals or authoritative bodies found to not comply to the plans are penalized, though the penalties were not specified in the act.

Agricultural-specific environmental policies

Aside from acts regulating water quality management from the Ministry of Environment, the province is also responsible for the welfare of the agricultural sector as well as rural affairs. In this regard, the province also has policies that protect the agricultural sector, as well as regulating it, resulting in interesting dynamics.

Normal Farm Practice Protection Act

The province's aim to protect the agricultural sector is most apparent in Ontario's version of the 'right-to-farm bill'. Originally developed in Manitoba as a way to protect farmers from nuisance suits from non-farming neighbours (Brubaker, 2007), the bill have spawned versions of itself in every province. Each version of the right-to-farm bill eliminate farmers' liability for generating nuisance in the form of odour, dust, noise, and other activities that may prevent others from enjoying their properties as long as farmers follow 'normal farm practice'. In Ontario, the right-to-farm bill takes the form of the Normal Farm Practice Protection Act. Normal farm practice is determined by the Normal Farm Practice Protection Board, with members appointed by the Minister of Agriculture, Food and Rural Affairs (OMAFRA, 2007). The board consists of a minimum of five members with expertise in agriculture and municipal affairs. Dealing with complaints through hearings on a case-by-case basis, the Board's main function is to determine what constitute as normal farm practices, then holds farmer that was determined to not follow normal farm practice liable for damages to the plaintiff. Farmers may also issue a complaint to the Board if it feels that municipal by-laws restrict normal farm practices. However, due to a ruling by the supreme court in 2002, the Board no longer has jurisdiction over municipal zoning by-laws, meaning that the Board can no longer change zoning by-laws even if it determined them to restricts normal farm practice (OMAFRA, 2005).

Because of its case-by-case approach, the Board cannot process very many cases each year. Of the 675 complaints OMAFRA receive on average each year, only about eight cases get through to the Board for review annually (OMAFRA, 2005). A few of these cases have also taken a few years to resolve, adding to the backlog. The Board also deals very little with nutrient management complains. Of all the forty-seven cases examined by the Board, only eleven cases are manure-related. Of these, only three of these cases are from after 2002, when the Nutrient Management Act (2002) came into power. Of the eight cases previous to 2002, six were from farmers complaints that municipal nutrient management by-laws were restricting normal farm practices. The rest of the cases were related to odour problems. Since the introduction of the Nutrient Management Act (2002), municipal by-laws were supplanted, making the rulings of these cases irrelevant now. However, it does reveal farmers discontent on nutrient management regulations by the government. Another revealing fact is that almost no manure-related complaints by non-farming neighbours stemmed from water quality issues, but rather odour emission from the spreading of manure. This could likely be because nutrient pollution in drinking water is difficult and expensive to detect. This can be justification for government control of nutrient management because of the resources the government has to detect water quality degradation.

Nutrient Management Act (2002)

The main piece of nutrient management policy that the province employs is the Nutrient Management Act (2002). First enacted in 2002, the Nutrient Management Act

(2002) specifically targets large, expanding, and new livestock operations. The act mandates all farms with over 300 nutrient units to have a nutrient strategy management strategy and a nutrient management plan. The both the nutrient management strategy and plan are also required for farms who submitted an application to expand or construct an animal housing facility, manure storage facility, or a in-ground permanent nutrient storage facility. Nutrient units are defined as the equivalent of the lower fertilizer replacement value of 43kg of nitrogen, or 55kg of phosphate. For dairy farms, this translates roughly to 170 milking Holstein cows, assuming the farms hold the same number of replacement heifers on farm. Since its last amendment in 2007, both a strategy and a plan is needed for farms of any size applying off-farm nutrient sources such as sewage bio-solids or pulp and paper bio-solids, and anaerobic digestive output. Expansion and construction of new structures housing animal or nutrient sources also need to follow specific guidelines outlined by the act in addition to requirements from the Building Act.

Nutrient Management Strategy and Plan

The nutrient management strategy and the nutrient management plan serve different purposes. The purpose of the nutrient management strategy is to manage the nutrient on the farm. It documents how much nutrients will be produced, received, and stored on the farm, as well as document the destination of those nutrients. If the strategy shows that nutrient has on the farm exceeds allowable application rates or storage capacity, there needs to be arrangements set up so that excess nutrients not applied are sent off to another farm unit through a brokerage deal.

Also included in the strategy are contingency plans for when more nutrients are produced than expected, storage capacity is impaired due to adverse weather conditions, or manure application equipment malfunction. Actions taken under the contingency plan can include increasing application rate if it is not at maximum, and if rates are already at maximum, transferring the nutrient off the farm through a brokerage deal, to an intermediate generator, acquire more land through ownership, application agreement, or rental, or landfill, incineration, and other processing methods.

The nutrient management plan, on the other hand, deals with the management of the nutrient that remains on the farm. Its purpose is to optimize land-based nutrient application, farm management, and crop removal of nutrients to best match the nutrient balance of the land. In order to do this, soil testing is required on land where nutrients are to be applied for phosphorous. The other set of application rate limits the total phosphorus applied within a five-year period. This is calculated based on the amount of phosphorous crops required (matching crop rotation requirement per hectare plus 85 kg of phosphorous per hectare), or the amount of phosphorous removed from the farm unit through harvest (phosphorous removed from harvesting portion per hectare plus 390 kg of phosphorous per hectare). Note that the regulation based on crop removal is the least binding one since it allows for more P to be applied. As such, the P application limit based on crop removal is is taken focus of the study.

Nutrient application rates are also constrained by site characteristics, seasonality, method of application, and the nature of the nutrient source. Typically, nutrients cannot be applied on land within 100m of municipal wells, 15m to drilled wells with a minimum depth of 15m and a watertight casing deeper than 6m, 15m from other wells if the nutrient is agriculturally sourced, and 90m if the nutrient is non-agriculturally sourced.

Depending on the dry matter content of the nutrient source applied and the slope of the land, there are various setback distances from water sources and wells. In all cases, non-agricultural source materials cannot be applied within 20m of the top bank of a surface water body. That distance is reduced to 13m for agricultural source materials. Setback distances increase for land with a steeper slope and less dry matter content. Different setbacks and application methods also differ when the ground is snow-covered or frozen.

The nutrient management strategies and plans can only be completed by qualified individuals. Qualification comes in the form of two certificates, obtained by completing courses and testing on nutrient management provided by OMAFRA. Both the strategy and the plan require the approval of a Director, after which the plan and strategy are reassessed and adjusted every year. The certificates, strategies, and plans expire five years after approval. Certificates are reacquired after testing and both the nutrient management strategies and plans are resubmitted for approval.

Regulation of Equipments and Structures

Aside from nutrient application and management, the Nutrient Management Act (2002) also regulates the equipment used for nutrient application, the structures used for processing and storage nutrients, as well as livestock confinement structures.

Restriction of nutrient application and processing equipments

Under the regulation, high trajectory irrigation guns capable of spraying more than 10m cannot be used for applying manure or non-agricultural nutrient sources, unless the nutrient is diluted into an aqueous solution with more than 99% water by weight. All nutrient application systems also require emergency shutoff functions, which mean either a remote shutoff system, or two operators with voice or electronic communication, one of whom can shut off the system in one minute. This is to prevent the continual application of nutrients if case of an error in delivery of system failure.

The Nutrient Management Act (2002) also regulates nutrient processing, such as a mixed anaerobic digestion that processes manure with non-agriculturally sourced material such as baking leftovers. The act have different storage requirements for digestive inputs depending on dry matter content and length of storage. It also has minimum temperature requirements for the digestive process as well as minimum time required for the digestion. All digestion facilities also require a primary and a secondary gas burner to combust the gas by-product from the digestion process.

Restrictions on Siting

In terms of structural restrictions, the location of these structures must be at least 15 meters away from field drainage tiles in addition to following the same setback distances for nutrient application. Also, these buildings cannot be placed on one-in-one-hundred-year floodplains. A hydrogeological study of the farm must be conducted by professionals before the expansion or construction of animal confinement or nutrient storage structures and sites. These studies assess the hydrological characteristics of the soil underlying the site of the proposed structures, as well as identify underlying aquifer structures and measure distances to the underlying bedrock. Approval of the proposed site of the new or expanding structure depends on whether the site meets the minimum requirements, including setback distances from surface water, drainage tiles, and minimum depth to underlying bedrock. The minimum distance from a facility to bedrock depends on the permeability of the soil underneath the structure, the floor of the structure (concrete or no concrete), presence of synthetic or compact-soil liners.

Professional engineer is required for design the building based on the results of the hydrogeological study as well as oversee the construction. If the site does not meet the minimum requirement for distances to bedrock, the engineer can design the facility in such a way that mitigates the impact of leakage. Ventilation systems are also part of the requirement for all nutrient storage facilities.

Site assessments are required not only for livestock housing and permanent nutrient storage, but also temporary field nutrient storage sites as well. Requirements for temporary storage sites have minimum distances to bedrock and setbacks to surface water similar to requirements for in-ground permanent nutrient storage facilities, with additional setbacks from residential housing and a larger setback to residential areas. Requirements for management of the temporary storage site include vegetative cover re-establishment if the site is to be used for another year, turning and inverting the material on a timely basis, covers and tarp for storage of and municipal bio-solid waste. The temporary storage sites are also restricted to only storing the nutrient materials that are slated for use in crop production, and non-agricultural materials stored this way cannot be transferred.

Proposed Amendments to the Clean Water Act (2007)

According to the proposed amendments to the Clean Water Act (2007), application of N and P are treated as threats to water quality within groundwater protection zones and surface water intake protection zones. Specifically, it lists that applications of N and P at 15% above crop requirement per hectare is considered to be a major threat to water quality. This is different from the Nutrient Management Act (2002) regulations where P application is restricted to a certain margin above crop removal rate.

The groundwater and service water intake protection zones are set by source water protection committees comprised of municipal government and the conservation authorities of the area. Currently, each source protection region is mapping out the protection zones; however, based on the Conservation Ontario (2009) website, only a handful of these regions have published these maps.

Municipalities and local participation

Officially, municipalities do not have jurisdiction on environmental issues. Nevertheless, before the introduction of the Nutrient Management Act (2002), many municipal governments addressed concerns about production, storage, and use of agriculturally source nutrients by mandating nutrient management mainly through zoning and land use planning by-laws. These by-laws mainly target large, new, or expanding livestock operations, and most by-laws require these operations to provide a nutrient management plan to the municipality. In a survey conducted by FitzGibbon *et al* (2002) in June and July of 2002, before the Nutrient Management Act (2002) was implemented, 26 counties in Ontario had nutrient management by-laws in place, of which seven counties implementing county-wide by-laws. Seven municipalities and two counties also put in place interim control by-laws prohibiting the construction or expansion of manure systems or livestock facilities during the time the Nutrient Management Act (2002) was first implemented between 2002 to 2003 (FitzGibbon, 2002). The earliest of these by-laws were enacted in 1998.

Nutrient management by-laws vary from county to county, with many similarities and differences in the range of operations affected by the nutrient management by-laws. Depending on the county or municipality, triggers for a nutrient management plan may be the number of livestock units for a given farm, density as determined by livestock per acre, or expansion in terms of increase in livestock units.

The details of what a nutrient management plan entails also varied widely. Variations include required minimum setback distances from a livestock facility to land base, land ownership requirements, renewal period for the nutrient management plan, required storage days, manure lease agreements, lot size, incorporation of manure into soil, as well as third party approval for nutrient management plans. Some municipalities require hydrogeological studies and / or engineering reports as part of the nutrient management plan. Consultants are also required for some by-laws.

Similarities of these by-laws include most municipalities following the Ontario Ministry of Agriculture and Food's formula in calculating Minimum Distance Separation. Enforcement of nutrient management by-laws were usually done with inspection from employees of municipalities.

With the introduction of the Nutrient Management Act (2002), however, most nutrient management by-laws are no longer active. Municipal by-laws can still regulate farms not covered by the Nutrient Management Act (2002), such as cash crop operations and smaller livestock farms. These by-laws are rare however, since it is the larger livestock operations that have raised concern for most residences.

Although municipal control of nutrient management for agricultural regulation was reduced after the introduction of the Nutrient Management Act (2002), there are still a few ways for municipalities to participate in nutrient management policy implementations. The Nutrient Management Act (2002), as well as other provincial farm practice management measures, has specific provisions for local committees, but specifically reduced the role of municipal participation.

The Nutrient Management Act (2002) has specific provisions for the establishment of local advisory committees to address nutrient management issues on a local scale. The local municipal government appoints five or more committee members. Committee members comprise of at least one resident with knowledge of nutrient management, at least one municipal employee, with farmers forming the rest (and always majority) of the committee. The local advisory committee's main function is to mediate conflicts involving nutrient management. These include matters that residences report to the municipalities that do not require the contravention of the Environmental Protection Act, the Ontario Water Resources Act, and the Ontario Safe Drinking Water Act. Matters reported to OMAFRA may also be referred to the local committee. Other matters the local advisory committees are responsible for may include the provision of educational seminars on nutrient management and consultation with representatives of the respective municipality.

There are also provisions made in the Ontario Clean Water Act (2007) that make municipal participation in enforcement and implementation mandatory. Municipalities can enter into agreements with the source protection authority of the area in the establishment of a source protection plan. Municipal governments are also required to configure by-laws and official plans to conform with the policies set out in the source protection plans.

Summary of Current Nutrient Management Policy Regime in Ontario

In the recent decades, the federal, provincial, and municipal governments all have had changes in the level of influence on water quality, and subsequently nutrient management of livestock operations.

Federal policies

At the federal level, water quality policies have shifted from solely protecting resources under the federal jurisdiction to boarder environmental policies that makes provisions to protect environmental quality as a whole. The development of the Canadian Water Quality Guideline have also been important in the development of federal and provincial water quality policy. The same guidelines were used as a standard for both the CEPA and the Ontario Safe Drinking Water Act. The guidelines become standards in determining what constitute as clean water for drinking, recreational use, and for ecosystem protection. These guidelines became standards in determining the efficacy of wastewater, sewage, and drinking water treatment systems. Although the guidelines themselves were not enforceable, later policies used them to determine compliance, and included enforceable penalties based on those guidelines.

Municipal Participation

Municipal participation in environmental regulations have seen major changes in the recent pass, as provincial policies have mostly taken away municipalities' power to control nutrient management of agricultural operations. The Normal Farm Practice Protection Board's mediation process was the first sign of the province's power in changing nutrient management by-laws. The Nutrient Management Act (2002) then eliminated municipalities' power to enact nutrient management by-laws altogether and eliminated past by-laws. Municipal involvement was limited to conflict mediation through the local advisory boards under the Nutrient Management Act (2002). The recently enacted Clean Water Act (2007) has given municipalities power to enact by-laws to regulate nutrient management to protect areas vulnerable to nutrient pollution. However this power is limited in that the decisions for enacting zoning-by-laws for the purpose of water quality protection is no longer the municipalities' alone, but it will likely be a shared decision between the municipal governments and their local conservation authority or other governing body with authority over source water protection.

Provincial Policies

The provincial government, on the other hand, has a comprehensive system of policies protecting water quality. The three pieces of water quality policies each targets different aspects in regulating water quality. The Ontario Water Resources act persecute individuals who pollutes water sources and aims to prevent entries of harmful compounds into surface and groundwater. The Ontario Safe Drinking Water Act ensures that that the water drinking treatment systems are working to standard to mitigate the health risk of drinking water. The Clean Water Act (2007) aims to protect water quality through limiting nutrient application on land considered to be aquifer recharge zones and vulnerable areas. Of the three water quality policies, the Clean Water Act (2007) may affect nutrient management decisions the most, through changes in zoning regulations that may limit farmer's ability to apply nutrients in what the act considers sensitive and vulnerable areas.

The province also has agricultural policies that influence farm practices. The Normal Farm Practice Protection Act is responsible for determining whether a farm is following normal farm practices in a case-by-case basis. In reality, however, none of the cases examined by the Board delved into water quality issues, and cases that involves manure management is mostly due to complaints about odour.

For the agricultural sector, the Nutrient Management Act (2002) is then the main provincial policy in place that regulates nutrient application on farm. The compliance cost of the Nutrient Management Act (2002) may be costly. The Nutrient Management Act (2002) includes a regulation that limits the P application rate to 390kg/ha above crop requirement over a 5-year period. In the near future, the proposed regulations in the Clean Water Act (2007) may also evolve into regulations that limit the application rate of N and P per hectare to below 15% above crop requirement.

Chapter 3 – Literature review on compliance costs for nutrient management regulations

Currently, there is no literature that specifically analyzes the economic impact of the current and proposed nutrient management regime on the Ontario dairy sector. Even though literature contains research on the economic impacts of virtually all types of policy instruments employed in the Ontario nutrient management regulatory regime, a comparison between the results of the studies is difficult due to diversity in the scope of the impact assessed, measurement of economic impact, and environmental indicators used. In this chapter, I will summarize differences in the methods used in analyzing compliance cost for nutrient management regulations observed in the literature. I will then provide a summary of previous work that has been done, in terms of measuring compliance cost of different policy instruments used in the current and proposed regimes (storage requirements, and limited application rate). Lastly, I will provide a review of what is missing in the literature.

Review of Literature on Measuring Economic Impact of Nutrient Management

There are three main variations in the literature that examine the economic impact of environmental regulations: scope of analysis, measurement of economic impact, and the environmental indicator used to assess the regulations' effectiveness in reducing nutrient pollution. The method of analysis is often driven by the scope of the analysis, and by which is taken as the measurement of the economic impact.

The most holistic approach for measuring the economic impact of a environmental regulation has been to look at social welfare, taking the benefit of adopting the environmental regulation minus the cost of regulation. However, consumer benefits derived from environmental amenities/improvement in quality, or cost of environmental disamenities with a degradation for consumers are both difficult to measure. To illustrate, Giraldez and Fox (1995) documented three common approaches found in the literature in measuring the costs of human health risk associated with groundwater contamination. The three measures are: value of a human life as the present value of lifetime average earnings, income differentials among occupations with different levels of mortality risk, and contingent valuation for willingness to pay for a reduction in risk. Giraldez and Fox (1995) found that the values obtained varied widely depending on the method of estimation. The large range of cost obtained through these valuations makes it difficult for cost-benefit analysis, since it is often unclear which measure is the best choice when analyzing policy impact.

Because of the difficulty in measuring costs and benefits of the consumer's side, most research on the economics of environmental regulations focuses on measuring the costs imposed by the regulation on the regulated individuals or industries. Industry level analysis is typically used to measures the impact on productivity, growth or competitiveness. Two methods of estimation exist here: regression and math programming, each with different uses depending on the measure of economic impact.

Regression analysis is used for *in medias res* or *ex post* analysis, measuring economic impact during or after the regulation is in place. For example, Piot-Lepetit and Le Moing (2007) used regression analysis to estimate the effect that nitrate management regulations have on the productivity in the French pig sector in terms of changes in efficiency gains. Valentin *et. al.* (2004) also used regression analysis to measure farm profitability of adopting Beneficial Management Practices (BMPs) for over 900 Kansas farms. Regression is possible at the industry scale because of the large sample size of firms, and can be used to assess how different farm and characteristics are related to compliance costs. However, regression analysis generally focuses on one or a few economic indicators only, it cannot capture changes in farm decision due to regulatory constraints, and does not track pollution emission well. Changes in production decisions can lead to unanticipated changes in farm production activities that regression analysis may not be able to capture (van Ham, 1995; Drucker and Latacz-Lohmann, 2003; Bonham, Bosch, and Pease, 2006). Also, because of data requirements, regression analysis can only analyze effects of current regulations. Effects of future or proposed regulations are difficult to estimate through regression analysis because changes of production decisions cannot be captured in regression analysis.

Math programming models are also used in industry scale analysis of economic impact. In particular, simulation models have been used to study the impact of environmental regulations on trade. Cassells and Meister (2001) analyzed the compliance costs and trade impact of manure management regulations on the New Zealand dairy sector using a Computable General Equilibruim (CGE) model (GTAP). Simulation models are often used to model trade flow in the presence of a policy shock (in this case, manure management). The GTAP model is often used for economic research on international trade.

Literature has also provided research on measuring the economic impact of nutrient management on a local level. The research objective for most research related with this scope of analysis is to determine the economic consequences of protecting a specific watershed (Drucker and Latacz-Lohmann, 2003). In most studies, the environmental compliance costs for each farm in the study area is modeled through an optimization model with a net-return-maximizing assumption. The compliance cost for all farms in the study areas are then aggregated to give a total economic impact of the area. Analysis that examines economic impact on an industry or a local scale gives a good comprehension of economic impact of nutrient management regulations. Compliance cost is calculated as the difference in optimized profit between an unregulated and a regulated scenario.

The advantage of location specific analyses lies in the fact they recognize that differences between farms' environmental characteristics may affect constraints. The inclusion on environmental factors may be required for realistic modeling, since some mandatory management practices (setback distances, buffer strips, slope-based application rate) depend on the environmental characteristics of a farm. However, Bonham, Bosch, and Pease (2006) found that when modeling the compliance cost of manure application limits and buffer strips for the Chesapeake Bay watershed, a spatially explicit model that recognizes the environmental characteristics of each farm did just as well as the multiple representative farm models that did not consider specific environmental characteristics of each farm in the watershed.

A disadvantage of evaluating environmental compliance costs at a local or watershed scale, is that since data and model results are generally aggregated, some important details are missing. Specifically, in the studies I reviewed, little attention is given to how compliance costs are distributed across firms within the area or industry. Analysis of compliance costs in a regional scale is also uninformative for the Ontario dairy industry, since dairy farms are spread out over the province, with several regions with a large number of dairy operations. Aggregate models cannot capture the changes in production practices under different policy scenarios.

Finally, the most popular approach in analyzing economic impact of nutrient management has been at the farm level. Farm level approaches use optimization models to estimate compliance costs with a profit-maximizing objective, and casts environmental regulations as production constraints. Assuming profit maximization also means that when the regulation is applied to the farm model, it provides the production decisions that generate the lowest compliance costs for the regulation in question.

The farm level approach mainly focuses on realistically simulating production processes. This approach is powerful in that simulating regulatory restrictions not only result in compliance costs for the farm unit modeled, but the model also provides a breakdown of the changes in production activities, as well as the respective changes in revenue and costs due to changes in these activities. Because of the large number of biophysical models that define the relationship between nutrient input and output based on biological and physical parameters, the link between production practices and nutrient emission is most readily made at the farm level. Farm level data are also easily available and real life data are easy to obtain, so that calibration and validation of farm models requires less effort than models in higher aggregated level. Representative farm models are flexible in that their parameters, and constraints can be manipulated to not only analyze existing policy shocks, but also can be used to predict the impacts of future policy configurations as well. Taken together, farm level optimization models can analyze the impact of environmental regulations, both in terms of economics (farm level compliance cost) as well as its effectiveness in achieving environmental objectives (nutrient output levels).

Temporal dynamics and stochasticity can be included in the farm level models as well. The element of time may be an important factor to model, simply because of the prevalence of crop rotation in modern agriculture. Crop rotation may also be important in managing nutrient balance in the soil, and can be modeled using a multi-period model over the range of the rotation (Yiridoe and Weersink, 1998). On the other hand, long term economic impacts of nutrient management regulations can be estimated using a dynamic model (i.e. Huang, Shank, and Hewitt, 1996), and compliance cost is taken at the steady state where optimized profit and production activities remain stable over time. Dynamic models may not be the best method for modeling because a stable equilibrium may only be reached after a long time. Since nutrient management regulations have seen drastic changes within the past 5 years, and is set to change again in the near future, dynamic modeling not be suitable in this case as the regulatory regime may change before the model has the required time to reach dynamic stability.

Stochasticity may also be an important element in modeling farmer's risk perception, as well as stochastic weather conditions, both of which affect farmer's production decisions. For example, Rajsic and Weersink (2008) found that risk averse farmers may apply more fertilizers to crop in variable rainfall conditions. Pannell (2006), however, pointed out that modeling risk aversion only changes the optimal production strategy by small amount, with little affect on the optimized income. Therefore, a simpler model assuming risk neutrality may work just as well.

Review of Literature Nutrient Management Regulations

There is no existing literature that has examined the compliance cost of the Ontario nutrient management regulatory regimes on the Ontario dairy industry. However, the literature has provided analysis of similar policy tools in other livestock sectors. In this section I will provide a review of these studies and discuss the implications of different analytical methods as defined by the previous section.

Nutrient Management Planning Application Limits

The Nutrient Management Act (2002) calls for phosphorous application on land to be matched by the amount of phosphorous removed from the soil through crop harvest, effectively keeping the agronomic balance of phosphorous in the soil at zero. However, the literature has focused on N-based application limits. P-based management may impose different costs as compared to nitrogen-based management because phosphorous and nitrogen do not exist in a one to one ration in manure or fertilizer. Thus, limits on application rates based on zero nitrogen balance in soil would be different from limit set on zero phosphorous balance. Phosphorus-based application limits may help limit nitrogen accumulation in soil, since Mullins (2000) suggested that the phosphorus to nitrogen ratio in manure is typically higher than the phosphorus to nitrogen ratio needed by plants. Using a regional mode of Virginia livestock operations allowing for sales and purchases of manure between counties, Feinerman, Bosch and Pease (2004) showed that P-based application standard is able to reduce both nitrogen and phosphorus accumulation in the soil to zero. Whereas, the same model found that a nitrogen based manure application standards only reduced nitrogen accumulation to zero, while actually increasing phosphorus content of the soil in the area by 13% compared to the unregulated case.

Using a structural-dynamic model to estimate the compliance cost of nitrogen-based restrictions for a 2100-animal dairy farm, Baerenklau, Nergis, and Schwabe (2008) estimated a loss of 12-19% in the Net Present Value for the modeled farm. Bonham, Bosch and Pease (2006) found that for using a watershed-scale model of Chesapeake Bay, a phosphorus-based application limit reduced net return for dairy farms over $167/acre, a significantly larger per-acre reduction than the average $85/acre reduction in the watershed. The reason for this large reduction specific to dairy is a result of increased manure export costs coupled with the large amount of manure that dairy farms produce. Feinerman, Bosch and Pease (2004) showed that using a regional mode of Virginia livestock operations allowing for sales and purchases of manure between counties, nitrogen based manure application standards reduced welfare of the livestock sector by 5% whereas phosphorous based manure application standard reduced welfare by 15%.

The literature suggests that limits on phosphorus-based manure application may be higher than average for dairy farmers, compared to other livestock operations. Also, estimates on nutrient compliance costs based on nitrogen-based application limits may be underestimated because phosphorus-based limits allow less nutrients to be applied on land. Because excess nutrients must be exported off the farm, brokerage agreements for manure are likely to be an important factor for farms with larger herd sizes to reduce their compliance cost. I will return to the manure transport discussion in a later section.

Factors Affecting Compliance Costs

Structural Restrictions

A few studies have looked that the cost impact of mandatory manure storage. Using the GTAP simulation model, Cassells and Meister (2001) analyzed the cost of adopting pond storage for manure for the New Zealand dairy sector. They estimated that manure storage only increased production cost by two to three percent. However, because the analysis is conducted at the aggregated industry level, there was no discussion on how farms of different sizes are affected. Baerenklau, Nergis and Schwabe (2008) also reviewed the cost of pond storage at the farm level under a nitrogen-based manure application limit. Although they did not explicitly state the cost of building and maintaining a nutrient storage unit, they stress the important changes in nitrogen loss in manure during storage due to volatilization into ammonia. The reduction in nitrogen content in manure may need to be replaced by fertilizer if the soil nitrogen balance is below optimal, which can increase the cost of production for the farmer.

Nutrient exporting

In the current Ontario regime, exporting excess nutrients off-farm is required when the estimated manure output of the farm is higher than the maximum manure application rates. Baerenklau, Nergis, and Schwabe (2008) have suggested that exporting excess manure off farm is a low cost method for farms to comply with nutrient management regulations, such as limits on application rates. They explored how willingness to accept manure affects the net present value of a manure-generating farm under a binding application limit. Lower willingness to accept manure is represented by higher average hauling distances from the model farm to a willing recipient, thus increasing the cost of transport. Through a dynamic model, they found that net present value loss increased by six and a half percentage points when average hauling distance increased from 1.8km to 8.9km.

Concluding remarks

The current literature contains a myriad of information on measuring the compliance cost for different aspects of the Ontario nutrient management regulatory regime. However, differences in the scale of analysis (in terms of length of time and number of firms modeled) make comparison between results from different studies difficult.

The literature suggests that phosphorus-based application rates are more costly to regulated farms than nitrogen-based limits, because with phosphorus-based application limits, both phosphorus and nitrogen surplus in the soil are eliminated. Mandatory buffer strips, however, can be very costly to farmers and not cost effective when firms are already regulated through a phosphorus-based management system: farmers may change their crop mix to grow more corn instead of alfalfa, increasing the erosivity of the soil. Cost imposed on the farm through mandatory manure storage structure may be low. Nitrogen content of manure volatilizes during storage, which may mean commercial fertilizers will need to make up for the loss depending on how much is lost and the length of storage. The ability for farms to export excess manure to be spread on other locations is an especially important cost-saving approach to reduce the compliance cost of the application limit, especially for dairy farms because of their large manure production. Increasing the cost of manure brokerage may have a notable effect on compliance cost of the nutrient management regime.

The legal aspects of the nutrient management regime are also rarely discussed in the literature. Although the interaction between process-based regulation and legal liability have been well discussed in economic literature, the majority of studies involve using a stochastic optimization program to find the optimal mix of government regulation and legal liability (Shavell, 1984; Innes, 2004). These models focus on a firm's perception on the risk of receiving a negligence suit and losing liability if the level of care is below the level that the judge decides is acceptable. Modeling the threat of liability may not need to be this complicated when it comes to nutrient management, where courts will likely rule on strict liability rather than negligence. Negligence suits require the defendant to carry the burden of proof, and in the case of manure mismanagement it is difficult to prove causation (that the defendant is responsible for nutrient pollution or bacterial contamination found in the water sources). Although there are no legal precedents in dealing with manure mismanagement, the government has determined the level of due diligence that farmers need to follow to avoid strict liability suits. Due diligence is both determined by the Nutrient Management Act (2002) which regulates specific farm practices relating to nutrient management, and by the Normal Farm Practice Protection Board, which determines what constitutes as normal for farm practices not under government regulations. In the case of nutrient management in Ontario, threat of liability is not an important consideration in modeling farm production practices because adherence to nutrient management regulations grants farmers protection from liability.

Chapter 4 – Conceptual Framework

This chapter describes the economic optimization and the biophysical models used in this research. The objective of the economic model is to measure the compliance cost of current and possible future configurations of nutrient management regulations for dairy farms of different herd sizes. The objective of the biophysical model is to track the changes in the nutrients of interest due to the farm operation and regulatory changes. The following section describes the models chosen and the rationale behind these choices.

Model Selection

The economic impact of regulations can be modeled using econometric models or math programming. Math programming is chosen for this research mainly because of the lack of data availability in estimating the compliance cost of current and future nutrient management. Mathematical programming models incorporate details of farm production practices into a system of equations: the manipulation of key parameters stimulates the economic impacts of a regulatory change.

Figure 4.1 is a graphical representation of a simple optimization model of a profit-maximizing farm that can produce two products for sale: milk and a crop. The x-axis denotes the quantity of milk produced and sold, Q^m, and the y-axis denotes the quantity of crop sold, $Q^c{}_s$. The solid line π^0 is an iso-net-return line: it represents all the combinations of Q^m and Q^c that will bring about the same net-return when sold at their respective per-unit prices, P^m and P^c. Note that the iso-net-return line is linear in this two-output model: the slope of the iso-net-return line represents the price ratios of the two goods being sold, and this ratio is constant when the per-unit price for each of the two

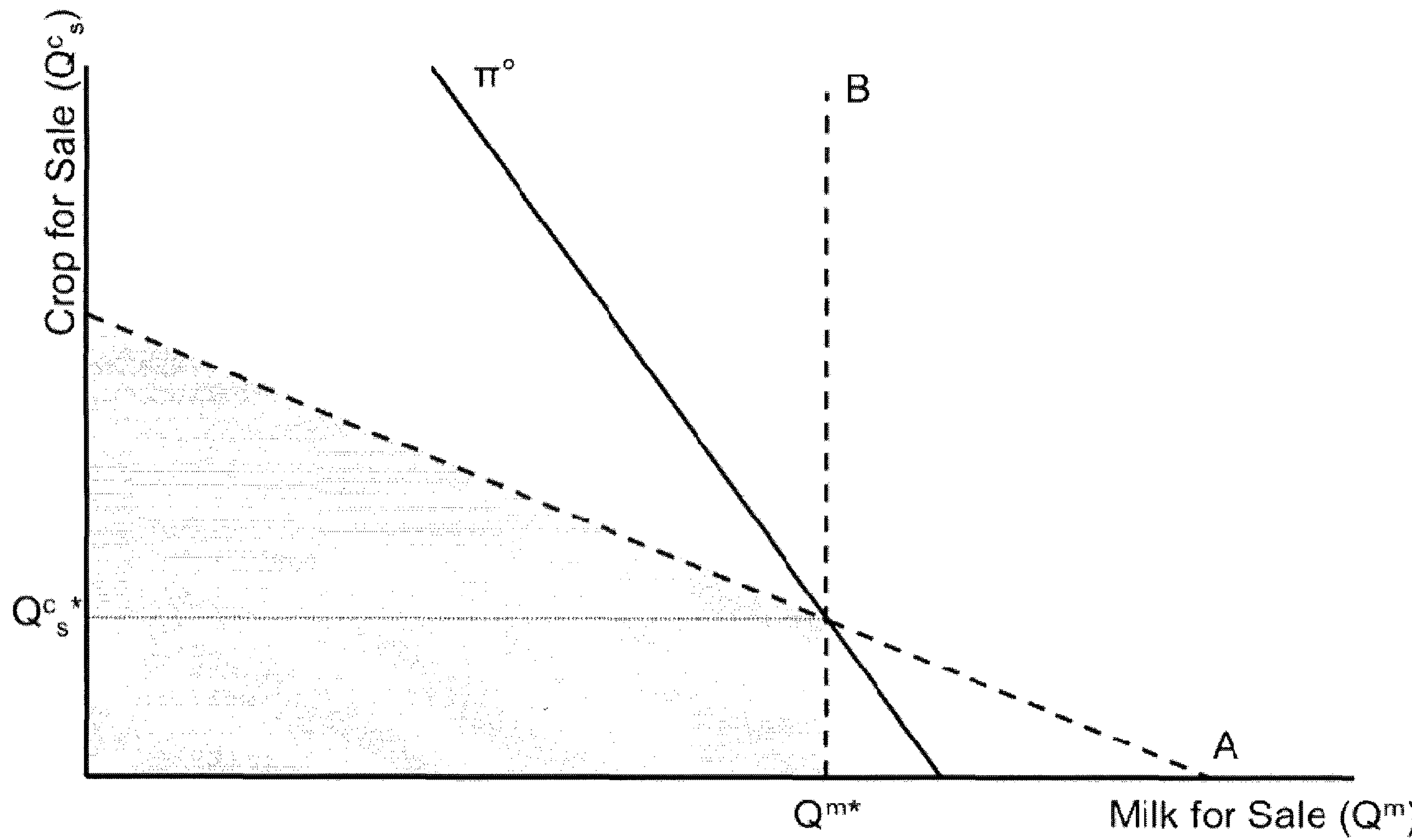

Figure 4.1 – Graphical representation of a farm-net-return optimization model with two products for sale under two production constraints.

outputs in this model is constant. Iso-net-return lines further from the origin represent combinations of Q^m and Q^c that will bring about a higher level of net return.

The objective of the farm is to maximize net return, and thus the objective function can be written as max π. The dashed lines in Figure 4.1 represent constraints the farm faces, limiting the production possibilities of Q^m and Q^c. The dashed line A reflects a constraint on the total available workable land. The dashed line B represents the limited capacity of a barn to accommodate milking cows.

The slope of the dashed line A represents a trade off between crop sales and milk sales: higher milk production requires a larger milking herd, which in turn requires more land to be transferred from sale crop production to feed crop production. Combined, the two constraints outlined the 'feasible region', represented by the grey-shaded area in Figure 4.1. The farm can only produce milk and crop combinations within the feasible area. The outer edge of the feasible area denotes the production possibility frontier.

The maximum net return is obtained at the iso-net-return line furthest from the origin while still within the feasible area. Graphically, this is the iso-net-return line furthest from the origin just touching the production possibility frontier. In Figure 4.1 the maximum net return is obtained at the iso-net-return line π^o by producing Q^{m*} quantity of milk and Q^{c*} quantity of crops. Note that in this example, land base and barn capacity are the only constraints.

Introduction of a nutrient management regulation may change farm net return by changing the profitability of an output and or introducing new constraints. Figure 4.2 illustrates a situation how a new regulation that limits the amount of nutrient applied to crop land may reduce farm net return by reducing the profitability of an output.

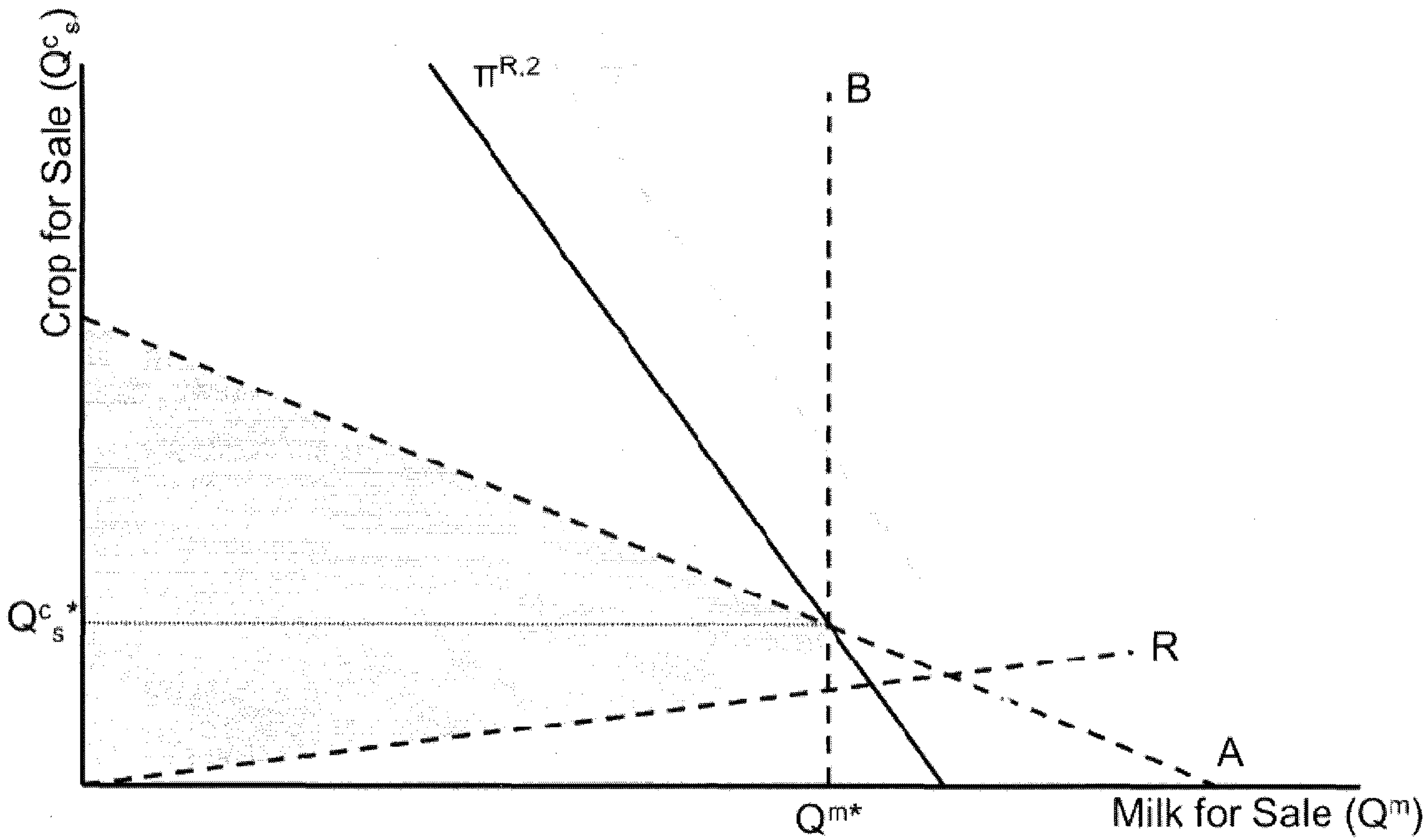

Figure 4.2 – Graphical representation of a farm-net-return optimization with two products for sale under two production constraints and a regulatory constraint limiting nutrient application.

Limiting nutrient application rates raises cost of crop production, reducing the revenue obtained from selling crops. Because crops are also used to feed the milking herd, an increase in the cost of crop production will also increase the cost incurred per milking cow, which reduces the revenue gained from milk sales. In Figure 4.2, this is shown by a shift of the iso-net-return line π^{o} away from the origin, denoting that more crops and milk need to be sold in the regulated scenario in order to obtain π^{o}. Limiting nutrient application will also constrain how many animals the land base can support. Assuming that all of the nutrient requirements of crops are met by manure application alone, a limit on nutrient application may limit the number of animals the farm can support in a given land base. This livestock-to-land constraint is represented by the dashed line R. R, which is upward sloping because as more land are used for crop production, more manure may be applied on land, allowing the farm a larger herd size. In Figure 4.2, the net return level π^{o} in the unregulated scenario is not longer feasible, and the iso-net-return line $\pi^{R,2}$ represents the highest net return level that can be obtained under the regulation. The difference between π^{o} and $\pi^{R,2}$ is one measure of the compliance cost of the maximum application rate regulation.

Note that in the graphical example outlined in Figure 4.2, the levels of output remain at $Q^{m}*$ and $Q^{c}_{s}*$. This occurs because in this example, the livestock-to-land constraint, R, is non-binding and does not limit the number of livestock on the farm. Figure 4.3 illustrates a situation where the farm is regulated under a stricter nutrient application limit. The stricter regulation allows for a smaller herd size on its land constraint, pivoting R upwards to R^{H}, reducing the feasible region. In this case, the regulation is so restrictive that the barn capacity constraint falls outside of the feasible

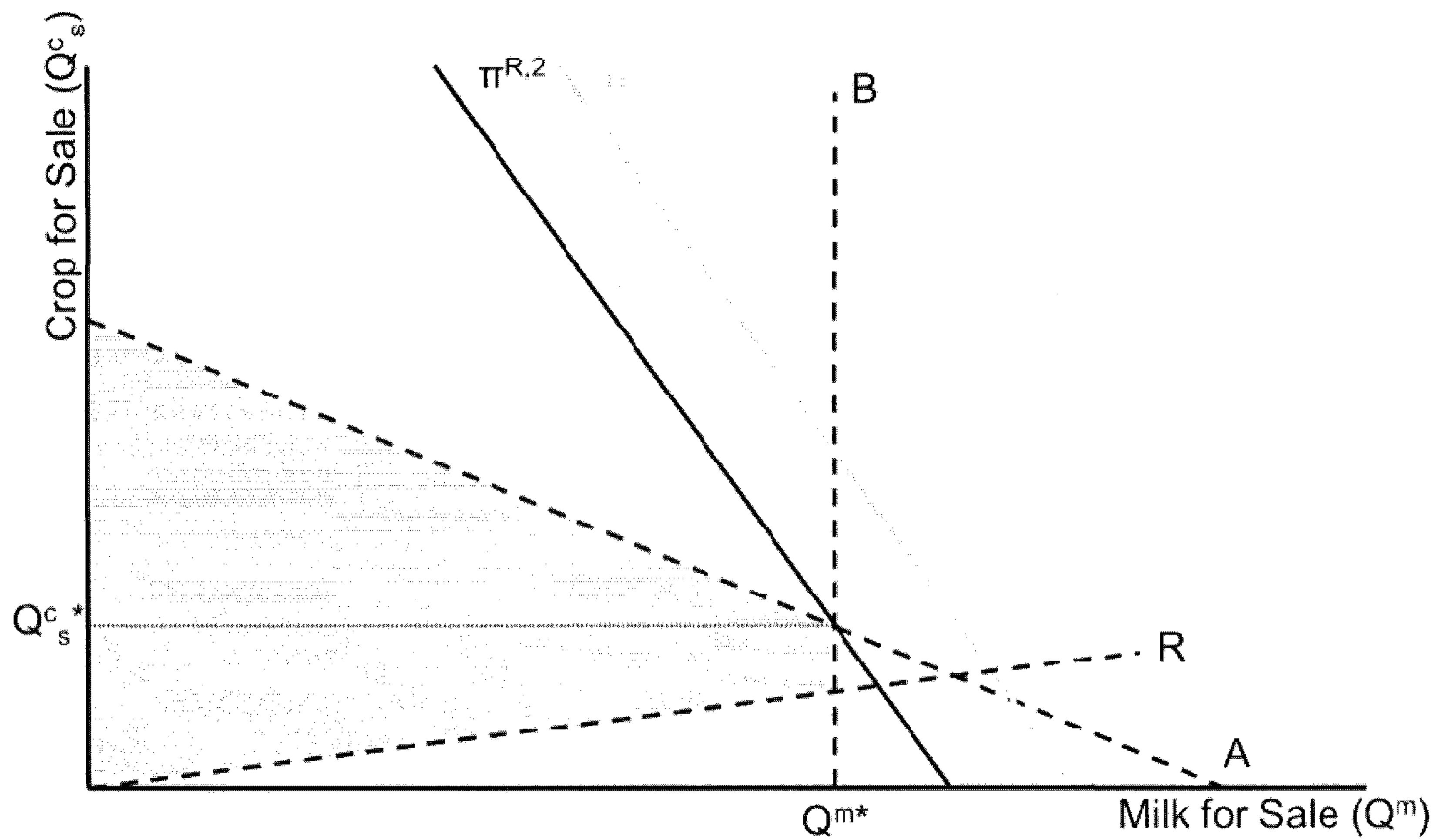

Figure 4.3 – Graphical representation of a farm-net-return optimization with two products for sale under two production constraints and a regulatory constraint limiting nutrient application.

region. In this scenario, the optimal level of crop production increases to Q^c_s', and the level of milk production falls to Q^{m}', producing a lower net return $\pi^{R,3}$.

There are ways for the farm to reduce the compliance cost of the nutrient management regulations, either through renting additional land to apply to manure or exporting manure off the farm to be applied onto other land. Figure 4.4 illustrates the situation where the farm rents additional land while regulated under the strict regulation presented in Figure 4.3. Renting additional land shifts the land constraint A away from the origin to A', expanding the feasible area and increases the optimal net return to $\pi^{r,4}$, increasing milk production from Q^{m}' to Q^{m}'' and increasing crop production from Q^c_s' to Q^c_s''. Figure 4.5 illustrates the situation where the farm exports manure off its farm while regulated under the stricter regulation presented in 4.3. In this case, the exportation of manure means not all manure generated by the herd needs to be applied onto the crop land, pivoting the livestock-to-land constraint R^H downwards to R^L. R^L expands the feasible region and allow the regulated farm to obtain a higher level of net return $\pi^{r,5}$, producing Q^{m}''' amount of milk and Q^c_s''' amount of crop for sale.

Nutrient Budget

The nutrient budgets in this research focus on tracking changes in nitrogen (N) and phosphate (P) contents of soil from agricultural practices. P is tracked because the current regulations limit application of nutrients to land by limiting the amount of phosphate being applied to land. N is tracked because the proposed Clean Water Act (2007) regulates both N and P application. Since manure is a source of both N and P, limiting manure application based of one nutrient may also change the amount of the other nutrient applied.

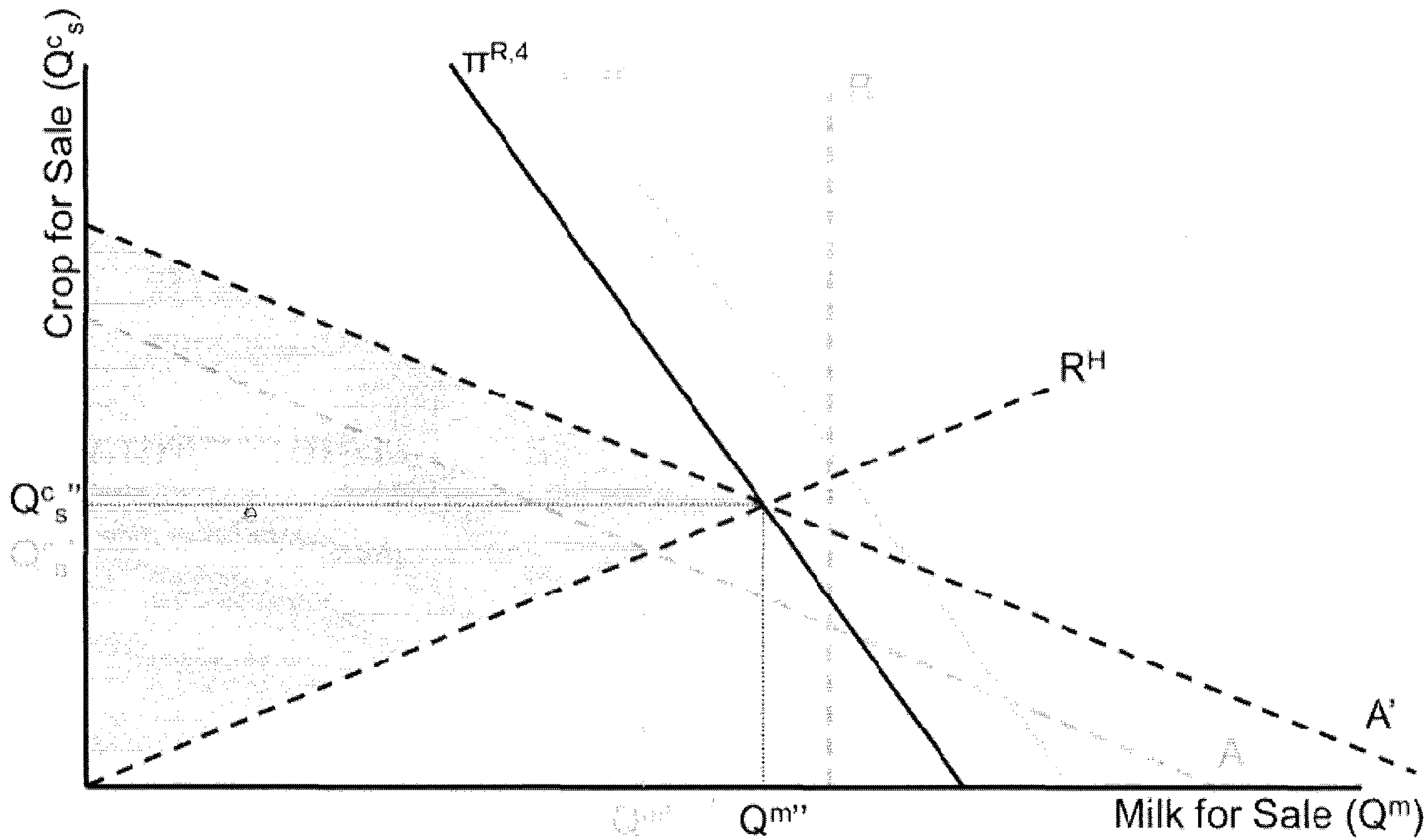

Figure 4.4 – Graphical representation of a farm-net-return optimization with two products for sale under two production constraints and a regulatory constraint limiting nutrient application allowing for land rental.

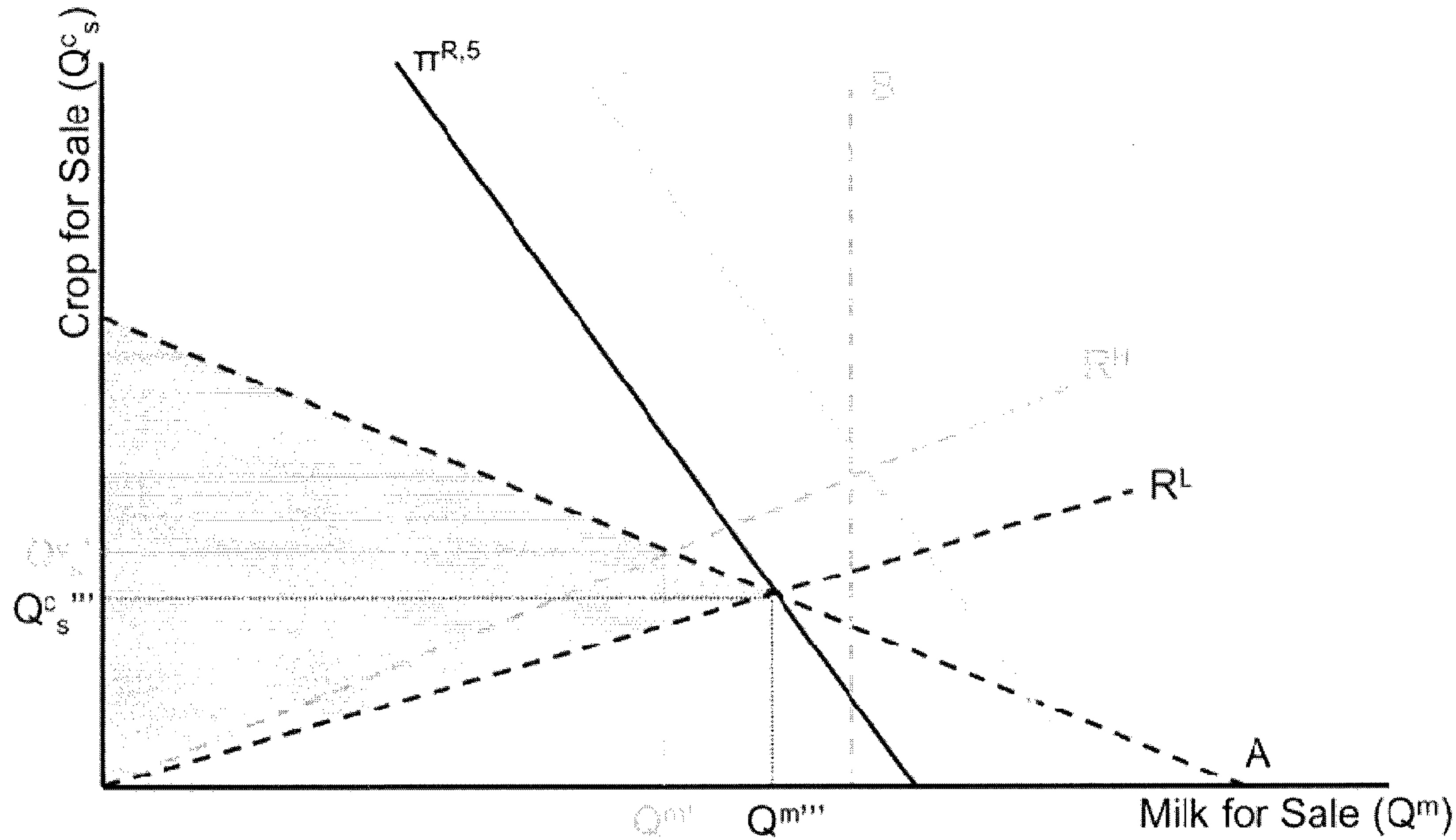

Figure 4.5 – Graphical representation of a farm-net-return optimization with two products for sale under two production constraints and a regulatory constraint limiting nutrient application, allowing for manure export.

In the model, the nutrient budgets track the nutrients going into and out of the soil. This budget is more narrowly focused than the whole-farm N budget used by van-Ham (1996). In van-Ham's model, all N inputs and outputs of farm are accounted for, including N inputs from feed and animal purchase, and N output through volatilization from storage, and crops and animals sold. The nutrient budget tracks two types of nutrient balances: a soil nutrient surplus balance, and a nutrient agronomic balance. The soil surplus balance measures the difference between nutrient input and the amount of nutrients removed through harvest. This nutrient balance is tracked because the Nutrient Management Act (2002) regulations place a limit the soil P surplus. The agronomic nutrient balance is the difference between nutrient input and the amount of nutrients required by crops to produce a specific yield. This nutrient balance is tracked because the proposed Clean Water Act's (2007) regulations place a limit on both the N and P agronomic balances.

Overview of the Conceptual Model

The optimization model of used for this research is a more complex version of the optimization program exemplified in Figures 4.1 to 4.5. In the previous graphical examples, the two inputs explicit in the figures were workable land and labour, which translates to milk and crop outputs. In the detailed model outlined in the following section, more inputs and outputs are included for a more realistic model. Production activities and the linkages between inputs and outputs are also made explicit.

The conceptual model will include two types of budgets: a monetary budget that tracks the revenue and costs of the farm based on different levels and methods of production, and soil nutrient budgets tracking the movement of P and N into and out of the soil. There are 2 soil nutrient budgets for P and N: a soil nutrient surplus and a nutrient agronomic balance. The soil nutrient surplus is the difference between nutrient inputs into the soil and the nutrients removed from the soil through crop harvest. The agronomic nutrient balance is the difference between nutrient inputs into the soil and the nutrients required by crops for production. The two soil nutrient budgets are included in this model because the two regulations modeled in the study each act on different soil nutrient budgets. The Nutrient Management Act (2002) regulations limit P application based on crop P removal and affect the soil P surplus budget; the proposed Clean Water Act (2007) regulations limit N and P application based on crop nutrient requirement and affect the N and P agronomic balances. The two soil nutrient budgets are different because nutrient removal is different than nutrient requirement. Nutrient removal is dependent on the per-hectare yield and independent on soil characteristics, therefore, increases in per-hectare yield will increase the amount of N and P removed from the soil, while amount of nutrients removed will be the same regardless of soil type and the amount of nutrients already present in soil. On the other hand, nutrient requirement is dependent on soil characteristics and independent of per-hectare yield. For example, crops grown on soil with high P content will have lower P requirement compared to crops grown on land with low soil P, because more P is available to the crops in the soil and requires less P from external sources. Another difference between the two soil nutrient balances is that the nutrient agronomic balance must be positive, while the soil nutrient surplus can be positive or negative. This occurs because nutrient input must be greater than nutrient requirements for each crop, and crops can remove more nutrients from the soil than the amount inputted if most of the nutrient requirements are met mainly though the nutrients already in the soil.

The model is separated into two sets of enterprises: crop enterprises modeling crop production, and livestock enterprises modeling milk production and herd management. In each of the enterprises, levels of inputs and outputs are tracked; and each enterprise has its specific production constraints.

In the crop enterprise, the inputs modeled are land, labour, N, P and potassium (K) fertilizers, as well as manure produced from the livestock enterprise. Note that soil K budget is not tracked in the model because it is not currently regulated. The output of the crop enterprise consists of six crops: Corn, silage corn, alfalfa hay, alfalfa haylage, soybeans, and wheat. All silage corn and alfalfa haylage are used as feed, and all soybeans and wheat are sold at market price. Note that corn and alfalfa haylage can be used as feed or sold to market. These crops are chosen for the model because they are the crops typically grown on Ontario dairy farms either for feed or to incorporate into their crop rotation. The model assumes the following crop rotation pattern:

corn → corn → corn → alfalfa → alfalfa → alfalfa → soybeans → wheat

where each hectare of land produces 3 years of corn or silage corn, 3 years or alfalfa hay or alfalfa haylage, following 1 year of soybeans and 1 year of wheat. This crop rotation simulates the typical crop rotation of a southern Ontario dairy farm. The production constraint for crop production in this model is a workable land constraint. Note that crop rotation requirement is worked into a workable land constraint by limiting the amount of land that each crop can use as a share of the total workable land.

In the livestock enterprise, the inputs modeled are: the crops grown in the crop enterprise used as cattle feed, additional feed purchased from off-farm sources, as well as labour. The output of the livestock enterprise is milk production, as well as manure. The manure produced is either used as nutrient input for crop enterprise as a source of N, P and K, or exported off farm at a cost. Production capacity in the livestock enterprise of the model is barn capacity and labour endowment.

The input and output levels of the two enterprises affect farm net return, as well as the amount of N, P, K required from the crops. The monetary budget tracks the changes in farm net return based on different levels of inputs purchased and outputs sold (with the exception of exported manure as an output, which incurs a cost rather than generates revenue). Note that the term net return is used instead of profit because the model is not able to track all the costs and revenues of a dairy farm, and net return is only a portion of a farm's total profit. Since the goal of obtaining the maximum profit is to compare the differences in net return generated under different policy scenarios, the monetary budget does not track the changes in the sources of revenues and costs that are not assumed to be affected by nutrient management regulations. For example, although sales and purchases of livestock are considered a large source of revenue and costs for a dairy farm, these activities are not included in the model because they are not expected to be changed by nutrient management regulations.

In terms of the soil N and P budgets, the inputs include fertilizer and manure that have been applied on land. The amount of nitrogen depends on the timing of the application, which can be spring, early-summer, fall, or winter. N, P, and K inputs must be greater than the amount of N,P, and K the crops need in order to produce crops, and crop harvest is the only source of removal from the soil phosphorus and nitrogen budget. Soil N surplus and soil P surplus is the sum of all the N and P input minus the N and P removed through harvest. N and P agronomic balance is the sum of all the N and P inputs minus all the N and P required by crops for production.

Note that the model did not include the sales and purchases of animals on farm, because it is assumed that the movement of animals into and out of the farms does not affect soil nutrient balances, only the number of animals on farm do. Along with this assumption is one that assumes that herd size does not change over the year.

The Farm Programming model

The optimization problem of the farm is laid out in three sections: the objective function, the constraints, and the soil nutrient budgets. The following is a formal description of each of these components laid out in Table A.1.

Objective Function

The objective of the farm operation is to maximize the net return of the dairy farm operations. The objective function is separated into two components: revenue generated from the farm operation, and cost associated with the farm operation. Net return in the objective function is sum of all revenues minus sum of all costs of the model.

Revenue

The revenue component of the objective function is summarized in the following equation:

$$\max\left(\sum_{c=1}^{6}(P_c Q_c^s) + P^{mn} Q^m\right) \tag{4.1a}$$

where…

c is the index denoting each of the six crops grown on farm: corn (c=1), corn silage (c=2), alfalfa hay (c=3), alfalfa silage (c=4), soybeans (c=5), and wheat (c=6),

a is the index denoting the two cohorts of livestock on the farm: milking age cow (c=1), replacement heifers (c=2). Replacement heifers are defined as cows that have not yet calved,

p_c is the per-metric-ton price of crop c

Q_c^s is the quantity (in metric tons of dry matter) of crop c sold

P^{mn} is the net price per hectoliter (HL) of milk

Q^m is the total quality of milk (measured in HL) produced on farm and sold

Revenue From Crop Sale

Not all crops produced on farm are sold, therefore , Q_c^s is only a fraction of the total quantity of crops produced on farm, described in the following equation.

$$Q_c = Q_c^s + Q_c^f \in c = \{1,3\} \tag{4.2}$$

$$Q_c = Q_c^f \in c = \{2,4\} \tag{4.3}$$

$$Q_c = Q_c^s \in c = \{5,6\} \tag{4.4}$$

where…

Q_c is the total quantity (in metric tons) of crop c produced on farm

Q_c^f is the quantity (in metric tons) of crop c used as cattle feed

Note that in the model, corn and alfalfa hay can be used as feed or sold. All corn silage and alfalfa haylage must be used as feed, and all soybleans and wheat must be sold.

Q_c is determined by the following equation:

$$Q_c = A_c + Y_c(n_c, p_c, k_c) \tag{4.5}$$

where…

A_c is the workable hectares of land devoted to producing crop c

Y_c is the metric-ton per hectare yield function of crop c

n_c is the per-hectare application rate of N in kilograms per hectare

p_c is the per-hectare application rate of P in kilograms per hectare

k_c is the per-hectare application rate of K in kilograms per hectare

Conceptually, Y_c is a production function with N, P, and K as variable inputs. In plant agriculture, there have been a number of functional forms proposed to estimate the effect of multiple variable inputs on crop yield. Most of these functions are based on the von Liebig's (1855) hypothesis that suggests plant growth is limited by one resource at any one time, and an increase in the limiting resource will promote plant growth until another resource becomes limiting. This is known as the law of minimum. Rubio *et al.* (2003) state that Mitscherlich expanded on von Liebig's hypothesis by introducing the law of diminishing yield increments, which states that yield response curves for a particular resource have an asymptotic limit. Both von Liebig and Mitscherlich emphasize the yield plateau reached when a resource becomes limiting. In the literature, however, yield response functions with all three nutrients as variable inputs were not found for any of the crops, but a few functional forms with N and P as variable inputs have been proposed.

Llewelyn and Featherstone (1997) commented that in agricultural economics, yield functional forms have traditionally been simplified to polynomial functional form, such as the quadratic or square root form. This is true for research in farm-level cost analysis of nutrient management (see van Ham, 1995), where the focus is usually placed on one nutrient only and the yield function used is single variable polynomials. Achello-Ogutu *et al.* (1985) argue that polynomial functions do not allow for plateau growth and often overestimate optimal fertilizer quantity.

In terms of yield functions involving two variable inputs, two functional forms have been adopted in previous agronomic literature: the von-Liebig Function and the Mitscherlich-Baule Function. The von-Liebig function assumes a zero elasticity of substitution between the two inputs, giving right-angled isoquants similar to a Leontief production function. The Mitscherlich-Baule functional form also produces L-shaped isoquants. Figure 4.6 illustrates the production isoquants of a Mitscherlich-Baule function fitted to Iowa Corn yield data by Heady and Pesek (1955). This dataset has been used in other literature assessing the goodness of fit of many other production functions. Note that the elasticity of substitution is related to the ratio of the two inputs. The elasticity of substitution approaches zero as the ratio of the two inputs approach infinity, the effects of which are vertical and horizontal sections of the production isoquant when the ratio of the two goods approach infinity. The elasticity of substitution approaches one as the ratio of the two inputs approaches one, the effect of which are a smooth convex isoquant when the ratio of the two inputs approach one.

The Mitscherlich-Baule is expressed in the following equation:

$$Y_c = Y_c^{\max} \cdot \left(1 - \exp[-\beta_c^n (n^s + n_c)]\right) \cdot \left(1 - \exp[-\beta_c^p (p^s + p_c)]\right) \tag{4.6}$$

where…

$Y_c^{\max}$	is the maximum yield obtained per hectare when both nitrate and phosphate inputs are in excess
β_c^n	is an estimated parameter that relates N input to crop yield
n^s	is the N content in soil in kg per hectare
β_c^p	is an estimated parameter that relates N input to crop yield
p^s	is the P content in soil in kg per hectare

Revenue From Milk Sales

Annual milk production is assumed to be uniform for all milking cows, and is summarized by the equation:

$$Q^m = mQ_a \in a = 1 \tag{4.7}$$

where…

a	is the index denoting the two cohorts of livestock on the farm: milking age cow (c=1), replacement heifers (c=2). Replacement heifers are defined as cows that have not yet calved,
m	is the annual milk production per milking cow, and
Q_a	is the number of animals in cohort a

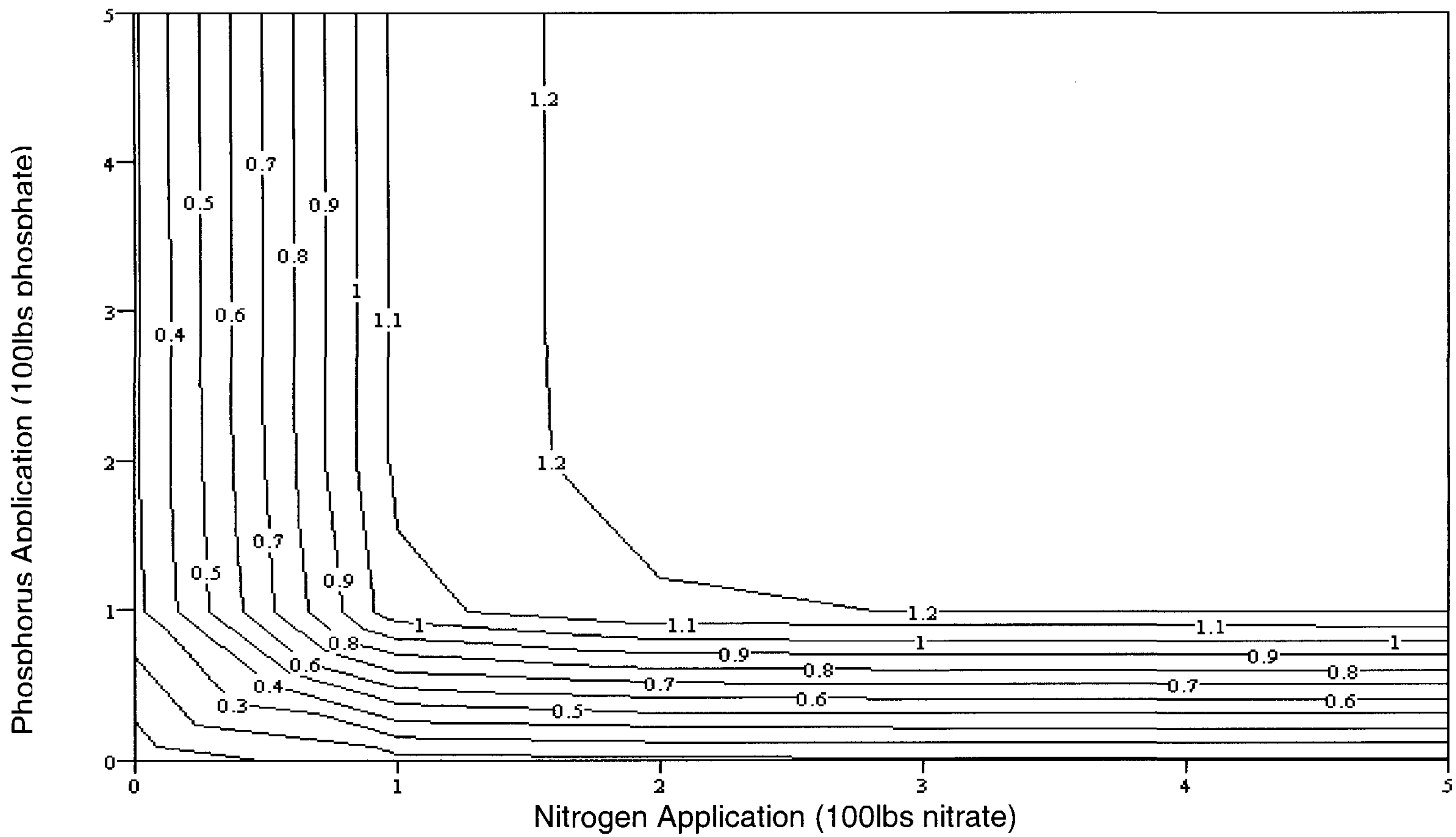

Figure 4.6 – Production isoquants of a Mitscherlich-Baule yield function fitted to Iowa Corn data provided by Heady and Pesek (1955), with a maximum yield at 1.2 hundred bushels.

Note that the price of milk P^m in equation (4.1) incorporates three important revenue and cost components related to quantity of milk produced. P^m is defined by the following equation:

$$P^{mn} = P^m - \left(\frac{iP^q}{365}\right) - C^m \tag{4.8}$$

where,

P^m	is the per hectoliter market price of milk that a producer would receive given a fixed proportion of butter fat, proteins, and other solids
i	is the estimated rental value of butter fat quota
P^q	is the current price of one daily butterfat quota, converted to a per-hectoliter price
C^m	is the cost associated with quantity of milk produced, such as transportation and marketing costs

Note that the quota cost is divided by 365 because each quota allows for 1 kg of butterfat to be produced per day, therefore allowing for 365kg of butterfat to be produced per year.

Cost

The cost of the dairy farm operation is divided into seven categories: cost of crop establishment, cost of fertilizer purchase, cost of manure application, cost of animal maintenance, cost of feed purchase, and labour costs.

Cost of crop establishment

Cost of crop establishment crops is summarized in the following equation:

$$\sum_{c=1}^{6} C_c A_c \tag{4.1b}$$

where...

C_c	is the crop establishment cost that are unrelated to yield

Note that this cost may include the cost of herbicides and pesticides.

Cost of commercial fertilizer purchase

The cost of purchasing commercial N, P and K fertilizers is summarized in the following equation:

$$\sum_{c=1}^{6} A_c (P^n n_c^f + P^p p_c^f + P^k k_c^f) \tag{4.1c}$$

where…

P^n is the per-kg price of N fertilizer plus the cost of application
n_c^f is the N fertilizer application rate on crop c in kg/ha
P^p is the per-kg price of P fertilizer plus the cost of application
p_c^f is the P fertilizer application rate on crop c in kg/ha
P^k is the per-kg price of K fertilizer plus the cost of application
k_c^f is the K fertilizer application rate on crop c in kg/ha

Cost of manure application

$$\sum_{c=1}^{6} A_c (C^s M_c^{sa} + C^l M_c^{la}) \tag{4.1d}$$

where…

M_a^l is the metric tons of liquid manure generated by one animal in cohort *a* in one year.
C^{sm} is the cost of applying one metric ton of solid manure
M_c^{sa} is the solid manure application rate on crop c in kg/ha
C^{lm} is the cost of applying one metric ton of liquid manure
M_c^{la} is the liquid manure application rate on crop c in kg/ha

Cost of animal maintenance

The cost of animal maintenance is summarized in the following equation:

$$\sum_{a=1}^{2} (C_a Q_a) \tag{4.1e}$$

where…

M_a^l is the metric tons of liquid manure generated by one animal in cohort *a* in one year.
C_a is the cost of raising and maintaining 1 animal in cohort *a*, and
Q_a is the number of animals in cohort *a*.

Note that the model assumes that there is for every milking age cow the farm also raises one heifer.

In the model, C_a includes veterinarian bills, medical costs, and licensing fees. The reason that heifers are included in the model but tracked separately from milking dairy cows is that heifers have different feed requirements and produce a different amount of manure with different nutrient values than manure from milking age cattle. Male calves are not tracked in this model, because the model assumes that male calves are sold soon after birth. On an annual basis, the short-term holdings of male calves have a negligent effect on increased feed requirement and increased manure production.

Cost of additional feed purchase

The cost of feed purchasing for the milking cow and heifer rations is summarized in the following equation:

$$\sum_{c=1}^{1} P_1^{fd} Q_1^{fd} + \sum_{c=3}^{3} P_3^{fd} Q_3^{fd} + \sum_{a=1}^{2} (P_a^{sp} Q_a^{sp}) \tag{4.1f}$$

where…

P_c^{fd}	is the cost per metric ton of purchasing additional feed crop c,
Q_c^{fd}	is the amount of feed crop f purchased in metric tons
P_a^{sp}	is the cost per metric ton of purchasing feed supplements for cohort a
Q_a^{sp}	is the amount of feed supplements purchased for cohort a in metric tons

Note that only corn and alfalfa hay can be purchased.

Cost of exporting manure

The cost of exporting manure off farm is summarized in the following equation:

$$C^{sx} M^{sx} + C^{lx} M^{lx} \tag{4.1g}$$

where...

C^{sx}	is the cost of exporting 1 metric ton of solid manure off farm
M^{sx}	is the amount of solid manure being exported off farm
C^{lx}	is the cost of exporting 1 metric ton of liquid manure off farm
M^{lx}	is the amount of liquid manure being exported off farm

M^{sx} and M^{lx} are portions of all solid and liquid manure generated by the herd. In this model, it is assumed that all heifers generate solid manure, while milking age cows may generate solid or liquid manure, depending on the type of barn they are housed in. Manure that is not exported off farm is applied on land as nutrient source. For solid manure, this is described in the following equation:

$$\sum_{c=1}^{6}(A_c M_c^{sa}) + M^{sx} = \sum_{a=1}^{2} Q_a M_a^s \tag{4.9}$$

where...

M_a^s is the metric tons of solid manure generated by one animal in cohort a in one year.

For liquid manure, this is described in the following equation:

$$\sum_{c=1}^{6}(A_c M_c^{la}) + M^{lx} = \sum_{a=1}^{2} Q_a M_a^l \tag{4.10}$$

where...

M_a^l is the metric tons of liquid manure generated by one animal in cohort a in one year.

Cost of Land Rental

The cost of land rental is described in the following equation:

$$C^r A^r \tag{4.1h}$$

where...

C^r	is the rental price of one hectare of land, and
A^r	is the hectare of land rented at C^r

Labour cost

Labour cost is summarized in the following equation:

$$wL \tag{4.1i}$$

where...

w	is the hourly wage rate, and
L	is the number of labour hours required for farm operation in one year.

L is further defined as:

$$L = \sum_{c=1}^{6} A_c \alpha_c + \sum_{a=1}^{2} \gamma_a Q_a \tag{4.11}$$

where...

α_c	is the number of hours required to tend to one hectare of cropland
γ_a	is the number of labour hours required to tend to one animal in cohort a each period

Constraints

Land Constraint

In this model, the farm operation has a limited amount of workable land to devote to growing crops. To simulate crop rotation, corn crops, alfalfa crops, soybeans and wheat are constrained separately, so that the model forces all crops to be grown on farm. These constraints are shown in the following set of equations:

$$\sum_{c=1}^{2} A_c \le \frac{T_{corn}}{\overline{T}} A^T \tag{4.12a}$$

$$\sum_{c=3}^{4} A_c \le \frac{T_{alfalfa}}{\overline{T}} A^T \tag{4.12b}$$

$$A_c \le \frac{T_{soy}}{\overline{T}} A^T \in c = 5 \tag{4.12c}$$

$$A_c \le \frac{T_{wheat}}{\overline{T}} A^T \in c = 6 \tag{4.12d}$$

where...

T_{corn}	is the number of years corn crops are grown on a hectare of land for one crop rotation cycle
$\overline{T}$	is total number of years of one crop rotation cycle
A_T	is the total hectares of workable land
$T_{alfalfa}$	is the number of years alfalfa crops are grown on a hectare of land for one crop rotation cycle

T_{soy} is the number of years soybeans are grown on a hectare of land for one crop rotation cycle

T_{wheat} is the number of years wheat is grown on a hectare of land for one crop rotation cycle

Note that A_T is the farm's total workable land, and can be expanded through land rental. This is described in the following equation:

$$A^T = \overline{A} + A^r \tag{4.13}$$

where…

$\overline{A}$ is land base that the farm owns.

There is a limit on how much the land the farm can rent, which cannot exceed 10% of the original land base. This is described in the following equation:

$$A^r \leq 0.1 \cdot \overline{A} \tag{4.14}$$

Barn Capacity

In this model, the number of animals held on the farm is constrained by the capacity of the farm. This is summarized by the following equation:

$$Q_a \leq B \in \ a = 1 \tag{4.15}$$

where…

B is the maximum number of milking dairy cows the barn can accommodate.

Crop Nutrient Requirement

In the model, nutrient application must be greater than the amount of nutrients that each crop requires to produce a specific yield. For N, P and K, this minimum constraint is summarized in the following equation:

$$n_c \geq n_c^r \tag{4.16a}$$
$$p_c \geq p_c^r \tag{4.16b}$$
$$k_c \geq k_c^r \tag{4.16c}$$

where…

n_c^r is the kg/ha of N crop c requires to yield a specific yield

p_c^r is the kg/ha of P crop c requires to yield a specific yield
k_c^r is the kg/ha of K crop c requires to yield a specific yield

n_c^{app} is further defined by the following equation:

$$n_c = (\theta^s M_c^{sa} + \theta^l M_c^{la} + n_c^f + n_c^{cred}) + (\varsigma_c + \eta + \mu) \tag{4.17a}$$

where…

θ^s is the kg of N per metric ton of solid manure
θ^l is the kg of N per metric ton of liquid manure
n_c^f is the kg of N of fertilizer applied to crop c
n_c^{cred} is the kg of N left for crop c from the crop residue of previous year's crop
ς_c is the symbiotic N fixation in kilograms of N for crop c
η is the non-symbiotic N fixation in kilograms of N per hectare
μ is the atmospheric deposition in kilograms of N per hectare

Note that ς_c is zero for corn crops and wheat; they are not legume crops and cannot fix their own N.

p_c is further defined by the following equation:

$$p_c = \varphi^s M_c^{sa} + \varphi^l M_c^{la} + p_c^f \tag{4.17b}$$

where…

φ^s is the kg of P in one metric-ton of solid manure
φ^l is the kg of P in one metric-ton of liquid manure.

k_c is further defined by the following equation:

$$k_c = \phi^s M_c^{sa} + \phi^l M_c^{la} + k_c^f \tag{4.17b}$$

where…

ϕ^s is the kg of K in one metric-ton of solid manure, and
ϕ^l is the kg of K in one metric-ton of liquid manure.

Minimum Feed Constraint

The amount of feed required by animals in each cohort is supplied by either crops produced on farm that were not sold, and (for corn and alfalfa hay) by additional feed purchased. For corn and alfalfa hay, the feed requirement is described by the following equation:

$$Q_c^f + Q_c^{fd} \geq \sum_{a=1}^{2} Q_a R_{a,c} \in c = \{1,3\} \tag{4.18a}$$

where..

$R_{a,c}$ is the metric ton of crop c an animal in cohort a requires as feed in a year.

For corn silage and alfalfa haylage for which additional feed cannot be purchased, feed requirement is described by the following equation:

$$Q_c^f \geq \sum_{a=1}^{2} Q_a R_{a,c} \in c = \{2,4\} \tag{4.18b}$$

For supplements that can only be purchased off farm, feed requirement is described by the following equation:

$$Q_a^{sp} \geq \sum_{a=1}^{2} Q_a R_a^{sp} \tag{4.18c}$$

where...

R_a^{sp} is the metric ton of supplement an animal in cohort a requires as feed in a year

Nutrient Budgets

There are two types of nutrient balances in this model for N and P: a soil nutrient surplus and a nutrient agronomic balance.

Soil nutrient surplus

Soil nutrient surplus is the difference between nutrient input and the nutrient removed by crop through harvest. Soil nutrient surplus are tracked over the whole farm. For N, the soil N surplus is summarized in the following equation:

$$Spls^N = \sum_{c=1}^{6} A_c (n_c - n_c^{rmvl}) \tag{4.19a}$$

where...

$Spls^N$ is the total amount of soil N surplus of the farm in kg, and
n_c^{rmvl} is the kg of N removed by crop c through harvest per hectare.

Soil P surplus is calculated in the same way, summarized in the following equation:

$$Spls^P = \sum_{c=1}^{6} A_c(p_c - p_c^{rmvl}) \tag{4.19b}$$

where...

$Spls^P$ is the total amount of soil P surplus of the farm in kg, and
p_c^{rmvl} is the kg of P removed by crop c through harvest per hectare.

Nutrient agronomic balance

Nutrient agronomic balance is the difference between nutrient input and the nutrient requirement. Unlike the soil nutrient surplus, nutrient agronomic balances are done on a per-crop basis. The N agronomic balance is summarized in the following equation:

$$Agro_c^N = n_c - n_c^r \tag{4.20a}$$

where...

$Agro_c^N$ is the N agronomic balance in kg/ha for crop c

P agronomic balance is calculated in the same way, summarized in the following equation:

$$Agro_c^P = p_c - p_c^r \tag{4.20b}$$

where...

$Agro_c^P$ is the P agronomic balance in kg/ha for crop c.

An average agronomic balance for the farm can be obtained by averaging the agronomic balances for all crops over the land used for crop production:

$$\overline{Agro}^N = \frac{\sum_{c=1}^{6}(A_c Agro_c^N)}{\sum_{c=1}^{6} A_c} \tag{4.21a}$$

$$\overline{Agro}^P = \frac{\sum_{c=1}^{6}(A_c Agro_c^P)}{\sum_{c=1}^{6} A_c} \tag{4.21b}$$

where…

$\overline{Agro}^N$ is the average N agronomic balance in kg/ha over the entire farm, and
$\overline{Agro}^P$ is the average P agronomic balance in kg/ha over the entire farm.

Regulatory Constraints

Nutrient Management Act (2002) Regulations

The Nutrient Management Act (2002) stipulates that for any regulated farm, the amount of P applied on each hectare of land over a 5-year period cannot exceed 390kg/ha above the amount of P removed from the soil through crop harvest. Since the model used in this study is a static one-year model, the application limit of 390kg/ha is averaged annually to obtain an average annual application limit of 78kg/ha/yr of P above the amount removed by crop harvest. This effectively limits the farm's soil P surplus to no larger that 78kg/ha/yr. This is described in the following equation:

$$Spls^P \cdot \sum_{c=1}^{6} A_c \leq 78 \cdot \sum_{c=1}^{6} A_c \tag{4.22}$$

Clean Water Act (2007) Regulations

The proposed regulations in the Clean Water Act (2007) stipulates that for any farm situated on a groundwater protection zone or a surface water intake protection zone, the amount of N and P applied on each hectare of land should not exceed 15% above the N and P crop requirement. This effectively limits the size of the N and P agronomic balance for each crop. The application limit applies to each hectare of land individually and is not aggregated over the whole farm. As such, each of the 6 types of cropland are restricted by the following set of regulations under the Clean Water Act (2007):

$$Agro_c^N \leq 0.15 \cdot n_c^r \tag{4.23a}$$
$$Agro_c^P \leq 0.15 \cdot p_c^r \tag{4.23b}$$

Chapter 5 – Empirical Framework

This chapter describes the process of calibrating the empirical model for measuring the cost of complying with the current and possible future configurations of nutrient management regulations on Ontario Dairy Farmers. This includes explaining the sources of data, as well as manipulating the data into parameters used to calibrate the model. Three models are built to represent three size categories of Ontario dairy farms. A small farm model is built assuming that the milking herd is housed in a tie-stall barn. For the medium and large farm model, it is assumed that the milking herd is housed in a free-stall barn. All three models assume that all of the animals on farm are of the Holstein breed.

Calibration of model

Sources of Data

There are five main sources of data used for calibrating the empirical model: the Ontario Ministry, Agriculture, Food and Rural Affairs (OMAFRA), Floradale Feed Mill Limited, the Dairy Farmers of Ontario (DFO), and interviews with dairy farmers.

Data from OMAFRA were obtained through online publications, the NMAN2 (OMAFRA, undated) software, the NMAN (OMAFRA, 2003) workbook, a nutrient management regulations and protocols course (2008), and key informant interviews. The data from OMAFRA are used to calibrate parameters for activities and constraints relating to crop and milk production, the nutrient budgets, the costs of livestock maintenance, as well as parameters used for modeling the nutrient management regulations. Specifically, the NMAN2 software (OMAFRA, undated) is used by farmers to produce a nutrient management plan. The software includes data on expected yields on a per-county basis, estimated nutrient requirements and nutrient removal of crops, as well as manure nutrient content. The NMAN workbook (2003) provided guidance on some background calculations required for the soil nutrient budgets used in the farm level models. Floradale Feed Mill provided data for calibrating livestock feed requirements. DFO provided data for calibrating the activities and constraints relating to livestock feeding and milk production through the Ontario Dairy Farm Accounting Project (ODFAP) 2007 Report. The report also contained data used to calculate the costs of production for 85 dairy farms in 2005, which were used for model validation. The DFO also provided the ODFAP raw data for 1990 to 2006 to calibrate the average herd size and barn capacity of the small, medium, and large farm model. Lastly, interviews were conducted at two dairy farms in Southern Ontario. The interviews provided data for labour requirements for crop production, milk production, crop rotation requirements, as well as additional information on livestock feed requirements.

In the empirical model, all data are specific to Ontario production estimates between 2006 and 2009. Whenever possible, county-specific data are calibrated to estimates from Oxford County. Oxford County is chosen because it has the highest number of dairy farms on a per-county basis.

The following next section will describe how the model parameters are calibrated, in the order in which they appeared in the conceptual framework in Chapter 4.

Calibrating the Objective Function

Crop Sales Prices

In the empirical model, there are four crops that the model dairy farms can sell for revenue: corn, alfalfa hay, soybeans, and wheat. The prices at which these corps are sold is obtained through the OMAFRA cost of production budgets for corn, alfalfa, soybeans and wheat (2009). Note that all prices are converted to the $/metric ton of dry matter. Table 5.1 shows the prices used in the model. Note that for grain corn, the sale price is lower than reported by the enterprise budget, because the cost of drying ($18.90/ metric ton) is deducted from the price in the empirical model. Also, price for winter wheat in this table is for the soft red variety, and only the wheat portion is sold. The straw portion of winter wheat is used as bedding for livestock.

Milk Price

The calculations for the price of milk are documented in Table 5.2. Composition of butter fat, protein, and other solids, as well as the prices for these components, were calibrated to data provided by the diary enterprise budget provided by OMAFRA (2008). Base on the price of butter fat, protein and other solid alone, the per-hectolitre price is $72.52/HL. Next, the cost of quota is incorporated into the model by subtracting the annual rental value of milk production quota from the milk price. Moschini and Meilke (1988) took the rental value of quota as the price of quota times the rental rate between 1978 and 1983. The rental rate is taken as the shadow value of quota, which was assumed to be 15%. This rental rate represents the rate of return of the quota, accounting for expected capital gains, expected nominal interest rates, planning horizons, as well as the risk of abolishing the supply management system of the dairy sector. Because the quota is a daily production quota

Table 5.1 – The calculations for the sale price per metric ton of dry matter for cash crops

Crops	$/bu	bu/metric ton	Drying Cost ($/ metric ton)	$/metric ton	%Dry Matter	**$ / metric tons of dry matter**
Corn	$4.50	43.40	18.9	$176.38	85.00%	**$207.51**
Alfalfa	-	-	-	$110.00	90.71%	**$121.27**
Soybeans	$11.00	40.50	-	$445.49	87.00%	**$512.06**
Winter Wheat	$5.90	40.50	-	$238.94	86.00%	**$277.84**

Sources: $/bu price, bu/metric ton conversion factor and drying cost are obtained from OMAFRA Ontario Enterprise Budget (2009), % Dry Matter for corn and alfalfa is obtained from Floradale Feed Mill, and % Dry matter for soybeans and winter wheat is obtained from OMAFRA Field Crop Handbook (2009).

Table 5.2 – Parameters used to calculate final milk price used in model.

Milk Composition	Butter Fat (kg/hl)	3.7	
	Protein (kg/hl)	3.3	
	Other solids (kg/hl)	5.7	
Component Prices	Butter Fat ($/kg)	$10.00	
	Protein ($/kg)	$8.00	
	Other solids ($/kg)	$1.60	
		Price by Volume	*$72.52/HL*
Cost of Purchasing Quota	$/kg Butter Fat/day	$30,000.00	
	$/HL/day	$8,108.11	
Annual Cost of Quota	$/HL/year[1]	$22.21	
	Rental rate	15%	
		Deduction from Rent Value of Quota	*-$3.33/HL*
OTHER EXPENSES	Cost per cow	Cost per HL	
Vet and drugs	-$156.00	-$1.84	
Artificial insemination	-$110.00	-$1.29	
Milkhouse supplies	-$117.00	-$1.38	
Transportation, license		-$4.33	
Livestock marketing	-$14.00	-$0.16	
Other dairy expenses	-$190.00	-$2.24	
Dairy Herd Improvement	-$66.00	-$0.78	
Fuel	-$55.00	-$0.65	
Machinery repair	-$61.00	-$0.72	
Building repair	-$108.00	-$1.27	
General variable cost	-$184.00	-$2.16	
Depreciation	-$246.00	-$2.89	
Interest on Term Loans	-$10.00	-$0.12	
General Fixed Cost	-$117.00	-$1.38	
		Deduction from Other Expenses	*-$21.20/HL*
		FINAL PRICE	**$47.99/HL**

Source: Milk composition, component prices, cost of purchasing quota, and other expenses from OMAFRA Dairy Enterprice Budget (2009). Rental rate of quota referenced from Moschini and Meilke (1988).

Note:

1 Dairy quotas are priced as is $ / kg Butter Fat/day, meaning that 1 kg of quota holding allows 365kg of Butter Fat to be produced in a year. In the model, this is converted into a $/HL/day assuming constant butterfat composition in milk, then divided by 365 to obtain the quota cost of milk production in the unit of $/HL/year.

for butter fat, the rental value is divided by 365 to get an annual quota rental value of $3.33/HL.

Other expenses are subtracted from milk price, including costs for animal maintenance, additional milkhouse supplies, transportation fees, administrative fees paid to DFO and Dairy Herd Improvement, as well as other general costs that increase with herd size. These other general costs include depreciation of capital interest on long term interest, and are included to better simulate the dynamics of dairy operations in a static model. These cost estimates are based on the dairy budget enterprise from OMAFRA (2008). The final net price per HL of milk is taken as $47.99.

Cost of crop establishment and harvest

The cost of establishing and harvesting each crop is presented in Table 5.3. Cost is in $/ha for each crop, and parameters are obtained from the enterprise budgets from OMAFRA (2009). Note that the establishment and harvesting cost of alfalfa hay and alfalfa haylage is identical. OMAFRA does not publish an enterprise budget for alfalfa haylage, so the per hectare cost is adopted from the enterprise budget for hay.

Cost of Manure Application

The cost of manure application is based on estimates by Brown (2002). The cost of liquid manure application is assumed to be $8 per gallon. The cost of solid manure application is assumed to be $3/ton. The cost of manure application is converted to $/metric ton of dry matter, for both solid and liquid manure. The dry matter content heifer and milking cow manure is referenced from the Nutrient Management Protocol (2002): the models assume heifers produce solid manure with 40% dry matter, milking age cows housed in tie-stall barns to produce solid manure with 21.3% dry matter, and milking age

Table 5.3 – Per-hectare costs of establishing and harvesting crops

	Corn	Corn silage	Alfalfa hay and haylage	Soybeans	Wheat
Establishment Costs					
Seed	$169.02	$173.88	$133.67	$109.13	$101.31
Seed Treatment			$2.59	$12.36	
Herbicide	$108.48	$108.48	$56.96	$93.90	$17.66
Cost of Custom Application					
Chemical Application	$22.24	$22.24		$22.36	$22.36
Pesiticde Application			$44.48		
Bale Wrapping			$76.23		
Harvest and Processing Costs					
Drying Costs				$31.27	
Storage	$70.86			$22.80	
Trucking	$61.91			$17.94	$36.06
Marketing Fees	$3.44			$2.80	$10.23
Other					$7.41
Other Costs					
Crop Insurance	$37.07	$37.07	$6.55	$30.39	$33.61
Fuel	$43.49	$66.47	$47.44	$28.42	$34.96
Machinary and Repair	$41.88	$50.90	$44.48	$42.50	$47.94
Depreciation	$59.30	$88.96	$85.99	$68.08	$74.87
Interest on Term Loans	$42.25	$66.72	$64.25	$49.42	$55.84
Land Costs			$19.77		
General Fixed Costs	$11.61	$14.33		$14.83	$13.22
Total $/ha cost	**$671.55**	**$629.05**	**$582.40**	**$546.20**	**$455.48**

Source: **OMAFRA Crop Enterprise Budgets (2009) for corn, corn silage, alfalfa hay, soybeans, and wheat.**

cows housed in free-stall barns to produce liquid manure with 9.1% dry matter. The cost of manure application is calculated as $8.27/metric ton of dry matter for solid heifer manure, $15.52/metric ton of dry matter for solid milking age cow manure, and $23.22/metric ton for liquid milking age cow manure.

Cost of animal maintenance

The cost of animal maintenance is included into the final milk price, documented in Table 5.2.

Cost of Commercial Fertilizers

The costs of commercial fertilizers are obtained from the crop enterprise budgets from OMAFRA (2009). N fertilizer is priced at $1.87/kg N, P fertilizer is priced at $1.85/kg N. The cost of K fertilizer is priced at $/1.98/kg K. The cost of fertilizer application is $0.13/kg, obtained from a survey by Brown (2002), is added on to the purchase price of fertilizer. This is calculated from the assumption that the rental rate of a dry bulk fertilizer applicator is $8.50/ac in 1999 dollars and that the average fertilizer application rate, based on van Ham (1996), is 196kg/ha. The Consumer Price Index is applied to the 1999 application cost to update it to 2008 dollars. The calculation is shown on Table 5.4.

Cost of off-farm feed purchase

In the empirical model, only corn, alfalfa hay, and supplements can be purchased as additional feed. This forces all corn silage and alfalfa haylage fed to livestock to be produced on farm. The cost of feed purchase was calibrated from farm visit data. Total cost of supplement purchase was obtained from a farm visit. Given the herd size, total amount of supplement fed was calculated from a dry matter per adult cow requirement calculated in Table 5.5. The cost of corn purchase is $230/metric ton of dry matter. The price for corn purchase is the sale price of corn without the drying cost. Drying cost is left out of the corn purchase price because dairy cows are fed high moisture corn that does not require drying. The purchase price of alfalfa hay is set at $123/metric ton of dry matter. The price of supplement is back calculated from the total cost of supplement purchase was obtained from a farm visit. Given the herd size, total amount of supplement fed was calculated from a per adult cow requirement calculated in Table 5.5. The total cost of supplement purchased is then divided by the estimated total amount of supplement required to obtain a price of $830/metric ton.

Rental Value of Land

In the base case of the farm levels models, land rental is not allowed. In this case, the rental value of land is set at $9999/ha to make it so that it is unprofitable for the model farm to rent additional land. In scenarios where land rental is allowed, the rental value of land is brought down to $300/ha, which is the average rental value for agricultural land in Southern Ontario (Hope, personal communication).

Cost of exporting manure

In the model scenarios where farms were not given the option to export manure, the cost of manure export is set to $999/metric ton of dry matter to force the model to not export manure. When the model allows the farm to export manure, the cost of manure export is set to 10% above the cost of manure application.

Table 5.4 – Calculations for per-kg application cost of commercial fertilizers

Per-Acre rental cost of Bulk Dry Applicator $/ac (1999 dollars)	Assumed application rate kg/ha	Consumer Price Index for 2008 (1999 dollars = 1)	**Application Cost $/kg (2008 dollars)**
$8.50	196	1.228	**$0.13**

Source: Per-Acre rental rate referenced from Brown (2002), assumed fertilizer application rate referenced from van Ham (1996)

Table 5.5 – Feed requirement calculations on a dry matter per adult milking age cow basis

	Daily Ration (kg of dry matter/day)			Daily Feed Intake[2] (kg of dry matter /milking age cow/day)			Daily Feed Requirement (kg of dry matter/milking age cow/day)	**Annual Feed Requirement (metric ton of dry matter/milking cow/yr)**
	Milking Cow	Dry Cow	Heifer	Milking Cow (x5/6)	Dry Cow (x1/6)	Heifer (x1)		
Alfalfa Hay	2.000	1.000	1.000	1.667	0.167	1.000	2.833	**1.034**
Alfalfa Haylage	4.880	1.340	4.340	4.067	0.223	4.340	8.630	**3.150**
Corn Silage	8.000	7.550	1.940	6.667	1.258	1.940	9.865	**3.601**
Corn	5.780	0.765	-	4.817	0.128	-	4.944	**1.805**
Protein and Mineral Supplement[3]	5.000	2.000	0.100	4.167	0.333	0.100	4.600	**1.679**

Source: Dairy rations were referenced from data provided by the Floradale Feed Mill

Note:

2 Model assumes a milking age cow with a lactation period of 305 days and a non-lactating 'dry' period of 60 days. This is translated to a laction period of 5/6[th] of the year and a 'dry' period of 1/6[th] of a year. The number of heifers is assumed to equal the number of milking age cows.

3 Model assumes that milking age cows and heifers are fed the same type of supplements with the same purchase price.

Labour cost

Rodenburg (2008) reviewed the wages of operator labour and hired labour in Ontario Dairy farms, and suggested that 2/3 of labour hours are filled by operator or family labour, with the remaining hours filled by hired labour. He then estimated the average wage rate of operator's labour to be \$21.77/hr, and hired labour to be approximately \$13/hr. Given this information, the wage rate is calculated using the following equation:

$$w = \left(\frac{2}{3} \cdot W_o\right) + \left(\frac{1}{3} \cdot W_h\right) \tag{5.1}$$

where...

w is the weighted average wage rate for all labour hours on farm,
W_o is the estimated operator's wage rate at \$21.77/hr, and
W_h is the estimated hired labour wage rate at \$13/hr.

Giving a weighted average wage rate w of \$18.85/hr.

Calibrating Production Parameters

Crop Yield

In the conceptual framework presented in Chapter 4, crop yields are determined by the Mitscherlich-Baule function that varies with both N and P input. Those yield functions matching Ontario-specific data were not found for any of the crops included in the model. Therefore, the crop yield for alfalfa hay, alfalfa haylage, soybeans, and winter wheat were modeled as a single-point per hectare yield, based on 2008 yield estimates in Oxford County provided by the NMAN2 software provided by OMAFRA. % dry matter for alfalfa hay and alfalfa haylage from Floradale Feed Mill, and % dry matter for soybeans and wheat from OMAFRA (2009) field pocket guide. The metric ton of dry matter per hectare yield is recorded in Table 5.6. For alfalfa hay, the model assumes the alfalfa is cut and harvested three times a year.

Yields for corn and corn silage are modeled as a quadratic N response function. The yield function is adapted from a corn yield function specific to Southern-Ontario developed by Beauchamp *et al.* (1987). To update the yield function to 2008 yield estimates, a coefficient is multiplied to the original yield function as followed:

$$Y_{new}(N) = Y_{Beauchamp}(N) \cdot \left(\frac{Y_{2008estimate}}{Y_{Beauchamp}*} \right) \tag{5.2}$$

where...

Y_{new}	is the new nitrogen response yield function representative of 2007 corn yield estimates in metric ton per ha,
N	is the kg her hectare application rate of N,
$Y_{Beauchamp}(N)$	is the N response yield function for corn in Southern Ontario specified by Beauchamp *et al.* (1987),
$Y_{2008estimate}$	is the 2008 corn yield for Oxford County at 6.45 metric ton dry matter per hectare, and
$Y_{Beauchamp}*$	is the maximum yield output of $Y_{Beauchamp}(N)$, at 8.658 metric ton per hectare.

After applying the coefficient to update the function to match current Southern Ontario yield, the new yield function for corn is as follows:

$$Y_{new}(N) = 3.727 + 3.16e^{-2}(N) + 9.51e^{-5}(N^2) \tag{5.3}$$

where the optimal yield for the new nitrogen response yield function for corn is 6.45 metric tons of dry matter per hectare, and the optimal nitrogen application rate is 166.67 kg/ha.

The per hectare yield for corn silage is also determined by the quadratic yield

Table 5.6– Metric ton dry matter per hectare yield for alfalfa hay, alfalfa haylage, soybeans, and winter wheat

	Yield		Dry Matter Yield
	metric ton/ha	% Dry Matter	metric ton dry matter / ha
alfalfa hay	12	90.71%	10.88
alfalfa haylage	10.2	31.00%	10.20
soybeans	2.5	87.00%	2.175
Wheat	4.8	86.00%	4.128

Source: yield estimates from NMAN2 software (OMAFRA, undated), % dry matter for alfalfa hay and alfalfa haylage from Floradale Feed Mill, and % dry matter for soybeans and wheat from OMAFRA (2009) field crop handbook.

function specified above. The final yield for corn silage is further multiplied 1.672 times to account for the additional weight of corn silage compared to grain corn, since the whole plant is harvested for corn silage, whereas only the ears are harvested for grain corn. The maximum yield for corn silage is 10.78 metric tons of dry matter/ha.

Milk Production

In the empirical model, milk production is assumed to be uniform for every milking age adult at 85HL/year. This value is obtained from the dairy enterprise budget provided by OMAFRA (2008).

Feed Requirement

Feed requirement data were obtained from Floradale Feed Mill Limited (personal communication). Floradale Feed Mill provided sample total mixed ration for milking cows, dry cows (adult age cows outside lactation period), and heifers. Feed requirement are calculated on a per-adult-age-milking-cow basis, based on the assumptions that the adult cow to heifer ratio is 1:1, with a 10-month lactation period for each adult age milking cows. Therefore, the feed requirement for milking cows is multiplied by 5/6, and the feed requirement for dry cows is multiplied by 1/6, then the new feed requirement for milking cows, dry cows, and heifers is added together to obtain a total dry matter feed requirement on a per adult age cow basis. This calculation is presented in Table 5.5. Note that to simplify the feed requirements for supplements, premixes fed to milking cows, dry cows, and heifers are assumed to be identical.

Labour Requirement for Crop Production

In the crop enterprise budgets from OMAFRA (2009), labour requirement is reported as cost per hectare To convert the per hectare labour requirement into hours, the costs reported by the crop enterprise budgets are divided by the wage rate *w*, at $18.85/hr. The labour hours required per hectare of land for each crop are reported in Table 5.7. Note that because there is no crop enterprise budget for alfalfa haylage provided by OMAFRA, the labour requirement for alfalfa hay is also used for alfalfa haylage.

Labour Requirement for Milk Production

Labour requirement for the milk production was calibrated based on data obtained from a farm interview. Participants were asked about their labour requirement for livestock maintenance and milk production on a daily basis. This data is then translated into annual labour requirements in hours. In addition, Manitoba Agriculture, Food and Rural Initiative (2009) suggests that raising dairy heifers requires approximately 20% labour. The labour requirement per milking cow is then divided by a factor of 0.8 to include the labour hours required for raising heifer, assuming a 1:1 adult to heifer ratio and a lactation period of 305 days. The annual labour requirement per adult age milking cow is 38.125. Labour requirement calculations are presented in Table 5.8.

Manure Production and Nutrient Content of Manure

Manure production for the small, medium, and large model farms is calibrated to manure production data provided by the NMAN2 (OMAFRA, undated) software from OMAFRA. Different types of manure are produced by the adult age cows in the small

Table 5.7 – Labour hours required for per hectare of cropland for each crop grown in model.

	Labour Cost $/ha	Labour hours required[4] hr/ha
Corn	$32.99	1.750
Corn Silage	$70.67	3.749
Alfalfa Hay	$87.23	4.627
Alfalfa Haylage	$87.23	4.627
Soybeans	$23.72	1.258
Soft Winter Wheat	$49.67	2.635

Source: per hectare cost of labour is provided by crop enterprise budgets from OMAFRA (2009).

Note:

4 Labour hours per hectare is calculated by dividing the per hectare cost of labour by a wage rate of $18.85/hr.

farm model that those in the medium and large farm models. This is to account for the difference in barn type. Small farms tend to have tie-stall barns with a manure pack system, which solid manure is produced. Medium and large farms tend to have free-stall barns, which produces liquid manure. Heifers produce solid manure in all three farm models. Both solid and liquid manure are measured in metric tons of dry matter. The amount of manure produced is presented in Table 5.9.

Nutrient content of manure is obtained from the manure nutrient profile database within the NMAN2 (OMAFRA, undated) software. For N, the database reports a % of total N in manure and % of inorganic N in the form of Ammonium N. % organic N is the difference between the %total N and % ammonium N. Only a fraction of organic N and inorganic N is available as nutrients for crop production. For solid manure, only 15% of organic N is available, and only 75% of ammonium N is available for crop production. For liquid manure, only 20% of organic N is available, and 100% of ammonium N is available.

Availability of N assumes that all solid manure is incorporated into the soil in one day, and all liquid manure is injected into the soil. Total % of available N for solid manure is then calculated as:

$$((\%OrganicN * 15\%) + ((\%ammoniumN * 75\%) \tag{5.4a}$$

and for liquid manure:

$$((\%OrganicN * 20\%) + (\%ammoniumN) \tag{5.4b}$$

Table 5.8 – Calculations for total labour hours required for livestock management on a per milking age cow basis.

Sample Herd Size	70		
Labour hours per day required			
	Milking	Manure clean up	Feeding
	2 hrs	4 hrs	1 hr
Total labour hours required per day		7	hrs
Total labour hours per year (305 days of lactation)		2135	hrs
Labour hours required per year for each milking age cow		30.5	hrs
Additional labour hours required for each heifers		7.625	hrs
Total Labour Hours required per milking age cow		**38.125**	**hrs**

Source: Farm Interviews

Table 5.9 – Manure production for heifers and milking cows housed in different barn types.

	Barn Type	Manure Type	Volume	Density	% Dry Matter	DM Basis per animal
Livetock Type			m3	kg/m3		metric tons of dry matter
Heifer	Manure Pack	Solid	5.546	721	0.4	1.599
Milking Cow	Tie Stall (Small farms)	Solid	22.066	833	0.213	3.915
	Free Stall (medium and large farms)	Liquid	27.009	1000	0.091	2.458

Source: NMAN (OMAFRA, 2003) workbook from OMAFRA.

For P, only 92% of the total P in manure is available. For K, 108% of total K in manure is available. Table 5.10 presents the total available N, P, and K in kg/metric tons manure in dry matter basis. Note that the % available nutrient contents reported as percentages are multiplied by 10 to obtain the unit in a kg/metric tons of dry matter basis. All of these calculations follow the instructions from the NMAN (OMAFRA, 2003) handbook.

Calibrating Production Constraints

Simulating Crop Rotation

In the farm models, the crop rotation simulated is three years of alfalfa, followed by three years of corn, then 1 year of soybeans and 1 year of soft red winter wheat. This crop rotation was adopted by one of the farms interviewed.

Workable Land Constraint

The workable land constraints for the small, medium, and large farms are arbitrarily calibrated to 60ha, 130ha, and 230ha respectively. This is done because of the large variation in cropland holding that exists for Ontario dairy farms. The calibrated land holding is matched against the 2006 ODFAP data. The ODFAP data is split into three categories depending on the recorded barn capacities: workable land was averaged for farms with barn capacity of under 40 milking cows; for farms with barn capacity between 41 and 99 milking cows; and barn capacity over 100 milking cows. From the ODFAP 2006 data, the average farm size is 61.58ha for the 16 farms with barn capacity under 40 milking cows, 131.34ha for the 43 farms with barn capacity between 41 and 99 milking cows, and 223.44ha for the 15 farms with barn capacity above 100 milking cows.

Table 5.10 – Nutrient content of manure for heifers and milking cows housed in different barn types

Livetock Type	Barn Type	Available nutrient			Available N	Available P	Available K
		N	P	K	kg N / metric ton Manure (dry matter)	kg P / metric ton Manure (dry matter)	kg K / metric ton Manure (dry matter)
Heifer	Manure Pack	1.218%	1.536%	2.171%	12.18	15.36	21.71
Milking Cow	Tie Stall (Small farms)	1.130%	1.380%	2.527%	11.30	13.80	25.27
	Free Stall (medium and large farms)	4.759%	3.744%	2.851%	47.59	37.44	28.51

Source: Manure Nutrient Database from NMAN2 software (OMAFRA, undated)

Barn Capacity

Barn capacity for the small, medium, and large farms are also arbitrarily chosen. The small farm model has barn capacity of 30 milking cows to reflect small dairy operations. Medium farms are calibrated with barn capacity of 70 milking cows to reflect the current average herd size (DFO, 2007). Lastly, the large farms are calibrated with barn capacity of 200 milking cows. This is the herd size which, assuming a 1:1 adult milking age cow to heifer ratio, triggers the current Nutrient Management Act (2002).

Calibrating Soil Nutrient Budgets

Other N inputs

In addition to N input from fertilizer and manure, 4 other forms of N input are: atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation, and N from crop residue of previous year's crop. Van Ham (1996) documented the atmospheric deposition and non-symbiotic N fixation for all crops in kg N / ha, as well as N from symbiotic fixation for alfalfa hay, alfalfa haylage and soybeans. N credits from crop residue are obtained from NMAN2 (OMAFRA, undated) software. These additional N inputs for each crop are presented in Table 5.11, summated into a parameter call 'other N inputs'.

Crop Nutrient Requirements

The crop nutrient requirements are presented in Table 5.12, which shows the P and K requirement for crops (in kg/ha) based on the soil P value and soil K value in mg/L, respectively. Because of the variation of soil nutrient content in Ontario agricultural land, a soil P value of 6-7 mg/L and a soil K value of 101-120mg/L was chosen, and the corresponding P and K requirement of crop on a per hectare basis is used.

N requirement for winter wheat is calibrated to 155.7 kg N/ha, referenced from the NMAN workbook (OMAFRA, 2003). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equals the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from the previous year's crop residue. The nitrogen requirement for corn and corn silage are driven by the quadratic N yield response function. For certain scenarios, the model allows soil P value to increase to 10-12mg/L or decrease to 0-3mg/L to examine the differences in model output under different soil P conditions. Note that the P and K requirements for all crops, as well as the N requirements for non-corn crops, are independent of the per-hectare yields for each crop; increases or decreases in per-hectare yield will not change the crop requirement for P and K for all crops, nor will it change the N requirement for non-corn crops.

Crop Nutrient Removal

Crop nutrient removal for N and P are based on the data provided by the NMAN2 software. Since nutrient removal through crop harvest increases as crop yield increases, the removal rate (in kg/ha) of N and P is shown at the base yield, which indicates that these removal rates are obtained. The NMAN workbook (OMAFRA, 2003) provided the following formula used to obtain the actual N and P removal rate of any given yield:

$$crop\ removal = base\ removal\ value \times \left(\frac{observed\ yield}{base\ yield} \right)$$

The base yield and the removal rate of N, P for the base yield is shown in Table 5.13. Base yield is the expected yield of a crop in Oxford County, given by the NMAN2

Table 5.11 – Calculations of other N input: source of N other than commercial fertilizer or manure.

	Atmospheric Deposition kg/ha	Non-symbiotic N fixation kg/ha	Symbiotic N fixation kg/ha	N credit kg/ha	**Other N input kg/ha**
Corn	18.4	5	-	6.67	**30.07**
Corn Silage	18.4	5	-	6.67	**30.07**
Alfalfa Hay	18.4	5	170	75.67	**269.07**
Alfalfa Haylage	18.4	5	200	75.67	**299.07**
soybeans	18.4	5	100	110	**233.4**
Wheat	18.4	5	-	30	**53.4**

Source: Atmospheric deposition, non-symbiotic fixation and symbiotic fixation values from van Ham (1996). N credit values referenced from NMAN2(OMAFRA, undated) software.

Table 5.12 – P and K requirements for crops based on soil P and K values.

	Soil P test values (mg/L)			soil K value (mg/L)
	0-3	**6-7**[5]	10-12	**101-120**
	P requirement (kg P/ha)			K requirement (kg K/ha)
corn	110	**90**	50	**30**
corn silage	110	**90**	50	**30**
alfalfa hay	180	**90**	30	**69**
alfalfa haylage	180	**90**	30	**69**
soybeans	81	**50**	30	**30**
Wheat	71	**50**	20	**20**

Source: NMAN (OMAFRA, 2003) workbook

Note:

5 The highlighted values are the requirement values used in the base solution. The other soil P values used in other scenarios of the models are also shown.

Table 5.13 –N, P crop removal through harvest on a per hectare basis.

Nutrient Removal		
Base Yield	Removal Base Value	
	P	N
metric ton / ha	kg / ha	kg / ha
6.46	57	112
10.8	92	205
10.8852	73	351
10.2	66	319
2.5	35	161
4.8	56	156

Source: NMAN (OMAFRA, 2003) workbook from OMAFRA software (OMAFRA, undated). Base removal values are the N and P per-hectare removal rate at the base yield for each crop given by the NMAN2 software (OMAFRA, undated). Note that K removal is not tracked since K is not regulated under nutrient management regulations.

Calculating Nutrient Surplus and Agronomic Balance

Nutrient surplus calculations for N and P are the same, where nutrient removed through crop harvest are subtracted from nutrient inputs. The amount of N and P removed are independent of the soil P test values, therefore N and P surplus only changes with differences in crop yield and N and P input.

The agronomic balance for N depends solely on crop requirement. For non-corn crops, crop requirement does not change in the models since a single yield was modeled for these crops. For corn crops, increase in yield would increase crop requirement. For P, crop requirements are related to the soil P test values: the higher the soil P test values, the lower the crop requirements for P. As such, models with higher soil P test values have higher P agronomic balance, holding all else constant.

Differences in nutrient surplus and agronomic balance calculations for N and P are summarized on Table 5.14.

Model Validation

The small, medium, and large farm models were validated against the ODFAP Annual Report 2007 (2008). The report separated the data collected in 2007 from 84 dairy farms into three categories based on cost of production: 15 farms with the lowest cost of production, 15 farms with the highest cost of production, and the medium 54. The report provided the average net farm income for each of the three categories. The report also provided the average workable land holding, average herd size, average milk output per animal for each of the three cost of production categories, which is presented in Table 5.15.

The net return of the small farm model is validated against the average net farm income of the low total cost of production data, the net return of the medium farm model is validated against average net farm income of the medium total cost of production, and the net return of the large farm model is validated against the average net farm income of the high total cost of production data. The ODFAP (2008) report is used for validation even though the data is separated by cost of production rather than size, because there are no other sources of data that can be used to validate the small, medium, and large farm model. Note that the low cost of production farms tend to have a small average herd size and a small average land base, the medium cost of production farms have a medium average herd size and a medium average land base, and the high cost of production farms have a large average herd size and a large average land base. The ODFAP (2008) report is used for validation instead of using the ODFAP raw data from 2006 because the report clearly defines sources of revenue and costs associated with milk production, whereas in the variable descriptions in the ODFAP raw data is not clear enough to be able to isolate the sources of costs.

In order to validate the objective value output of the farm models to the net farm income reported by the ODFAP report (2008), the workable land constraint, barn capacity constraint, and milk production per cow are calibrated to their respective values

Table 5.14 – Changes in N and P soil surplus and agronomic balance under different soil P test values and yield conditions

	Units	Base Value	Different Soil P Test Values: Lower Value	Different Soil P Test Values: Higher Value	Increase in Yield
N input per ha	kg/ha/yr	108.4	108.4	108.4	**127.4**
N Requirement per ha[6]	kg/ha/yr	108.4	108.4	108.4	**127.4**
N Agronomic Balance per ha[7]	kg/ha/yr	0	0	0	0
N Removal per ha[8]	kg/ha/yr	106.4	106.4	106.4	**109.7**
N surplus per ha[9]	kg/ha/yr	2	2	2	18
P input per ha	kg/ha/yr	90	90	90	90
P Requirement per ha[10]	kg/ha/yr	90	**110**	**50**	90
P Agronomic Balance per ha[11]	kg/ha/yr	0	**20**	**-40**	0
P Removal per ha[12]	kg/ha/yr	79.78	79.78	79.78	82.04
P surplus per ha[13]	kg/ha/yr	10.22	10.22	10.22	**7.96**

Source: calculations based on model output

Note:

6 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

7 N agronomic balance is calculated as N input per hectare minus N required per hectare (see note 5).

8 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

9 Soil N surplus is calculated as N input per hectare minus N removed per hectare (see note 8).

10 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield (see note 1). The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

11 P agronomic balance is calculated as P input per hectare minus P required per hectare (see notes 10 and 11).

12 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

13 Soil P surplus is calculated as P input per hectare minus P removed per hectare (see notes 13 and 14).

Table 5.15 – Production parameters and additional costs not included in the empirical model associated with three total-cost-of-production categories as reported by ODFAP Annual Report: 2007 (2008)

	Lowest total cost of production	Medium total cost of production	Highest total cost of production
Production Parameters			
Average Herd Size	45	71	134
Average Cropland Holding	138ha	135ha	157ha
Average HL of milk per cow	69.72HL/cow	85.12HL/cow	85.95HL/cow
Additional Costs			
Rest Estate Taxes	$3,940	$5,329	$6,775
Telephone and Hydro	$10,243	$12,272	$17,052
Other General Cash Expenses	$9,800	$10,967	$19,386
Sum of Additional Costs	$23,983	$28,568	$43,213
Reported ODFAP Net Farm income	**$18,433**	**$117,304**	**$229,292**

Source: ODFAP Annual Report: 2007 (2008) associated with each cost of production category. The net return output of the models then must be further transformed to match the net farm incomes reported by the ODFAP report (2008). This is because the net farm incomes of the report includes three additional costs not included in the empirical model: real estate taxes, telephone and hydro, and 'other general cash expenses' (such as personal car expenses and miscellaneous farm expenses). These costs are unique for each total cost of production category, and are presented in Table 5.1. Also, the net return output of the model farm includes the costs of rental value of quota, which isn't included in the net farm income provided by the report. These additional costs are subtracted from the model output, then the rental cost of quota (at $3.33/HL) is added back onto the model output to generate a net farm income comparable to the ones from the ODFAP report. The validation results are presented in Table 5.15. Note that the medium farm model's net farm income output is 97% of observed net farm income of 54 dairy farms with medium cost of production, with an absolute difference of $3,121.75 between the modeled and observed net farm income. The model overestimates the net farm income of small farms compared to low cost of production farms by 282%, with model production an additional net farm income of $33,591.26. The model underestimated the net farm income of large dairy farms compared to high cost of production farms by approximately the same magnitude, with the model generating a net farm income that is$26,487.35 lower than the ODFAP report numbers, an 88% difference in net farm income between the model and the ODFAP average. The differences in model outputs of the small and large farm models are likely due to the fact that the net return outputs by the models are calculated differently than the net farm income in the ODFAP report. There may be other sources of revenue and costs not included in the farm models.

The conclusion from the validation results in that the medium farm model is a good reflection of Ontario Dairy farms with average cost of production. Because the analysis mainly focuses on changes in the model output in different scenarios, the fact that the net farm incomes do not exactly match reality is not a critical issue, so long as the model output is within a range of the expected income reported by ODFAP.

Sensitivity analysis was also performed to provide further validation of the model. The results of the sensitivity analysis are presented in Table 5.16, showing the sensitivity elasticities of nine key parameters in the model. Sensitivity elasticities represent the % change in net return due to a 1% change in a parameter. Milk prices are expected to have the biggest impact, as milk production is the major source of revenue. Increasing milk prices has a sensitivity elasticity greater than 1% because revenue is increased while cost stays fixed. Increases in feed requirement are also expected to have a negative impact on net return, and increase in yield to have a positive impact. Increases in fertilizer prices and manure nutrient content have little impact, mainly because they have little impact on milk production.

Table 5.16 - Sensitivity analysis results for small, medium, and large farm models, presented as sensitivity elasticities.

Parameters		Small[14]	Medium[1]	Large[1]
Milk Price				
	Direction of Change	Increase	Increase	Increase
	Sensitivity Elasticity[15]	2.635%	2.433%	2.962%
Feed Requirement				
	Direction of Change	Increase	Increase	Increase
	Sensitivity Elasticity	-1.679%	-1.551%	-1.889%
Yield				
	Direction of Change	Increase	Increase	Increase
	Sensitivity Elasticity	1.569%	1.356%	1.054%
Fertilizer Price				
N Fertilizer Price				
	Direction of Change	Increase	Increase	Increase
	Sensitivity Elasticity	-0.065%	0.000%	0.000%
P Fertilizer Price				
	Direction of Change	Increase	Increase	Increase
	Sensitivity Elasticity	-0.130%	-0.038%	0.000%
K Fertilizer Price				
	Direction of Change	Increase	Increase	Increase
	Sensitivity Elasticity	0.000%	-0.010%	0.000%
Nutrient Content of Manure				
N Manure Content				
	Direction of Change	Decrease	Decrease	Decrease
	Sensitivity Elasticity	0.024%	0.068%	0.000%
P Manure Content				
	Direction of Change	Decrease	Decrease	Decrease
	Sensitivity Elasticity	-0.075%	0.138%	0.000%
K Manure Content				
	Direction of Change	Decrease	Decrease	Decrease
	Sensitivity Elasticity	-0.041%	-0.010%	0.000%

Source: model output

Notes:

[14] The model of small farm houses its herd in a tie-stall barn, and the medium and the large farms each house its herd in a free-stall barn. See note 3 for the implication of farm type on the type of manure the milking herd produces.

[15] Sensitivity elasticities represent the % change in profit due to a 1% change in a parameter.

Chapter 6 – Model Results and Discussion

This chapter presents the model results for small, medium, and large Ontario dairy farms under different nutrient management Scenarios. Table 6.1a and Table 6.1b lay out the scenarios modeled for this study, and also references the results to the detailed results tables in Chapter 6. Note that all results tables in this Chapter are split into Table a, Table b, and Table c. Two categories of regulatory scenarios were evaluated for each of the three farm models, with each model assuming three soil P values: a base soil P value of 6-7mg/L, a lower soil P value of 0-3mg/L and a higher soil P value of 10-12mg/L. The first category of regulatory scenarios, models the regulation under the Nutrient Management Act (2002), limiting the per-hectare P application to under 78kg/ha/yr above P removal per hectare through crop harvest. The second category of regulatory scenarios models the proposed regulation under the Clean Water Act (2007), where N and P application rates must be less than 115% of the crop requirement per hectare each year.

For the first category of regulatory scenario that measures the compliance cost of Nutrient Management Act (2002), four sub-scenarios are examined. Sub-scenarios 1.1 and 1.2 simulate the nutrient management regulations that are currently enforced. Sub-scenario 1.1 measures the compliance cost of the Nutrient Management Act (2002) when the regulation is triggered by herd-size (which only the large farm model triggers), and sub-scenario 1.2 measures the compliance cost when the regulation is triggered by barn expansion, where barn capacity is allowed to increase by 10% (applicable to all farm sizes). Sub-scenarios 1.3 and 1.4 simulate hypothetical situations where the regulations

Table 6.1a – Description of scenarios for compliance cost analysis and table of reference for analysis results for the models of small, medium, and large Ontario dairy farms.

	Small[16]	Medium[1]	Large[1]
Base Solution			
Original soil P test values: 6-7 mg/L	Table[17] 6.2	Table 6.2	Table 6.2
Per-crop Basis	Table 6.3	Table 6.4	Table 6.5
Lower soil P test values[18]: 0-3mg/L	Table 6.6	Table 6.7	Table 6.8
Higher soil P test values: 10-12mg/L	Table 6.6	Table 6.7	Table 6.8
Scenario 1: Nutrient Management Act (2002)			
Application Limit: P application (kg P/ha/yr) < crop removed P[19] + 78kg/ha/yr			
1.1 Herd Size Trigger (>170 head of milking age cattle)			
Original soil P test values: 6-7 mg/L	Herd size less	Herd size less	x
Lower soil P test values: 0-3mg/L	than regulation	than regulation	x
Higher soil P test values: 10-12mg/L	trigger	trigger	x
1.2 Barn Expansion Trigger (Barn Capacity + 10%)			
Original soil P test values: 6-7 mg/L	x	x	x
Lower soil P test values: 0-3mg/L	x	x	x
Higher soil P test values: 10-12mg/L	x	x	x
1.3 Stricter Application Limit: P application (kg P/ha/yr) < crop removed P + 19.5kg/ha/yr			
Original soil P test values: 6-7 mg/L	x	x	Table 6.9
Lower soil P test values: 0-3mg/L	x	x	x
Higher soil P test values: 10-12mg/L	x	x	Table 6.10
Manure export	x	x	Table 6.11
Land rental	x	x	Table 6.11
1.4 Stricter Application Limit: P application (kg P/ha/yr) < crop removed P + 15kg/ha/yr			
Original soil P test values: 6-7 mg/L	Table 6.12	Table 6.14	Table 6.16
Per-crop Basis	Table 6.13	Table 6.15	Table 6.17
Lower soil P test values: 0-3mg/L	x	x	x
Higher soil P test values: 10-12mg/L	x	x	Table 6.18
Manure export	x	x	Table 6.19
Land rental	x	x	Table 6.19

Notes:

[16] The model of small farm houses its herd in a tie-stall barn, and the medium and the large farms each house its herd in a free-stall barn. See note 3 for the implication of farm type on the type of manure the milking herd produces.

[17] Tables 6.2 to 6.19 are split into three separate tables noted a,b, and c.

[18] Crops grown on soil with low soil P value have high per-hectare P requirements, and low per-hectare P requirements in soil with high soil P values. See Table 5.10 for P requirement values associated with soil P values.

[19] P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

Table 6.1b – Description of scenarios for compliance cost analysis and table of reference for analysis results for the models of small, medium, and large Ontario dairy farms.

	Small[20]	Medium[1]	Large[1]
Scenario 2: Clean Water Act (2007)			
Application Limit: N and P application (kg/ha/yr) < crop requirement[21,22] + 15%			
2.1: Proposed N and P application Limit			
Original soil P test values: 6-7 mg/L	x	Table[23] 6.20	Table 6.22
Per-crop Basis	x	Table 6.21	Table 6.23
Lower soil P test values: 0-3mg/L	x	x	Table 6.24
Higher soil P test values: 10-12mg/L	Table 6.25	Table 6.26	Table 6.27
Manure export	x	Table 6.28	Table 6.29
Land rental	x	Table 6.28	Table 6.29
2.2: Stricter Application Limit: N and P application (kg/ha/yr) < crop requirement + 10%			
Original soil P test values: 6-7 mg/L	x	Table 6.30	Table 6.32
Per-crop Basis	x	Table 6.31	Table 6.33
Lower soil P test values: 0-3mg/L	x	x	Table 6.34
Higher soil P test values: 10-12mg/L	Table 6.35	Table 6.36	Table 6.37
Manure export	x	Table 6.38	Table 6.39
Land rental	x	Table 6.38	Table 6.39

Notes:

[20] The model of small farm houses its herd in a tie-stall barn, and the medium and the large farms each house its herd in a free-stall barn. See note 3 for the implication of farm type on the type of manure the milking herd produces.

[21] N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

[22] P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield. The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

[23] Tables 6.20 to 6.39 are split into three separate tables noted a,b, and c.

under the Nutrient Management Act (2002) are made stricter. Sub-scenario 1.3 measures the compliance cost with a stricter regulation where the application limit is reduced by 75%, so that the P application limit is lowered to 19.5kg/ha/yr above crop removal. Sub-scenario 1.4 measures the compliance costs of a further restricted regulation where the application limit is further reduced by 79%, so that the P application limit is further lowered to 15kg/ha/yr above crop removal.

For the second category of regulatory scenario modeling the proposed Clean Water Act (2007) regulations, two sub-scenarios are examined. Sub-scenario 2.1 models the currently proposed application limit where per-hectare N and P application rate must be lower than 115% of the crop requirement per hectare per year; and sub-scenario 2.2 models a an hypothetical situation where stricter application limit where per-hectare application rate must be lower than 110% of the crop requirement per hectare per year.

If a farm model incurs compliance cost with the base soil P value of 6-7mg/L within a regulatory scenario, the model is then allow to export manure at a cost of 10% over the cost of application, or rent extra land at a cost of $300/ha, with the maximum amount of land rented constrained at 10% of the land base.

Base Solution

The model output and nutrient balances of the base solution for the model of small, medium, and large dairy farm model is presented in Tables 6.2. The model output and the per-hectare nutrient balances on a per-crop basis for the small, medium, and large farm models are presented in Tables 6.3, 6.4, and 6.5, respectively. For all three farm models, the barns are filled to capacity and the entire land base is used. Note that the shadow value of land for the small and medium farm models are just slightly below the

Table 6.2a – Model output for models of small, medium, and large Ontario dairy farms:

Base solution

Model Output	Units	Small[24]	Medium[1]	Large[1]
Net Return	**$/yr**	**$47,210**	**$115,211**	**$232,236**
Milking Herd Size[25]	cows	30	70	170
Land Base	ha	60	130	200
Land Rented	ha	0	0	0
Total Land Used	ha	60	130	200
Shadow Value of Land	$/ha/yr	$276	$279	$619
Shadow Value of Barn Capacity	$/cow/yr	$1,021	$1,128	$638
Total Manure Applied[26]	metric tons/yr	165.4	284	689.7
Total Manure Exported	metric tons/yr	0	0	0
N fertilizer purchased	metric tons/yr	1.464	0.7115	0
P fertilizer purchased	metric tons/yr	2.443	2.240	0
K fertilizer purchased	metric tons/yr	0	0.8857	0

Source: model output

Notes:

24 The model of small farm houses its herd in a tie-stall barn, and the medium and the large farms each house its herd in a free-stall barn. See note 3 for the implication of farm type on the type of manure the milking herd produces.

25 Milking herd size only counts the number of milking age cows. Models assume number of heifers equals number of milking age cows.

26 Total manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.2b – N balances for models of small, medium, and large Ontario dairy farms: Base solution

N Balances	Units	Small[27]	Medium[1]	Large[1]
Total N required[28,29]	metric tons/yr	11.91	26.77	44.67
Total N input[30]	**metric tons/yr**	**12.53**	**30.15**	**54.37**
from manure	metric tons/yr	1.911	9.551	23.19
from fertilizer	metric tons/yr	1.464	0.711	0
from other sources[31]	metric tons/yr	9.16	19.89	31.18
Total N Removed[32,33]	metric tons/yr	13.3	29.07	46.23
Soil N Surplus[34]	metric tons/yr	-0.767	1.081	8.143
Soil N surplus / ha	**kg/ha/yr**	**-12.78**	**8.314**	**40.72**
N agronomic balance[35]	metric tons/yr	0.628	3.387	9.701
N agronomic balance / ha	**kg/ha/yr**	**10.47**	**26.05**	**48.51**

Source: model output

Notes:

27 The model of small farm houses its herd in a tie-stall barn, and the medium and the large farms each house its herd in a free-stall barn. See note 3 for the implication of farm type on the type of manure the milking herd produces.

28 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

29 Total N required is the sum of the per-hectare N requirement of each crop (see note 2) times land used for production of each crop.

30 Total N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

31 N from other sources is calculated as the hectares of land used multiplied by the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

32 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

33 Total N removed is the sum of the per-hectare N removal rate (see note 8) of each crop times land used for production of each crop.

34 Soil N surplus is calculated as total N input minus total N removed (see notes 4 and 5)

35 N agronomic balance is calculated as total N input minus total N required (see notes 2 and 3)

Table 6.2c – P balances for models of small, medium, and large Ontario dairy farms: Base solution

P Balances		Units	Small[36]	Medium[1]	Large[1]
Total P Required[37,38]		metric tons/yr	4.800	10.40	16.00
Total P Input[39]		**metric tons/yr**	**4.800**	**10.40**	**19.82**
	from manure	metric tons/yr	2.357	8.160	19.82
	from fertilizer	metric tons/yr	2.443	2.240	0
Total P Removed[40,41]		metric tons/yr	3.664	8.038	12.35
Soil P surplus[42]		metric tons/yr	1.136	2.362	7.468
Soil P surplus / ha		**kg/ha/yr**	**18.93**	**18.17**	**37.34**
P agronomic balance[43]		metric tons/yr	0	0	3.818
P agronomic balance / ha		**kg/ha/yr**	**0**	**0**	**19.09**

Source: model output

Notes:

36 The model of small farm houses its herd in a tie-stall barn, and the medium and the large farms each house its herd in a free-stall barn. See note 3 for the implication of farm type on the type of manure the milking herd produces.

37 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield. The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

38 Total P required is the sum of per-hectare P requirement of each crop (see note 12) times land used for production of each crop.

39 Total P input is the sum of P input from manure and from fertilizer

40 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

41 Total P removed is the sum of the per-hectare P removal rate (see note 15) of each crop times land used for production of each crop.

42 Soil P surplus is calculated as total P input minus total P removed (see note 15,16).

43 P agronomic balance is calculated as total P input minus total P required (see notes 12 and13).

Table 6.3a – Model outputs on a per-crop basis for the model of small Ontario dairy farms: Base solution

Model Outputs by Crop		Crops					
	Units	Corn	Corn Silage	Alfalfa Hay	Alfalfa Haylage	Soybeans	Wheat
Land Used	**ha**	**11.97**	**10.54**	**13.24**	**9.265**	**7.500**	**7.500**
Yield[44]	**metric tons/ha/yr**	6.135	10.254	10.89	10.2	2.5	4.8
Crop Produced[45]	**metric tons/yr**	73.41	108.0	144.1	94.50	18.75	36.00
% sold		39.21%		80.47%		100%	100%
% fed		60.79%	100%	19.53%	100%		
Crop Purchased[46]	**metric tons/yr**	0	0	0	0	0	0
Manure Applied[47]	**metric tons/yr**	72.84	13.05	37.68	26.38	9.283	6.189
N fertilizer Applied	kg/yr	95.90	672.0	0.0	0.0	0.0	695.7
P fertilizer Applied	kg/yr	38.97	762.2	654.3	458.0	242.7	286.8
K fertilizer Applied	kg/yr	0	0	0	0	0	0

Source: Model output

Notes:

44 Yield of each crop is measured in metric tons of dry matter per hectare. Yield for alfalfa hay, alfalfa haylage, soybeans, and wheat are calibrated to 2008 yield estimates in Oxford County, referenced from the NMAN2 Software (OMAFRA, undated). Corn and corn silage yield is determined by a quadratic N-response yield function (see Chapter 5).

45 Crop produced is measured in metric tons of dry matter, and is calculated as the yield of each crop multiplied by land used for production for each crop. All corn silage and alfalfa haylage produced must be used for feed, and all soybeans and wheat produced must be sold.

46 Crop purchased is measured in metric tons of dry matter. Soybeans and wheat cannot be purchased.

47 Manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.3b – Per-hectare N balances on a per-crop basis for the model of small Ontario dairy farms: Base solution

Nutrient Balance by Crop		Crops					
	Units	Corn	Corn Silage	Alfalfa Hay	Alfalfa Haylage	Soybeans	Wheat
N Balances by Crop							
N Requirement per ha[48]	kg/ha/yr	108.4	108.2	276.4	306.4	240.7	155.7
N input per ha[49]	**kg/ha/yr**	**108.4**	**108.2**	**302.0**	**332.0**	**247.7**	**155.7**
from manure	kg/ha/yr	70.34	14.31	32.89	32.89	14.30	9.534
from fertilizer	kg/ha/yr	8.02	63.79	0	0	0	92.77
from other input[50]	kg/ha/yr	30.07	30.07	269.1	299.1	233.4	53.40
N Removal per ha[51]	kg/ha/yr	106.4	194.6	351.0	319.0	161.0	156.0
N surplus per ha[52]	**kg/ha/yr**	**2.056**	**-86.45**	**-49.04**	**12.96**	**86.70**	**-0.3000**
N Agronomic Balance per ha[53]	**kg/ha/yr**	**0**	**0**	**25.59**	**25.59**	**7.001**	**0**

Source: Model output

48 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

49 N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

50 N from other sources is the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

51 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

52 Soil N surplus is calculated as N input per hectare minus N removed per hectare (see note 8).

53 N agronomic balance is calculated as N input per hectare minus N required per hectare (see note 5).

Table 6.3c – Per-hectare P balances on a per-crop basis for the model of small Ontario dairy farms: Base solution

Nutrient Balance by Crop		Crops					
	Units	Corn	Corn Silage	Alfalfa Hay	Alfalfa Haylage	Soybeans	Wheat
P Balances by Crop							
P Requirement per ha[54]	kg/ha/yr	90	90	90	90	50	50
P input per ha[55]	**kg/ha/yr**	90.00	90.00	90.00	90.00	50.00	50.00
from manure	kg/ha/yr	86.74	17.65	40.56	40.56	17.64	11.76
from fertilizer	kg/ha/yr	3.26	72.35	49.44	49.44	32.36	38.24
P Removal per ha[56]	kg/ha/yr	79.78	72.63	53.08	53.08	57.60	42.46
P surplus per ha[57]	**kg/ha/yr**	**10.22**	**17.37**	**36.92**	**36.92**	**-7.60**	**7.540**
P Agronomic Balance per ha[58]	**kg/ha/yr**	**0**	**0**	**0**	**0**	**0**	**0**

Source: Model output

Note:

54 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield (see note 1). The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

55 Total P input is the sum of P input from manure and from fertilizer.

56 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

57 Soil P surplus is calculated as P input per hectare minus P removed per hectare (see notes 13 and 14).

58 P agronomic balance is calculated as P input per hectare minus P required per hectare (see notes 10 and 11).

Table 6.4a – Model outputs on a per-crop basis for the model of medium Ontario dairy farms: Base solution

Model Outputs by Crop		Crops					
	Units	Corn	Corn Silage	Alfalfa Hay	Alfalfa Haylage	Soybeans	Wheat
Land Used	**ha**	**24.85**	**23.90**	**27.13**	**21.62**	**16.25**	**16.25**
Yield[59]	**metric tons/ha/yr**	6.309	10.55	10.89	10.2	2.5	4.8
Crop Produced[60]	**metric tons/yr**	156.8	252.0	295.5	220.50	40.63	78.00
% sold		33.59%	0%	77.78%	0%	100%	100%
% fed		66.41%	100%	22.22%	100%	0%	0%
Crop Purchased[61]	**metric tons/yr**	0	0	0	0		
Manure Applied[62]	**metric tons/yr**	71.89	69.02	38.19	57.75	18.87	28.28
N fertilizer Applied	kg/yr	0	0	0	0	0	711.5
P fertilizer Applied	kg/yr	171.0	167.7	134.5	286.3	270.2	0.0
K fertilizer Applied	kg/yr	0	0	885.7	0	0	0

Source: Model output

Notes:

59 Yield of each crop is measured in metric tons of dry matter per hectare. Yield for alfalfa hay, alfalfa haylage, soybeans, and wheat are calibrated to 2008 yield estimates in Oxford County, referenced from the NMAN2 Software (OMAFRA, undated). Corn and corn silage yield is determined by a quadratic N-response yield function (see Chapter 5).

60 Crop produced is measured in metric tons of dry matter, and is calculated as the yield of each crop multiplied by land used for production for each crop. All corn silage and alfalfa haylage produced must be used for feed, and all soybeans and wheat produced must be sold.

61 Crop purchased is measured in metric tons of dry matter. Soybeans and wheat cannot be purchased.

62 Manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.4b – Per-hectare N balances on a per-crop basis for the model of medium Ontario dairy farms: Base solution

Nutrient Balance by Crop		Crops					
	Units	Corn	Corn Silage	Alfalfa Hay	Alfalfa Haylage	Soybeans	Wheat
N Balances by Crop							
N Requirement per ha[63]	kg/ha/yr	127.4	127.2	276.4	306.4	240.7	155.7
N input per ha[64]	**kg/ha/yr**	**127.4**	**127.2**	**316.4**	**388.9**	**272.5**	**155.7**
from manure	kg/ha/yr	97.28	97.12	47.34	89.83	39.06	58.52
from fertilizer	kg/ha/yr	0	0	0	0	0	43.78
from other input[65]	kg/ha/yr	30.07	30.07	269.1	299.1	233.4	53.40
N Removal per ha[66]	kg/ha/yr	109.4	200.2	351.0	319.0	161.0	156.0
N surplus per ha[67]	**kg/ha/yr**	**17.97**	**-73.00**	**-34.60**	**69.90**	**111.5**	**-0.3000**
N Agronomic Balance per ha[68]	**kg/ha/yr**	**0**	**0**	**40.04**	**82.53**	**31.76**	**0**

Source: Model output

63 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

64 N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

65 N from other sources is the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

66 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

67 Soil N surplus is calculated as N input per hectare minus N removed per hectare (see note 8).

68 N agronomic balance is calculated as N input per hectare minus N required per hectare (see note 5).

Table 6.4c – Per-hectare P balances on a per-crop basis for the model of medium Ontario dairy farms: Base solution

Nutrient Balance by Crop		Crops					
	Units	Corn	Corn Silage	Alfalfa Hay	Alfalfa Haylage	Soybeans	Wheat
P Balances by Crop							
P Requirement per ha[69]	kg/ha/yr	90	90	90	90	50	50
P input per ha[70]	**kg/ha/yr**	90.00	90.00	90.00	90.00	50.00	50.00
from manure	kg/ha/yr	83.12	82.98	40.44	76.76	33.37	50.00
from fertilizer	kg/ha/yr	6.879	7.019	49.56	13.24	16.63	0.00
P Removal per ha[71]	kg/ha/yr	82.04	74.71	53.08	53.08	57.60	42.46
P surplus per ha[72]	**kg/ha/yr**	**7.964**	**15.30**	**36.92**	**36.92**	**-7.600**	**7.540**
P Agronomic Balance per ha[73]	**kg/ha/yr**	0	0	0	0	0	0

Source: Model output

Note:

69 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield (see note 1). The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

70 Total P input is the sum of P input from manure and from fertilizer.

71 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

72 Soil P surplus is calculated as P input per hectare minus P removed per hectare (see notes 13 and 14).

73 P agronomic balance is calculated as P input per hectare minus P required per hectare (see notes 10 and 11).

Table 6.5a – Model outputs on a per-crop basis for the model of large Ontario dairy farms: Base solution

Model Outputs by Crop		Crops					
	Units	Corn	Corn Silage	Alfalfa Hay	Alfalfa Haylage	Soybeans	Wheat
Land Used	**ha**	**18.26**	**56.74**	**22.50**	**52.50**	**25.00**	**25.00**
Yield[74]	**metric tons/ha/yr**	6.45	10.79	10.89	10.2	2.5	4.8
Crop Produced[75]	**metric tons/yr**	117.8	612.1	245.0	535.5	62.50	120.0
% sold		0%	0%	34.91%	0%	100%	100%
% fed		100%	100%	65.09%	100%	0%	0%
Crop Purchased[76]	**metric tons/yr**	135.1	0	0	0	0	0
Manure Applied[77]	**metric tons/yr**	73.88	229.6	70.47	196.2	43.50	76.05
N fertilizer Applied	kg/yr	0.00	0.0	0.0	0.0	0.0	0.0
P fertilizer Applied	kg/yr	0.00	0.0	0.0	0.0	0.0	0.0
K fertilizer Applied	kg/yr	0	0	0	0	0	0

Source: Model output

Notes:

74 Yield of each crop is measured in metric tons of dry matter per hectare. Yield for alfalfa hay, alfalfa haylage, soybeans, and wheat are calibrated to 2008 yield estimates in Oxford County, referenced from the NMAN2 Software (OMAFRA, undated). Corn and corn silage yield is determined by a quadratic N-response yield function (see Chapter 5).

75 Crop produced is measured in metric tons of dry matter, and is calculated as the yield of each crop multiplied by land used for production for each crop. All corn silage and alfalfa haylage produced must be used for feed, and all soybeans and wheat produced must be sold.

76 Crop purchased is measured in metric tons of dry matter. Soybeans and wheat cannot be purchased.

77 Manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.5b – Per-hectare N balances on a per-crop basis for the model of large Ontario dairy farms: Base solution

Nutrient Balance by Crop		Crops					
	Units	Corn	Corn Silage	Alfalfa Hay	Alfalfa Haylage	Soybeans	Wheat
N Balances by Crop							
N Requirement per ha[78]	kg/ha/yr	166.1	166.1	276.4	306.4	240.7	155.7
N input per ha[79]	**kg/ha/yr**	**166.1**	**166.1**	**374.4**	**424.8**	**291.9**	**155.7**
from manure	kg/ha/yr	136.1	136.1	105.3	125.7	58.52	102.3
from fertilizer	kg/ha/yr	0	0	0	0	0	0
from other input[80]	kg/ha/yr	30.07	30.07	269.1	299.1	233.4	53.40
N Removal per ha[81]	kg/ha/yr	111.9	204.8	351.0	319.0	161.0	156.0
N surplus per ha[82]	**kg/ha/yr**	**54.28**	**-38.63**	**23.40**	**105.8**	**130.9**	**-0.3000**
N Agronomic Balance per ha[83]	**kg/ha/yr**	**0**	**0**	**98.03**	**118.4**	**51.22**	**0**

Source: Model output

78 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

79 N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

80 N from other sources is the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

81 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

82 Soil N surplus is calculated as N input per hectare minus N removed per hectare (see note 8).

83 N agronomic balance is calculated as N input per hectare minus N required per hectare (see note 5).

Table 6.5c – Per-hectare P balances on a per-crop basis for the model of large Ontario dairy farms: Base solution

Nutrient Balance by Crop		Crops					
	Units	Corn	Corn Silage	Alfalfa Hay	Alfalfa Haylage	Soybeans	Wheat
P Balances by Crop							
P Requirement per ha[84]	kg/ha/yr	90	90	90	90	50	50
P input per ha[85]	**kg/ha/yr**	116.3	116.3	90.00	107.4	50.00	87.41
from manure	kg/ha/yr	116.3	116.3	90.00	107.4	50.00	87.41
from fertilizer	kg/ha/yr	0	0	0	0	0	0
P Removal per ha[86]	kg/ha/yr	83.90	76.41	53.08	53.08	57.60	42.46
P surplus per ha[87]	**kg/ha/yr**	**32.37**	**39.85**	**36.92**	**54.31**	**-7.60**	**44.95**
P Agronomic Balance per ha[88]	**kg/ha/yr**	90	90	90	90	50	50

Source: Model output

Note:

84 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield (see note 1). The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

85 Total P input is the sum of P input from manure and from fertilizer.

86 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

87 Soil P surplus is calculated as P input per hectare minus P removed per hectare (see notes 13 and 14).

88 P agronomic balance is calculated as P input per hectare minus P required per hectare (see notes 10 and 11).

rental value of $300/ha, whereas the shadow value of land for the large farm model is over twice the rental value. This large shadow value reflects the higher profitability of land owned by the large farm for two reasons: firstly, the large farm is able to supply enough nutrients required for crop production through manure alone, without having to purchase any additional fertilizer at all; secondly, by looking at the model output on a per-crop basis. In Tables 6.3 and 6.4, neither the small or medium farm models purchased additional feed, whereas Table 6.5 revealed that the large farm model purchased over 135 metric tons (in dry matter basis) of high moisture corn to feed the herd. By increasing the land base, the large farm can grow additional crops for feed at a lower per-hectare cost, as well as reduce the cost incurred by feed purchases. The shadow value of barn capacity reflects the opposite pattern compared to the shadow value of land: the shadow value of barn capacity for the small and medium farm models is almost twice as high compared to that of the large farm model. This occurs because the small and medium farms currently have the land base to grow more than enough feed crops to support a larger herd, and a larger herd also provides more manure that is a cheaper source of nutrients for crop growth compared to commercial fertilizers.

There are also differences in the soil N and P surplus and the N and P agronomic balances for the small, medium, and large farm models. Table 6.2 presents the N and P soil balances for the three farm models. Soil N surplus is negative for the small farm model, and positive for the medium and large farm models. N agronomic balance, however, is positive for all three of the farm models. On the per-hectare nutrient balances of the small farm presented in Table 6.3, it is shown that the positive contribution to the soil N surplus through soybean is offset by a negative soil N surplus from growing corn silage. The same pattern is shown for the medium farm model on Table 6.4. For the large farm, however, Table 6.5 shows that growing alfalfa haylage is also a major contributor to a positive soil N surplus. The source of the N surplus on alfalfa haylage land is mainly from over-application of manure.

For the N agronomic balance, Table 6.3 shows that growing alfalfa hay, alfalfa haylage, and soybeans all contribute to a positive N agronomic balance in the small farm: since almost all of the N requirements for these crops come from symbiotic fixation, almost all of the N supplied by manure is excess of the N requirement of the crop. The same pattern is generated by the medium and large farm model, shown on Tables 6.4 and 6.5 respectively.

For the soil P balance, Table 6.2 shows that the small and medium farm models both generated a soil P surplus of approximately 18 kg/ha/yr, with the large farm model generating a soil P surplus double of that, at over 36kg/ha/yr. Table 6.3 shows that for the small farm model, alfalfa and alfalfa haylage are the main contributors to the positive P surplus, and Tables 6.4 shows that this pattern holds true for the medium farm model. For the large farm model, however, Table 6.5 shows that all of the crops except for soybeans become major contributors to the positive soil P surplus.

The soil P surplus results for the three farm models are strongly driven by P requirements of the crops. For the small and medium farms, Table 6.2 shows that the agronomic P balance for both models is 0, meaning that the P input is just meeting crop P requirements. This is not the case for the large farm model, with a positive agronomic P balance of over 19kg/ha/yr. Table 6.5 reveals that except for alfalfa hay and soybeans, P is being applied over the crop P requirement for all other crops. Since manure is the only source of P in the large farm model, this shows the herd size generates enough manure to exceed crop requirement as well as crop removal for both N and P.

Raising and lowering the soil P levels affects the net return and the soil P balances of the three farm models differently. Table 6.6 compares the model output and the nutrient balances of the small farm model when different soil P values were modeled. When modeled with a lower soil P value, net return of the model dropped by 12%, accompanied with a 34% drop in the shadow value of land, and a 117% increase in P fertilizer purchase. The fact that agronomic P balances remains at 0kg/L reveals that the increase in P fertilizer is necessary to meet the higher P requirement in a low soil P environment. Note that the P removal value did not change, leading to an increase in soil P surplus of 252%. Modeling with a higher soil P value of 10-12mg/L had the opposite effect: the 55% lower P requirement almost eliminated the need for P fertilizers, translating to a negative soil P surplus, 51% higher shadow value of land and a higher net return of 10% compared to the model output based on the base soil P value of 6-7mg/L. Note that since the P requirement of all crops are lower compared to the base model, the agronomic P balance is now positive, as the P from manure is more than enough to meet crop requirement.

Table 6.7 compares the model output and nutrient balances of the medium farm model when modeled with different soil P values, and shows similar patterns compared to the small farm model. The medium farm model with lower soil P test values gives similar percentage changes compared to the small farm modeled with lower soil P test value. However, the percentage changes in net return and soil P surplus is less for the medium farm model when modeled with a higher soil P value, with a net return only 4% higher

Table 6.6a – Comparison of model output, assuming higher or lower soil P test values, for the model of small Ontario dairy farms: Base solution

Program Outputs	Units	Original P soil value[89] 6-7mg/L	Lower P soil value[1] 0-3mg/L	% change from base solution	Higher P soil value[1] 10-12mg/L	% change from base solution
Net Return	**$/yr**	**$47,210**	**$41,537**	**-12%**	**$51,877**	**10%**
Milking Herd Size[90]	cows	30	30	0%	30	0%
Total Land Used	ha	60	60	0%	60	0%
Shadow Value of Land	$/ha/yr	$276	$182	-34%	$418	51%
Shadow Value of Barn	$/yr	$1,021	$1,021	0%	$894	-12%
Total Manure Applied[91]	metric tons/yr	165.4	165.4	0%	165.4	0%
N fertilizer purchased	metric tons/yr	1.464	1.464	0%	1.494	2%
P fertilizer purchased	metric tons/yr	2.443	5.308	117%	0.056	-98%
K fertilizer purchased	metric tons/yr	0	0		0	

Source: model outputs

Notes:

89 Crops grown on soil with low soil P value have high per-hectare P requirements, and low per-hectare P requirements in soil with high soil P values. See Table 5.10 for P requirement values associated with soil P values.

90 Milking herd size only counts the number of milking age cows. Models assume number of heifers equals number of milking age cows.

91 Total manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.6b – Comparison of N balances, assuming higher or lower soil P test values, for the model of small Ontario dairy farms: Base solution

N Balances	Units	Original P soil value[92] 6-7mg/L	Lower P soil value[1] 0-3mg/L	% change from base solution	Higher P soil value[1] 10-12mg/L	% change from base solution
Total N required[93,94]	metric tons/yr	11.91	11.91	0%	11.91	0%
Total N input[95]	**metric tons/yr**	**12.53**	**12.53**	**0%**	**12.56**	**0%**
from manure	metric tons/yr	1.911	1.911	0%	1.911	0%
from fertilizer	metric tons/yr	1.464	1.464	0%	1.494	2%
from other sources[96]	metric tons/yr	9.160	9.160	0%	9.160	0%
Total N Removed[97,98]	metric tons/yr	13.30	13.30	0%	13.30	0%
Soil N surplus / ha[99]	**kg/ha/yr**	**-12.78**	**-12.78**	**0%**	**-12.28**	**4%**
N agronomic balance / ha[100]	**kg/ha/yr**	**10.47**	**10.47**	**0%**	**10.97**	**5%**

Source: model outputs

Notes:

92 Crops grown on soil with low soil P value have high per-hectare P requirements, and low per-hectare P requirements in soil with high soil P values. See Table 5.10 for P requirement values associated with soil P values.

93 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

94 Total N required is the sum of the per-hectare N requirement of each crop (see note 2) times land used for production of each crop.

95 Total N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

96 N from other sources is calculated as the hectares of land used multiplied by the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

97 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

98 Total N removed is the sum of the per-hectare N removal rate (see note 8) of each crop times land used for production of each crop.

99 Soil N surplus is calculated as total N input minus total N removed (see notes 8 and 9), divided by total land use.

100 N agronomic balance is calculated as total N input minus total N required (see notes 4 and 5), divided by total land use.

Table 6.6c – Comparison of P balances, assuming higher or lower soil P test values, for the model of small Ontario dairy farms: Base solution

P Balances		Units	Original P soil value[101] 6-7mg/L	Lower P soil value[1] 0-3mg/L	% change from base solution	Higher P soil value[1] 10-12mg/L	% change from base solution
Total P Required[102,103]		**metric tons/yr**	**4.800**	**7.665**	**60%**	**2.175**	**-55%**
Total P Input[104]		**metric tons/yr**	**4.800**	**7.665**	**60%**	**2.413**	**-50%**
	from manure	metric tons/yr	2.357	2.357	0%	2.357	0%
	from fertilizer	metric tons/yr	2.443	5.308	117%	0.05572	-98%
Total P Removed[105,106]		metric tons/yr	3.664	3.664	0%	3.664	0%
Soil P surplus / ha[107]		**kg/ha/yr**	**18.93**	**66.68**	**252%**	**-20.86**	**-210%**
P agronomic balance / ha[108]		**kg/ha/yr**	**0**	**0**		**3.961**	

Source: model outputs

Notes:

101 Crops grown on soil with low soil P value have high per-hectare P requirements, and low per-hectare P requirements in soil with high soil P values. See Table 5.10 for P requirement values associated with soil P values.

102 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield. The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

103 Total P required is the sum of per-hectare P requirement of each crop (see note 12) times land used for production of each crop.

104 Total P input is the sum of P input from manure and from fertilizer

105 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

106 Total P removed is the sum of the per-hectare P removal rate (see note 15) of each crop times land used for production of each crop.

107 Soil P surplus is calculated as total P input minus total P removed (see notes 15 and 16), divided by total land use.

108 P agronomic balance is calculated as total P input minus total P required (see notes 12 and 13), divided by total land use.

Table 6.7a – Comparison of model output, assuming higher or lower soil P test values, for the model of medium Ontario dairy farms: Base solution

Program Outputs	Units	Original P soil value[109] 6-7mg/L	Lower P soil value[1] 0-3mg/L	% change from base solution	Higher P soil value[1] 10-12mg/L	% change from base solution
Net Return	**$/yr**	**$115,211**	**$103,182**	**-10%**	**$120,112**	**4%**
Milking Herd Size[110]	cows	70	70	0%	70	0%
Total Land Used	ha	130	130	0%	130	0%
Shadow Value of Land	$/ha/yr	$279	$187	-33%	$441	58%
Shadow Value of Barn	$/yr	$1,128	$1,128	0%	$897	-20%
Total Manure Applied[111]	metric tons/yr	284.0	284.0	0%	284.0	0%
N fertilizer purchased	metric tons/yr	0.711	0.312	-56%	0	-100%
P fertilizer purchased	metric tons/yr	2.240	8.447	277%	0	-100%
K fertilizer purchased	metric tons/yr	0.8857	1.192	134%	1.432	83%

Source: model outputs

Notes:

109 Crops grown on soil with low soil P value have high per-hectare P requirements, and low per-hectare P requirements in soil with high soil P values. See Table 5.10 for P requirement values associated with soil P values.

110 Milking herd size only counts the number of milking age cows. Models assume number of heifers equals number of milking age cows.

111 Total manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.7b – Comparison of N balances, assuming higher or lower soil P test values, for the model of medium Ontario dairy farms: Base solution

N Balances	Units	Original P soil value[112] 6-7mg/L	Lower P soil value[1] 0-3mg/L	% change from base solution	Higher P soil value[1] 10-12mg/L	% change from base solution
Total N required[113,114]	metric tons/yr	26.77	26.77	0%	26.77	0%
Total N input[115]	**metric tons/yr**	**30.15**	**29.75**	**-1%**	**29.44**	**-2%**
from manure	metric tons/yr	9.551	9.551	0%	9.551	0%
from fertilizer	metric tons/yr	0.711	0.312	-56%	0	-100%
from other sources[116]	metric tons/yr	19.89	19.89	0%	19.89	0%
Total N Removed[117,118]	metric tons/yr	29.07	29.07	0%	29.07	0%
Soil N surplus / ha[119]	**kg/ha/yr**	**8.31**	**5.24**	**-37%**	**2.84**	**-66%**
N agronomic balance / ha[120]	**kg/ha/yr**	**26.05**	**22.98**	**-12%**	**20.58**	**-21%**

Source: model outputs

Notes:

112 Crops grown on soil with low soil P value have high per-hectare P requirements, and low per-hectare P requirements in soil with high soil P values. See Table 5.10 for P requirement values associated with soil P values.

113 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

114 Total N required is the sum of the per-hectare N requirement of each crop (see note 2) times land used for production of each crop.

115 Total N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

116 N from other sources is calculated as the hectares of land used multiplied by the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

117 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

118 Total N removed is the sum of the per-hectare N removal rate (see note 8) of each crop times land used for production of each crop.

119 Soil N surplus is calculated as total N input minus total N removed (see notes 8 and 9), divided by total land use.

120 N agronomic balance is calculated as total N input minus total N required (see notes 4 and 5), divided by total land use.

Table 6.7c – Comparison of P balances, assuming higher or lower soil P test values, for the model of medium Ontario dairy farms: Base solution

P Balances		Units	Original P soil value[121] 6-7mg/L	Lower P soil value[1] 0-3mg/L	% change from base solution	Higher P soil value[1] 10-12mg/L	% change from base solution
Total P Required[122,123]		**metric tons/yr**	10.40	16.61	60%	4.713	-55%
Total P Input[124]		**metric tons/yr**	**10.40**	**16.61**	**60%**	**8.160**	**-22%**
	from manure	metric tons/yr	8.160	8.160	0%	8.160	0%
	from fertilizer	metric tons/yr	2.240	8.447	277%	0	-100%
Total P Removed[125,126]		metric tons/yr	8.038	8.038	0%	8.038	0%
Soil P surplus / ha[127]		**kg/ha/yr**	**18.17**	**65.92**	**263%**	**0.94**	**-95%**
P agronomic balance / ha[128]		**kg/ha/yr**	**0**	**0**		**26.52**	

Source: model outputs

Notes:

121 Crops grown on soil with low soil P value have high per-hectare P requirements, and low per-hectare P requirements in soil with high soil P values. See Table 5.10 for P requirement values associated with soil P values.

122 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield. The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

123 Total P required is the sum of per-hectare P requirement of each crop (see note 12) times land used for production of each crop.

124 Total P input is the sum of P input from manure and from fertilizer

125 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

126 Total P removed is the sum of the per-hectare P removal rate (see note 15) of each crop times land used for production of each crop.

127 Soil P surplus is calculated as total P input minus total P removed (see notes 15 and 16), divided by total land use.

128 P agronomic balance is calculated as total P input minus total P required (see notes 12 and 13), divided by total land use.

than the model with the base soil P test value, paired with a much larger increase in the P agronomic balance. Notice that P fertilizer is a much smaller share of the P input in the medium farm model compared to the small farm; therefore, a reduction in P requirement means a much smaller reduction in P fertilizer cost for the medium farm.

Table 6.8 compares the model output and nutrient balances of the large farm model when modeled with different soil P values, and the changes in net return are even smaller. This is due to the fact that in the large farm model with the base soil P value, manure has already provided more than enough P to meet crop requirement. A reduction in P requirement will not change production practices because the farm will simply apply P over the crop requirement. The large amount of P in manure also buffers the impact on net return when modeled with a higher P requirement, since less P fertilizer needs to be purchased on top of that. Note that when the large farm is modeled with the lower soil P value, the majority of the higher soil P requirement is met using the P from manure that was excess in the base model, with P fertilizer purchase only making up a small share of the P applied.

Scenario 1: Nutrient Management Act (2002)

Scenario 1.1: Herd Size Trigger (Milking herd ≥ 170 head)

Under the nutrient management Act (2002), one of the triggers of the regulations is when the farm has over 300 nutrient units on the farm. For a dairy farm, assuming a Holstein milking herd with an equal number of heifers, the milking herd of 170 exceeds the 300 nutrient unit trigger, making the P application limit based on crop P removal applicable to these farms. The small and medium farm models have barn capacities lower

Table 6.8a – Comparison of model output, assuming higher or lower soil P test values, for the model of large Ontario dairy farms: Base solution

Program Outputs	Units	Original P soil value[129] 6-7mg/L	Lower P soil value[1] 0-3mg/L	% change from base solution	Higher P soil value[1] 10-12mg/L	% change from base solution
Net Return	**$/yr**	**$232,236**	**$219,996**	**-5%**	**$232,236**	**0%**
Milking Herd Size[130]	cows	170	170	0%	170	0%
Total Land Used	ha	200	200	0%	200	0%
Shadow Value of Land	$/ha/yr	$619	$362	-42%	$619	0%
Shadow Value of Barn	$/yr	$638	$868	36%	$638	0%
Total Manure Applied[131]	metric tons/yr	689.7	689.7	0%	689.7	0%
N fertilizer purchased	metric tons/yr	0	0		0	
P fertilizer purchased	metric tons/yr	0	6.142		0	
K fertilizer purchased	metric tons/yr	0	0		0	

Source: model outputs

Notes:

129 Crops grown on soil with low soil P value have high per-hectare P requirements, and low per-hectare P requirements in soil with high soil P values. See Table 5.10 for P requirement values associated with soil P values.

130 Milking herd size only counts the number of milking age cows. Models assume number of heifers equals number of milking age cows.

131 Total manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.8b – Comparison of N balances, assuming higher or lower soil P test values, for the model of large Ontario dairy farms: Base solution

N Balances	Units	Original P soil value[132] 6-7mg/L	Lower P soil value[1] 0-3mg/L	% change from base solution	Higher P soil value[1] 10-12mg/L	% change from base solution
Total N required[133,134]	metric tons/yr	44.67	44.12	-1%	44.67	0%
Total N input[135]	**metric tons/yr**	**54.37**	**54.37**	**0%**	**54.37**	**0%**
from manure	metric tons/yr	23.19	23.19	0%	23.19	0%
from fertilizer	metric tons/yr	0	0	0	0	0
from other sources[136]	metric tons/yr	31.18	31.18	0%	31.18	0%
Total N Removed[137,138]	metric tons/yr	46.23	46.22	0%	46.23	0%
Soil N surplus / ha[139]	**kg/ha/yr**	**40.72**	**40.75**	**0%**	**40.72**	**0%**
N agronomic balance / ha[140]	**kg/ha/yr**	**48.51**	**51.26**	**-100%**	**48.51**	**-100%**

Source: model outputs

Notes:

132 Crops grown on soil with low soil P value have high per-hectare P requirements, and low per-hectare P requirements in soil with high soil P values. See Table 5.10 for P requirement values associated with soil P values.

133 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

134 Total N required is the sum of the per-hectare N requirement of each crop (see note 2) times land used for production of each crop.

135 Total N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

136 N from other sources is calculated as the hectares of land used multiplied by the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

137 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

138 Total N removed is the sum of the per-hectare N removal rate (see note 8) of each crop times land used for production of each crop.

139 Soil N surplus is calculated as total N input minus total N removed (see notes 8 and 9), divided by total land use.

140 N agronomic balance is calculated as total N input minus total N required (see notes 4 and 5), divided by total land use.

Table 6.8c – Comparison of P balances, assuming higher or lower soil P test values, for the model of medium Ontario dairy farms: Base solution

P Balances		Units	Original P soil value[141] 6-7mg/L	Lower P soil value[1] 0-3mg/L	% change from base solution	Higher P soil value[1] 10-12mg/L	% change from base solution
Total P Required[142,143]		**metric tons/yr**	16.000	25.550	60%	7.250	-55%
Total P Input[144]		**metric tons/yr**	**19.82**	**25.96**	**31%**	**19.82**	**0%**
	from manure	metric tons/yr	19.82	19.82	0%	19.82	0%
	from fertilizer	metric tons/yr	0	6.142	0	0	0
Total P Removed[145,146]		metric tons/yr	12.35	12.35	0%	12.35	0%
Soil P surplus / ha[147]		**kg/ha/yr**	**37.34**	**68.08**	**82%**	**37.34**	**0%**
P agronomic balance / ha[148]		**kg/ha/yr**	**19.09**	**2.501**	**-89%**	**62.84**	**229%**

Source: model outputs

Notes:

141 Crops grown on soil with low soil P value have high per-hectare P requirements, and low per-hectare P requirements in soil with high soil P values. See Table 5.10 for P requirement values associated with soil P values.

142 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield. The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

143 Total P required is the sum of per-hectare P requirement of each crop (see note 12) times land used for production of each crop.

144 Total P input is the sum of P input from manure and from fertilizer

145 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

146 Total P removed is the sum of the per-hectare P removal rate (see note 15) of each crop times land used for production of each crop.

147 Soil P surplus is calculated as total P input minus total P removed (see notes 15 and 16), divided by total land use.

148 P agronomic balance is calculated as total P input minus total P required (see notes 12 and 13), divided by total land use.

Table 6.9a – Compliance cost of a large Ontario dairy farm under a more restrictive Nutrient Management Act (2002)[149]: 75% lower application limit[150].

Program Outputs	Units	Base Solution	Solution in regulated scenario	% change from base solution
Compliance Cost	**$/yr**		**$22,565**	
Net Return	**$/yr**	**$232,236**	**$209,671**	**-10%**
Milking Herd Size[151]	cows	170	139	-18%
Total Land Used	ha	200	200	0%
Shadow Value of Land	$/ha/yr	$619	$1,048	69%
Shadow Value of Barn	$/cow/yr	$638	$0	-100%
Total Manure Applied[152]	metric tons/yr	689.7	565.1	-18%
N fertilizer purchased	metric tons/yr	0	0.8146	
P fertilizer purchased	metric tons/yr	0	0	
K fertilizer purchased	metric tons/yr	0	0	

Source: model output

Notes:

149 The Nutrient Management Act (2002) includes a regulation that limits the per-hectare P application rate to less than 390kg/ha over per-hectare P removal (see note 16) over 5 years. The model takes the annual average of the regulation and translate it to an application limit of less than 78kg/ha/yr over the per-hectare P removal rate.

150 The lower application limit is 75% of the 75kg/ha/yr, reducing it to 19.5kg/ha/yr

151 Milking herd size only counts the number of milking age cows. Models assume number of heifers equals number of milking age cows.

152 Total manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.9b – N balances of a large Ontario dairy farm under a more restrictive Nutrient Management Act (2002)[153]: 75% lower application limit[154].

Program Outputs	Units	Base Solution	Solution in regulated scenario	% change from base solution
N Balances				
Total N required[155,156]	metric tons/yr	44.67	42.08	-6%
Total N input[157]	**metric tons/yr**	**54.37**	**50.72**	**-7%**
from manure	metric tons/yr	23.19	19.01	-18%
from fertilizer	metric tons/yr	0	0.8146	
from other sources[158]	metric tons/yr	31.18	30.90	-1%
Total N Removed[159,160]	metric tons/yr	46.23	45.47	-2%
Soil N surplus / ha[161]	**kg/ha/yr**	**40.72**	**26.25**	**-36%**
N agronomic balance / ha[162]	**kg/ha/yr**	**48.51**	**43.16**	**-11%**

Source: model output

Notes:

153 The Nutrient Management Act (2002) includes a regulation that limits the per-hectare P application rate to less than 390kg/ha over per-hectare P removal (see note 16) over 5 years. The model takes the annual average of the regulation and translate it to an application limit of less than 78kg/ha/yr over the per-hectare P removal rate.

154 The lower application limit is 75% of the 75kg/ha/yr, reducing it to 19.5kg/ha/yr

155 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

156 Total N required is the sum of the per-hectare N requirement of each crop (see note 2) times land used for production of each crop.

157 Total N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

158 N from other sources is calculated as the hectares of land used multiplied by the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

159 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

160 Total N removed is the sum of the per-hectare N removal rate (see note 8) of each crop times land used for production of each crop.

161 Soil N surplus is calculated as total N input minus total N removed (see notes 8 and 9), divided by total land use.

162 N agronomic balance is calculated as total N input minus total N required (see notes 4 and 5), divided by total land use.

Table 6.9c – P balances of a large Ontario dairy farm under a more restrictive Nutrient Management Act (2002)[163]: 75% lower application limit[164].

Program Outputs	Units	Base Solution	Solution in regulated scenario	% change from base solution
P Balances				
Total P Required[165,166]	metric tons/yr	16.00	16.00	0%
Total P Input[167]	**metric tons/yr**	**19.82**	**16.24**	**-18%**
from manure	metric tons/yr	19.82	16.24	-18%
from fertilizer	metric tons/yr	0	0	
Total P Removed[168,169]	metric tons/yr	12.35	12.34	0%
Soil P surplus / ha[170]	**kg/ha/yr**	**37.34**	**19.50**	**-48%**
P agronomic balance / ha[171]	**kg/ha/yr**	**19.09**	**1.196**	**94%**

Source: model output

Notes:

[163] The Nutrient Management Act (2002) includes a regulation that limits the per-hectare P application rate to less than 390kg/ha over per-hectare P removal (see note 16) over 5 years. The model takes the annual average of the regulation and translate it to an application limit of less than 78kg/ha/yr over the per-hectare P removal rate.

[164] The lower application limit is 75% of the 75kg/ha/yr, reducing it to 19.5kg/ha/yr

[165] P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield. The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

[166] Total P required is the sum of per-hectare P requirement of each crop (see note 12) times land used for production of each crop.

[167] Total P input is the sum of P input from manure and from fertilizer

[168] P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

[169] Total P removed is the sum of the per-hectare P removal rate (see note 15) of each crop times land used for production of each crop.

[170] Soil P surplus is calculated as total P input minus total P removed (see notes 15 and 16), divided by total land use.

[171] P agronomic balance is calculated as total P input minus total P required (see notes 12 and 13), divided by total land use.

than the herd size trigger, meaning that the regulation only applies to the large farm model.

In the models, the current Nutrient Management Regulation restricting the P application to below 390kg/ha above crop removal values over five years is translated to restricting the P surplus per ha to below 78kg/ha/yr. Given this regulatory trigger, the large farms do not incur any compliance costs. Table 6.2 shows that for the large farm model, the soil P surplus value is at 37.34kg/ha/yr, well below the regulatory limit of 78kg/ha/yr. Thus, the current regulation under the Nutrient Management Act (2002) does not generate any compliance costs for the large farms under a herd size trigger. Even for lower soil P test values, forcing the large farm model to increase P application to meet increased crop P requirements, the soil P surplus raises to 68.08kg/ha/yr, remaining below the regulatory limit of 78kg/ha/yr.

Scenario 1.2: Barn Expansion Trigger

Another trigger for the Nutrient Management Act (2002) regulation is when a farm expands the barn or manure storage capacity, regardless of herd size. This is simulated by allowing all three farm models to increase barn capacity by 10%. No compliance costs were observed for the three farm models, even when modeled with a lower soil P value, which raises the crop P requirements, because soil P surplus remains below the regulatory limit of 78kg/ha/yr for all three farm models.

Scenario 1.3: Stricter Application Limit: P application < crop removed P + 19.5kg/ha/yr

For the first of the sub-scenarios where the regulation under the Nutrient Management Act (2002) is made stricter, a 75% reduction of the current P application limit of 78kg/ha/yr above crop removal is chosen, reducing the application limit to

19.5kg/ha/yr above crop removal. This rate of reduction is chosen arbitrarily to examine the impact of a binding P-removal based regulations on the large farm model. The compliance cost for the large farm model under the more restrictive regulations is presented in Table 6.9. The stricter regulations restricts the farm's soil P surplus to 19.5kg/ha/yr. Meeting this standard reduces net return by $22,565, a 20% reduction compared to the base solution. The source of the compliance cost is due to an 18% reduction in herd size, in order to reduce the amount of P generated by manure. Because manure is also a source of N, a reduction in the manure generated increases the amount of N fertilizer purchased. Land shadow values increases to $1,048/ha, since additional land allows more manure to be applied, which relaxes the restriction on herd size, and subsequently increases milk production.

When the stricter regulation is applied to the three farm models for lower soil P test values (and therefore higher crop P requirement), infeasibility occurs for all models, and all farm models report a net return of $0/yr. This is because with the strict regulation, farms with low soil P test values will find crop P requirements larger than the regulatory limit based on crop P removal values, since nutrient removal values are independent of soil nutrient values. Compliance with highly restrictive crop P-removal based regulations will be impossible for farms with very low soil P to begin with, because of the differences in how soil P removal and soil P requirement are calculated.

When the stricter regulation is applied to the three farm models for a higher soil P test values (and therefore lower crop P requirement), the compliance costs for the small and medium farm models are still zero. Table 6.10 presents the model output and nutrient balances of the large farm model under the more restrictive application limit when

Table 6.10a – Compliance cost of a large Ontario dairy farm under a more restrictive Nutrient Management Act (2002)[172] at 75% lower application limit[173]: assuming higher soil P test values.

Program Outputs	Units	Base solution with higher P soil value[174] 10-12mg/L	Regulated scenario with higher P soil value[3] 10-12mg/L	% change from base solution with higher P soil value
Compliance Cost	**$/yr**		**$19,786**	
Net Return	**$/yr**	**$232,236**	**$212,450**	**-9%**
Milking Herd Size[175]	cows	170	140	-18%
Total Land Used	ha	200	200	0%
Shadow Value of Land	$/ha/yr	$619	$1,062	72%
Shadow Value of Barn	$/cow/yr	$638	$0	-100%
Total Manure Applied[176]	metric tons/yr	689.7	567.0	-18%
N fertilizer purchased	metric tons/yr	0	0	
P fertilizer purchased	metric tons/yr	0	0	
K fertilizer purchased	metric tons/yr	0	0	

Source: model output

Notes:

172 The Nutrient Management Act (2002) includes a regulation that limits the per-hectare P application rate to less than 390kg/ha over per-hectare P removal (see note 16) over 5 years. The model takes the annual average of the regulation and translate it to an application limit of less than 78kg/ha/yr over the per-hectare P removal rate.

173 The lower application limit is 75% of the 75kg/ha/yr, reducing it to 19.5kg/ha/yr.

174 Crops grown on soil with high soil P value have low per-hectare P requirements. See Table 5.10 for P requirement values associated with soil P values.

175 Milking herd size only counts the number of milking age cows. Models assume number of heifers equals number of milking age cows.

176 Total manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.10b – N balances of a large Ontario dairy farm under a more restrictive Nutrient Management Act (2002)[177] at 75% lower application limit[178]: assuming higher soil P test values.

Program Outputs	Units	Base solution with higher P soil value[179] 10-12mg/L	Regulated scenario with higher P soil value[3] 10-12mg/L	% change from base solution with higher P soil value
N Balances				
Total N required[180,181]	metric tons/yr	44.67	42.99	-4%
Total N input[182]	**metric tons/yr**	**54.37**	**49.97**	**-8%**
from manure	metric tons/yr	23.19	19.07	-18%
from fertilizer	metric tons/yr	0	0	
from other sources[183]	metric tons/yr	31.18	30.90	-1%
Total N Removed[184,185]	metric tons/yr	46.23	45.55	-1%
Soil N surplus / ha[186]	**kg/ha/yr**	**40.72**	**22.10**	**-46%**
N agronomic balance / ha[187]	**kg/ha/yr**	**48.51**	**34.92**	**-28%**

Source: model output

Notes:

177 The Nutrient Management Act (2002) includes a regulation that limits the per-hectare P application rate to less than 390kg/ha over per-hectare P removal (see note 16) over 5 years. The model takes the annual average of the regulation and translate it to an application limit of less than 78kg/ha/yr over the per-hectare P removal rate.

178 The lower application limit is 75% of the 75kg/ha/yr, reducing it to 19.5kg/ha/yr.

179 Crops grown on soil with high soil P value have low per-hectare P requirements. See Table 5.10 for P requirement values associated with soil P values.

180 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

181 Total N required is the sum of the per-hectare N requirement of each crop (see note 2) times land used for production of each crop.

182 Total N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

183 N from other sources is calculated as the hectares of land used multiplied by the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

184 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

185 Total N removed is the sum of the per-hectare N removal rate (see note 8) of each crop times land used for production of each crop.

186 Soil N surplus is calculated as total N input minus total N removed (see notes 8 and 9), divided by total land use.

187 N agronomic balance is calculated as total N input minus total N required (see notes 4 and 5), divided by total land use.

Table 6.10c – Compliance cost of a large Ontario dairy farm under a more restrictive Nutrient Management Act (2002)[188] at 75% lower application limit[189]: assuming higher soil P test values.

Program Outputs	Units	Base solution with higher P soil value[190] 10-12mg/L	Regulated scenario with higher P soil value[3] 10-12mg/L	% change from base solution with higher P soil value
P Balances				
Total P Required[191,192]	metric tons/yr	7.25	7.250	-55%
Total P Input[193]	**metric tons/yr**	**19.82**	**16.29**	**-18%**
from manure	metric tons/yr	19.82	16.29	-18%
from fertilizer	metric tons/yr	0	0	
Total P Removed[194,195]	metric tons/yr	12.35	12.39	0%
Soil P surplus / ha[196]	**kg/ha/yr**	**37.34**	**19.50**	**-48%**
P agronomic balance / ha[197]	**kg/ha/yr**	**62.84**	**45.22**	**-28%**

Source: model output

Notes:

188 The Nutrient Management Act (2002) includes a regulation that limits the per-hectare P application rate to less than 390kg/ha over per-hectare P removal (see note 16) over 5 years. The model takes the annual average of the regulation and translate it to an application limit of less than 78kg/ha/yr over the per-hectare P removal rate.

189 The lower application limit is 75% of the 75kg/ha/yr, reducing it to 19.5kg/ha/yr.

190 Crops grown on soil with high soil P value have low per-hectare P requirements. See Table 5.10 for P requirement values associated with soil P values.

191 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield. The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

192 Total P required is the sum of per-hectare P requirement of each crop (see note 12) times land used for production of each crop.

193 Total P input is the sum of P input from manure and from fertilizer

194 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

195 Total P removed is the sum of the per-hectare P removal rate (see note 15) of each crop times land used for production of each crop.

196 Soil P surplus is calculated as total P input minus total P removed (see notes 15 and 16), divided by total land use.

197 P agronomic balance is calculated as total P input minus total P required (see notes 12 and 13), divided by total land use.

modeled with a higher soil P value, reducing the crop P requirement. The compliance cost in this case is $19,786, approximately 9% of the net return in the base model assuming a higher soil P. Under the stricter crop P-removal based regulation, a large farm with high soil P will have similar compliance cost compared with a large farm with an faverage soil P. The main difference between the two situations is that the model assuming the base soil P value has a larger reduction in agronomic P compared to the model assuming a higher soil P value.

By exporting manure or renting extra land, the large farm model can reduce most of the cost of complying with the more restrictive crop P-removal based regulation. Table 6.11 presents the compliance cost of a large dairy farm under the more restrictive regulation, when the farm is able to export manure at a cost 10% above the cost of manure application, or rent land at a cost of $300/ha up to 10% of the land base. Given an option to export manure, the large farm model is able to reduce the compliance cost to $3,393/yr, or 1% of the net return in the base solution. By exporting 127.2 metric tons of manure off the farm per year, the large farm model increases its milking herd size back to 170 head. Given the option to rent land, the large farm is also able to reduce the compliance cost of the regulation to $7,598/yr, or 3% of the base net return. The reduction in compliance cost is less if the farm chooses to rent land rather than export manure, since the 10% increase in land base is not enough for the farm to spread manure for the herd size in the base scenario while staying within the regulatory limit.

Scenario 1.4: Stricter Application Limit: P application < crop P removal + 15kg/ha/yr

For the second of the sub-scenarios where the regulation under the Nutrient Management Act (2002) is made stricter, a 79% reduction of the current P-removal

Table 6.11a – Compliance cost of a large Ontario dairy farm under a more restrictive Nutrient Management Act (2002)[198] at 75% lower application limit[199]: allowing for manure export[200] or land rental[201].

Program Outputs	Units	Base Solution	Regulated scenario with manure export	% change from base solution	Regulated scenario with land rental	% change from base solution
Compliance Cost	**$/yr**		**$3,393**		**$7,598**	
Net Return	**$/yr**	**$232,236**	**$228,842**	**-1%**	**$224,638**	**-3%**
Milking Herd Size[202]	cows	170	170	0%	153	-10%
Total Land Used	ha	200	200	0%	220	10%
Shadow Value of Land	$/ha/yr	$619	$613	-1%	$1,048	69%
Shadow Value of Barn	$/cow/yr	$638	$625	-2%	$0	-100%
Total Manure Applied[203]	metric tons/yr	689.7	562.5	-18%	621.7	-10%
Total Manure Exported	metric tons/yr	0	127.2		0	
N fertilizer purchased	metric tons/yr	0	0.9044		0.8961	
P fertilizer purchased	metric tons/yr	0	0		0	
K fertilizer purchased	metric tons/yr	0	0		0	

Source: program output

Notes:

198 The Nutrient Management Act (2002) includes a regulation that limits the per-hectare P application rate to less than 390kg/ha over per-hectare P removal (see note 16) over 5 years. The model takes the annual average of the regulation and translate it to an application limit of less than 78kg/ha/yr over the per-hectare P removal rate.

199 The lower application limit is 75% of the 75kg/ha/yr, reducing it to 19.5kg/ha/yr.

200 Manure export allow the farm to remove manure from the farm at a cost of 10% above manure application cost

201 Land rental allows the farm to rent additional land at a cost of $300/ha, and is restricted to rent no more than 10% of its land base.

202 Milking herd size only counts the number of milking age cows. Models assume number of heifers equals number of milking age cows.

203 Total manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.11b – N balances of a large Ontario dairy farm under a more restrictive Nutrient Management Act (2002)[204] at 75% lower application limit[205]: allowing for manure export[206] or land rental[207].

Program Outputs	Units	Base Solution	Regulated scenario with manure export	% change from base solution	Regulated scenario with land rental	% change from base solution
N Balances						
Total N required[208,209]	metric tons/yr	44.67	42.37	-5%	46.29	4%
Total N input[210]	**metric tons/yr**	**54.37**	**51.00**	**-6%**	**55.79**	**3%**
from manure	metric tons/yr	23.19	18.92	-18%	20.91	-10%
from fertilizer	metric tons/yr	0	0.9044		0.8961	
from other sources[211]	metric tons/yr	31.18	31.18	0%	33.99	9%
Total N Removed[212,213]	metric tons/yr	46.23	46.11	0%	50.01	8%
Soil N surplus / ha[214]	**kg/ha/yr**	**40.72**	**24.43**	**-40%**	**26.25**	**-36%**
N agronomic balance / ha[215]	**kg/ha/yr**	**48.51**	**43.16**	**-11%**	**43.17**	**-11%**

Source: program output

Notes:

204 The Nutrient Management Act (2002) includes a regulation that limits the per-hectare P application rate to less than 390kg/ha over per-hectare P removal (see note 16) over 5 years. The model takes the annual average of the regulation and translate it to an application limit of less than 78kg/ha/yr over the per-hectare P removal rate.

205 The lower application limit is 75% of the 75kg/ha/yr, reducing it to 19.5kg/ha/yr.

206 Manure export allow the farm to remove manure from the farm at a cost of 10% above manure application cost

207 Land rental allows the farm to rent additional land at a cost of $300/ha, and is restricted to rent no more than 10% of its land base.

208 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

209 Total N required is the sum of the per-hectare N requirement of each crop (see note 2) times land used for production of each crop.

210 Total N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

211 N from other sources is calculated as the hectares of land used multiplied by the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

212 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

213 Total N removed is the sum of the per-hectare N removal rate (see note 8) of each crop times land used for production of each crop.

214 Soil N surplus is calculated as total N input minus total N removed (see notes 8 and 9), divided by total land use.

215 N agronomic balance is calculated as total N input minus total N required (see notes 4 and 5), divided by total land use.

Table 6.11c – P balances of a large Ontario dairy farm under a more restrictive Nutrient Management Act (2002)[216] at 75% lower application limit[217]: allowing for manure export[218] or land rental[219].

Program Outputs	Units	Base Solution	Regulated scenario with manure export	% change from base solution	Regulated scenario with land rental	% change from base solution
P Balances						
Total P Required[220,221]	metric tons/yr	7.25	16.00	121%	17.60	143%
Total P Input[222]	**metric tons/yr**	**19.82**	**16.16**	**-18%**	**17.86**	**-10%**
from manure	metric tons/yr	19.82	16.16	-18%	17.86	-10%
from fertilizer	metric tons/yr	0	0		0	
Total P Removed[223,224]	metric tons/yr	12.35	12.26	-1%	13.57	10%
Soil P surplus / ha[225]	**kg/ha/yr**	**37.34**	**19.50**	**-48%**	**19.50**	**-48%**
P agronomic balance / ha[226]	**kg/ha/yr**	**19.09**	**0.8125**	**-96%**	**1.196**	**-94%**

Source: program output

Notes:

216 The Nutrient Management Act (2002) includes a regulation that limits the per-hectare P application rate to less than 390kg/ha over per-hectare P removal (see note 16) over 5 years. The model takes the annual average of the regulation and translate it to an application limit of less than 78kg/ha/yr over the per-hectare P removal rate.

217 The lower application limit is 75% of the 75kg/ha/yr, reducing it to 19.5kg/ha/yr.

218 Manure export allow the farm to remove manure from the farm at a cost of 10% above manure application cost

219 Land rental allows the farm to rent additional land at a cost of $300/ha, and is restricted to rent no more than 10% of its land base.

220 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield. The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

221 Total P required is the sum of per-hectare P requirement of each crop (see note 12) times land used for production of each crop.

222 Total P input is the sum of P input from manure and from fertilizer

223 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

224 Total P removed is the sum of the per-hectare P removal rate (see note 15) of each crop times land used for production of each crop.

225 Soil P surplus is calculated as total P input minus total P removed (see notes 15 and 16), divided by total land use.

226 P agronomic balance is calculated as total P input minus total P required (see notes 12 and 13), divided by total land use.

application limit from 78kg/ha/yr to 15kg/ha/yr is chosen. The 79% reduction in the application limit is chosen arbitrarily to examine the impact of a binding P-removal based regulation on all three farm models. The compliance cost of a small farm under the more restrictive regulation is presented in Table 6.12. The stricter regulation restricts the farm's soil P surplus to 15kg/ha/yr, reducing net return by $3,388/yr, a 7% reduction compared to the base solution. Note that while there is no reduction in herd size under the stricter regulation, there is an underutilization of the land base. The per-hectare program output and nutrient balances for the small farm under the more restrictive Nutrient Management Act (2002) is shown in Table 6.13, and shows not all land allocated for growing alfalfa hay is used. Table 6.13 also shows that the P requirements per hectare for alfalfa hay and haylage are much higher than the P removed per hectare. In order to reduce the average soil P surplus from 18.93kg/ha/yr in the base solution to 15kg/ha/yr, land dedicated to alfalfa hay is reduced, and additional alfalfa hay is purchased as feed to make up for the reduced hay production. This land is not used for growing other crops because of the crop rotation constraint placed in the model: 3/8th of the land base must be used for alfalfa hay or haylage production to satisfy the crop rotation constraint, and this land cannot be allotted for growing other crops. The land is also not used for growing haylage because of the feed requirement constraint in the model stating that the amount of feed fed to cattle must equal feed requirement. Lastly, alfalfa haylage cannot be sold.

The stricter regulation reduced the shadow value of land by 12%. The reduction in shadow value of land comes about because of the increased N fertilizer purchase. The increase in N fertilizer purchase corresponds with an increased yield for both corn and

Table 6.12a – Compliance cost of a small Ontario dairy farm under a more restrictive Nutrient Management Act (2002)[227]: 79% lower application limit[228].

Program Outputs	Units	Base Solution	Solution in regulated scenario	% change from base solution
Compliance Cost	**$/yr**		**$3,388**	
Net Return	**$**	**$47,210**	**$43,821**	**-7%**
Milking Herd Size[229]	cows	30	30	0%
Total Land Used	ha	60	52.72	-12%
Shadow Value of Land	$/ha/yr	$276	$243	-12%
Shadow Value of Barn	$/cow/yr	$1,021	$975	-5%
Total Manure Applied[230]	metric tons/yr	165.4	165.4	0%
N fertilizer purchased	metric tons/yr	1.464	1.966	34%
P fertilizer purchased	metric tons/yr	2.443	1.787	-27%
K fertilizer purchased	metric tons/yr	0	0	

Source: model output

Notes:

227 The Nutrient Management Act (2002) includes a regulation that limits the per-hectare P application rate to less than 390kg/ha over per-hectare P removal (see note 16) over 5 years. The model takes the annual average of the regulation and translate it to an application limit of less than 78kg/ha/yr over the per-hectare P removal rate.

228 The lower application limit is 79% of the 75kg/ha/yr, reducing it to 15kg/ha/yr

229 Milking herd size only counts the number of milking age cows. Models assume number of heifers equals number of milking age cows.

230 Total manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.12b – N balances of a small Ontario dairy farm under a more restrictive Nutrient Management Act (2002)[231]: 79% lower application limit[232].

Program Outputs	Units	Base Solution	Solution in regulated scenario	% change from base solution
N Balances				
Total N required[233,234]	metric tons/yr	11.91	10.64	-11%
Total N input[235]	**metric tons/yr**	**12.53**	**11.08**	**-12%**
from manure	metric tons/yr	1.911	1.911	0%
from fertilizer	metric tons/yr	1.464	1.966	34%
from other sources[236]	metric tons/yr	9.160	7.200	-21%
Total N Removed[237,238]	metric tons/yr	13.30	10.85	-18%
Soil N surplus / ha[239]	**kg/ha/yr**	**-12.78**	**4.39**	**-134%**
N agronomic balance / ha[240]	**kg/ha/yr**	**10.47**	**9.009**	**-14%**

Source: model output

Notes:

231 The Nutrient Management Act (2002) includes a regulation that limits the per-hectare P application rate to less than 390kg/ha over per-hectare P removal (see note 16) over 5 years. The model takes the annual average of the regulation and translate it to an application limit of less than 78kg/ha/yr over the per-hectare P removal rate.

232 The lower application limit is 79% of the 75kg/ha/yr, reducing it to 15kg/ha/yr

233 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

234 Total N required is the sum of the per-hectare N requirement of each crop (see note 2) times land used for production of each crop.

235 Total N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

236 N from other sources is calculated as the hectares of land used multiplied by the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

237 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

238 Total N removed is the sum of the per-hectare N removal rate (see note 8) of each crop times land used for production of each crop.

239 Soil N surplus is calculated as total N input minus total N removed (see notes 8 and 9), divided by total land use.

240 N agronomic balance is calculated as total N input minus total N required (see notes 4 and 5), divided by total land use.

Table 6.12c – P balances of a small Ontario dairy farm under a more restrictive Nutrient Management Act (2002)[241]: 79% lower application limit[242].

Program Outputs		Units	Base Solution	Solution in regulated scenario	% change from base solution
P Balances					
Total P Required[243,244]		metric tons/yr	4.800	4.144	-14%
Total P Input[245]		**metric tons/yr**	**4.800**	**4.144**	**-14%**
	from manure	metric tons/yr	2.357	2.357	0%
	from fertilizer	metric tons/yr	2.443	1.787	-27%
Total P Removed[246,247]		metric tons/yr	3.664	3.354	-8%
Soil P surplus / ha[248]		**kg/ha/yr**	**18.93**	**15.00**	**-21%**
P agronomic balance / ha[249]		**kg/ha/yr**	**0**	**0**	

Source: model output

Notes:

241 The Nutrient Management Act (2002) includes a regulation that limits the per-hectare P application rate to less than 390kg/ha over per-hectare P removal (see note 16) over 5 years. The model takes the annual average of the regulation and translate it to an application limit of less than 78kg/ha/yr over the per-hectare P removal rate.

242 The lower application limit is 79% of the 75kg/ha/yr, reducing it to 15kg/ha/yr

243 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield. The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

244 Total P required is the sum of per-hectare P requirement of each crop (see note 12) times land used for production of each crop.

245 Total P input is the sum of P input from manure and from fertilizer

246 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

247 Total P removed is the sum of the per-hectare P removal rate (see note 15) of each crop times land used for production of each crop.

248 Soil P surplus is calculated as total P input minus total P removed (see notes 15 and 16), divided by total land use.

249 P agronomic balance is calculated as total P input minus total P required (see notes 12 and 13), divided by total land use.

Table 6.13a – Model outputs on a per-crop basis for the model of small Ontario dairy farms under the Nutrient Management Act (2002)[250]: 79% more restrictive application limit[251].

Model Outputs by Crop		Units	Corn	Corn Silage	Alfalfa Hay	Alfalfa Haylage	Soybeans	Wheat
Land Used		**ha**	**12.40**	**10.11**	**5.951**	**9.265**	**7.500**	**7.500**
Yield[252]		**metric tons/ha/yr**	**6.393**	**10.689**	**10.89**	**10.2**	**2.50**	**4.80**
Crop Produced[253]		**metric tons/yr**	79.24	108.0	64.80	94.50	18.75	36.00
	% sold		43.69%		56.57%		100%	100%
	% fed		56.31%	100%	43.43%	100%		
Crop Purchased[254]		**metric tons/yr**	0	0	0	0	0	0
Manure Applied[255]		**metric tons/yr**	68.75	17.75	16.94	26.38	9.283	26.32
N fertilizer Applied		kg/yr	584.6	918.6	0	0	0	463.2
P fertilizer Applied		kg/yr	136.0	656.5	294.2	458.0	242.7	0
K fertilizer Applied		kg/yr	0	0	0	0	0	0

Source: Model output

Notes:

250 The Nutrient Management Act (2002) includes a regulation that limits the per-hectare P application rate to less than 390kg/ha over per-hectare P removal (see note 16) over 5 years. The model takes the annual average of the regulation and translate it to an application limit of less than 78kg/ha/yr over the per-hectare P removal rate.

251 The lower application limit is 79% of the 89kg/ha/yr, reducing it to 15kg/ha/yr.

252 Yield of each crop is measured in metric tons of dry matter per hectare. Yield for alfalfa hay, alfalfa haylage, soybeans, and wheat are calibrated to 2008 yield estimates in Oxford County, referenced from the NMAN2 Software (OMAFRA, undated). Corn and corn silage yield is determined by a quadratic N-response yield function (see Chapter 5).

253 Crop produced is measured in metric tons of dry matter, and is calculated as the yield of each crop multiplied by land used for production for each crop. All corn silage and alfalfa haylage produced must be used for feed, and all soybeans and wheat produced must be sold.

254 Crop purchased is measured in metric tons of dry matter. Soybeans and wheat cannot be purchased.

255 Manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.13b – Per-hectare N balances on a per-crop basis for the model of small Ontario dairy farms under the Nutrient Management Act (2002)[256]: 79% more restrictive application limit[257].

Nutrient Balance by Crop	Units	Crops					
		Corn	Corn Silage	Alfalfa Hay	Alfalfa Haylage	Soybeans	Wheat
N Balances by Crop							
N Requirement per ha[258]	kg/ha/yr	141.3	141.3	276.4	306.4	240.7	155.7
N input per ha[259]	**kg/ha/yr**	**141.3**	**141.3**	**302.0**	**332.0**	**247.7**	**155.7**
from manure	kg/ha/yr	64.09	20.30	32.89	32.89	14.30	40.55
from fertilizer	kg/ha/yr	47.16	90.91	0	0	0	61.76
from other input[260]	kg/ha/yr	30.07	30.07	269.1	299.1	233.4	53.40
N Removal per ha[261]	kg/ha/yr	110.8	202.9	351.0	319.0	161.0	156.0
N surplus per ha[262]	**kg/ha/yr**	**30.47**	**-61.63**	**-49.04**	**12.96**	**86.70**	**-0.3000**
N Agronomic Balance per ha[263]	**kg/ha/yr**	**0**	**0**	**25.59**	**25.59**	**7.001**	**0**

Source: Model output

Notes:

256 The Nutrient Management Act (2002) includes a regulation that limits the per-hectare P application rate to less than 390kg/ha over per-hectare P removal (see note 16) over 5 years. The model takes the annual average of the regulation and translate it to an application limit of less than 78kg/ha/yr over the per-hectare P removal rate.

257 The lower application limit is 79% of the 89kg/ha/yr, reducing it to 15kg/ha/yr.

258 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

259 N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

260 N from other sources is the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

261 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

262 Soil N surplus is calculated as N input per hectare minus N removed per hectare (see note 8).

263 N agronomic balance is calculated as N input per hectare minus N required per hectare (see note 5).

Table 6.13c – Per-hectare P balances on a per-crop basis for the model of small Ontario dairy farms under the Nutrient Management Act (2002)[264]: 79% more restrictive application limit[265].

Nutrient Balance by Crop		Crops					
	Units	Corn	Corn Silage	Alfalfa Hay	Alfalfa Haylage	Soybeans	Wheat
P Balances by Crop							
P Requirement per ha[266]	kg/ha/yr	90	90	90	90	50	50
P input per ha[267]	**kg/ha/yr**	90.00	90.00	90.00	90.00	50.00	50.00
from manure	kg/ha/yr	79.03	25.03	40.56	40.56	17.64	50.00
from fertilizer	kg/ha/yr	10.97	64.97	49.44	49.44	32.36	0
P Removal per ha[268]	kg/ha/yr	83.13	75.72	53.08	53.08	57.60	42.46
P surplus per ha[269]	**kg/ha/yr**	**6.866**	**14.28**	**36.92**	**36.92**	**-7.600**	**7.540**
P Agronomic Balance per ha[270]	**kg/ha/yr**	**0**	**0**	**0**	**0**	**0**	**0**

Source: Model output

Notes:

264 The Nutrient Management Act (2002) includes a regulation that limits the per-hectare P application rate to less than 390kg/ha over per-hectare P removal (see note 16) over 5 years. The model takes the annual average of the regulation and translate it to an application limit of less than 78kg/ha/yr over the per-hectare P removal rate.

265 The lower application limit is 79% of the 89kg/ha/yr, reducing it to 15kg/ha/yr.

266 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield (see note 1). The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

267 Total P input is the sum of P input from manure and from fertilizer.

268 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

269 Soil P surplus is calculated as P input per hectare minus P removed per hectare (see notes 13 and 14).

270 P agronomic balance is calculated as P input per hectare minus P required per hectare (see notes 10 and 11).

corn silage, shown in Table 6.13: in order to reduce soil P surplus, additional nitrogen in applied to corn land to increase corn yield, subsequently increasing the P removal rates for these crops. The increase in N fertilization of corn land corresponds with a 134% increase in soil N surplus.

The compliance cost of a medium farm under the more restrictive regulation is presented in Table 6.14. The stricter regulation restricts the farm's soil P surplus to 15kg/ha/yr, and reducing net return by $6,104, a 5% reduction compared to the base solution. Like the small farm model output, there is no reduction in herd size, and there is an underutilization of the land base. The per-hectare program output and nutrient balances for the medium farm under the more restrictive Nutrient Management Act (2002) is shown in Table 6.15, and shows that, like the small farm model, not all land allocated for alfalfa production is used due to the crop rotation constraint. Corn and corn silage yield is also increased through additional N fertilization for higher P removal. The increase in N fertilization of corn land corresponds with a 172% increase in soil N surplus.

The compliance cost of a large farm under the more restrictive regulation is presented in Table 6.16. The stricter regulation reduces the net return of the large farm model by $55,032, a 24% reduction compared to the base solution. Unlike the small and medium farm model output, there is a reduction in herd size as well as the underutilization of the land base. This happens because in the base scenario, all of the P applied on land is from manure in the large farm model; whereas for the small and medium farm models, P fertilizers are used. When the small and medium farm models comply with the stricter regulations, they are able to meet the regulatory limit by

Table 6.14a – Compliance cost of a medium Ontario dairy farm under a more restrictive Nutrient Management Act (2002)[271]: 79% lower application limit[272].

Program Outputs	Units	Base Solution	Solution in regulated scenario	% change from base solution
Compliance Cost	**$/yr**		**$6,104**	
Net Return	**$**	**$115,211**	**$109,107**	**-5%**
Milking Herd Size[273]	cows	70	70	0%
Total Land Used	ha	130	113	-13%
Shadow Value of Land	$/ha/yr	$279	$254	-9%
Shadow Value of Barn	$/cow/yr	$1,128	$1,087	-4%
Total Manure Applied[274]	metric tons/yr	284.0	284.0	0%
N fertilizer purchased	metric tons/yr	0.7115	0.8978	26%
P fertilizer purchased	metric tons/yr	2.240	0.741	-67%
K fertilizer purchased	metric tons/yr	0.8857	0.04140	-95%

Source: model output

Notes:

271 The Nutrient Management Act (2002) includes a regulation that limits the per-hectare P application rate to less than 390kg/ha over per-hectare P removal (see note 16) over 5 years. The model takes the annual average of the regulation and translate it to an application limit of less than 78kg/ha/yr over the per-hectare P removal rate.

272 The lower application limit is 79% of the 75kg/ha/yr, reducing it to 15kg/ha/yr

273 Milking herd size only counts the number of milking age cows. Models assume number of heifers equals number of milking age cows.

274 Total manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.14b – N balances of a medium Ontario dairy farm under a more restrictive Nutrient Management Act (2002)[275]: 79% lower application limit[276].

Program Outputs	Units	Base Solution	Solution in regulated scenario	% change from base solution
N Balances				
Total N required[277,278]	metric tons/yr	26.77	22.75	-15%
Total N input[279]	**metric tons/yr**	**30.15**	**25.86**	**-14%**
from manure	metric tons/yr	9.551	9.551	0%
from fertilizer	metric tons/yr	0.7115	0.8978	26%
from other sources[280]	metric tons/yr	19.89	15.41	-23%
Total N Removed[281,282]	metric tons/yr	29.07	23.29	-20%
Soil N surplus / ha[283]	**kg/ha/yr**	**8.31**	**22.65**	**172%**
N agronomic balance / ha[284]	**kg/ha/yr**	**26.05**	**27.45**	**5%**

Source: model output

Notes:

275 The Nutrient Management Act (2002) includes a regulation that limits the per-hectare P application rate to less than 390kg/ha over per-hectare P removal (see note 16) over 5 years. The model takes the annual average of the regulation and translate it to an application limit of less than 78kg/ha/yr over the per-hectare P removal rate.

276 The lower application limit is 79% of the 75kg/ha/yr, reducing it to 15kg/ha/yr

277 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

278 Total N required is the sum of the per-hectare N requirement of each crop (see note 2) times land used for production of each crop.

279 Total N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

280 N from other sources is calculated as the hectares of land used multiplied by the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

281 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

282 Total N removed is the sum of the per-hectare N removal rate (see note 8) of each crop times land used for production of each crop.

283 Soil N surplus is calculated as total N input minus total N removed (see notes 8 and 9), divided by total land use.

284 N agronomic balance is calculated as total N input minus total N required (see notes 4 and 5), divided by total land use.

Table 6.14c – P balances of a medium Ontario dairy farm under a more restrictive Nutrient Management Act (2002)[285]: 79% lower application limit[286].

Program Outputs	Units	Base Solution	Solution in regulated scenario	% change from base solution
P Balances				
Total P Required[287,288]	metric tons/yr	10.400	8.902	-14%
Total P Input[289]	**metric tons/yr**	**10.40**	**8.902**	**-14%**
from manure	metric tons/yr	8.160	8.160	0%
from fertilizer	metric tons/yr	2.240	0.7413	-67%
Total P Removed[290,291]	metric tons/yr	8.038	7.201	-10%
Soil P surplus / ha[292]	**kg/ha/yr**	**18.17**	**15.00**	**-17%**
P agronomic balance / ha[293]	**kg/ha/yr**	**0**	**0**	

Source: model output

Notes:

285 The Nutrient Management Act (2002) includes a regulation that limits the per-hectare P application rate to less than 390kg/ha over per-hectare P removal (see note 16) over 5 years. The model takes the annual average of the regulation and translate it to an application limit of less than 78kg/ha/yr over the per-hectare P removal rate.

286 The lower application limit is 79% of the 75kg/ha/yr, reducing it to 15kg/ha/yr

287 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield. The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

288 Total P required is the sum of per-hectare P requirement of each crop (see note 12) times land used for production of each crop.

289 Total P input is the sum of P input from manure and from fertilizer

290 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

291 Total P removed is the sum of the per-hectare P removal rate (see note 15) of each crop times land used for production of each crop.

292 Soil P surplus is calculated as total P input minus total P removed (see notes 15 and 16), divided by total land use.

293 P agronomic balance is calculated as total P input minus total P required (see notes 12 and 13), divided by total land use.

Table 6.15a – Model outputs on a per-crop basis for the model of medium Ontario dairy farms under the Nutrient Management Act (2002)[294]: 79% more restrictive application limit[295]

Model Outputs by Crop			Crops					
		Units	Corn	Corn Silage	Alfalfa Hay	Alfalfa Haylage	Soybeans	Wheat
Land Used		**ha**	**25.13**	**23.62**	**10.48**	**21.62**	**16.250**	**16.250**
Yield[296]		**metric tons/ha/yr**	**6.383**	**10.67**	**10.89**	**10.2**	**2.5**	**4.8**
Crop Produced[297]		**metric tons/yr**	160.43	252.0	114.2	220.50	40.63	78.00
	% sold		35.10%		42.48%		100%	100%
	% fed		64.90%	100%	57.52%	100%		
Crop Purchased[298]		**metric tons/yr**	0	0	0	0	0	0
Manure Applied[299]		**metric tons/yr**	78.72	73.97	26.40	57.75	18.87	28.28
N fertilizer Applied		kg/yr	96.69	89.63	0	0	0	711.5
P fertilizer Applied		kg/yr	0	0	184.9	286.3	270.2	0
K fertilizer Applied		kg/yr	0	0	41.40	0	0	0

Source: Model output

Notes:

294 The Nutrient Management Act (2002) includes a regulation that limits the per-hectare P application rate to less than 390kg/ha over per-hectare P removal (see note 16) over 5 years. The model takes the annual average of the regulation and translate it to an application limit of less than 78kg/ha/yr over the per-hectare P removal rate.

295 The lower application limit is 79% of the 89kg/ha/yr, reducing it to 15kg/ha/yr.

296 Yield of each crop is measured in metric tons of dry matter per hectare. Yield for alfalfa hay, alfalfa haylage, soybeans, and wheat are calibrated to 2008 yield estimates in Oxford County, referenced from the NMAN2 Software (OMAFRA, undated). Corn and corn silage yield is determined by a quadratic N-response yield function (see Chapter 5).

297 Crop produced is measured in metric tons of dry matter, and is calculated as the yield of each crop multiplied by land used for production for each crop. All corn silage and alfalfa haylage produced must be used for feed, and all soybeans and wheat produced must be sold.

298 Crop purchased is measured in metric tons of dry matter. Soybeans and wheat cannot be purchased.

299 Manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.15b – Per-hectare N balances on a per-crop basis for the model of medium Ontario dairy farms under the Nutrient Management Act (2002)[300]: 79% more restrictive application limit[301]

Nutrient Balance by Crop		Crops					
	Units	Corn	Corn Silage	Alfalfa Hay	Alfalfa Haylage	Soybeans	Wheat
N Balances by Crop							
N Requirement per ha[302]	kg/ha/yr	141.3	141.3	276.4	306.4	240.7	155.7
N input per ha[303]	**kg/ha/yr**	**141.3**	**141.3**	**302.0**	**332.0**	**247.7**	**155.7**
from manure	kg/ha/yr	64.09	20.30	32.89	32.89	14.30	40.55
from fertilizer	kg/ha/yr	47.16	90.91	0	0	0	61.76
from other input[304]	kg/ha/yr	30.07	30.07	269.1	299.1	233.4	53.40
N Removal per ha[305]	kg/ha/yr	110.8	202.9	351.0	319.0	161.0	156.0
N surplus per ha[306]	**kg/ha/yr**	**30.47**	**-61.63**	**-49.04**	**12.96**	**86.70**	**-0.3000**
N Agronomic Balance per ha[307]	**kg/ha/yr**	**0**	**0**	**25.59**	**25.59**	**7.001**	**0**

Source: Model output

Notes:

300 The Nutrient Management Act (2002) includes a regulation that limits the per-hectare P application rate to less than 390kg/ha over per-hectare P removal (see note 16) over 5 years. The model takes the annual average of the regulation and translate it to an application limit of less than 78kg/ha/yr over the per-hectare P removal rate.

301 The lower application limit is 79% of the 89kg/ha/yr, reducing it to 15kg/ha/yr.

302 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

303 N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

304 N from other sources is the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

305 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

306 Soil N surplus is calculated as N input per hectare minus N removed per hectare (see note 8).

307 N agronomic balance is calculated as N input per hectare minus N required per hectare (see note 5).

Table 6.15c – Per-hectare P balances on a per-crop basis for the model of medium Ontario dairy farms under the Nutrient Management Act (2002)[308]: 79% more restrictive application limit[309]

Nutrient Balance by Crop	Units	Crops					
		Corn	Corn Silage	Alfalfa Hay	Alfalfa Haylage	Soybeans	Wheat
P Balances by Crop							
P Requirement per ha[310]	kg/ha/yr	90	90	90	90	50	50
P input per ha[311]	**kg/ha/yr**	90.00	90.00	90.00	90.00	50.00	50.00
from manure	kg/ha/yr	90.00	90.00	72.36	76.76	33.37	50.00
from fertilizer	kg/ha/yr	0.00	0.00	17.64	13.24	16.63	0.00
P Removal per ha[312]	kg/ha/yr	83.00	75.60	53.08	53.08	57.60	42.46
P surplus per ha[313]	**kg/ha/yr**	**7.00**	**14.40**	**36.92**	**36.92**	**-7.60**	**7.54**
P Agronomic Balance per ha[314]	**kg/ha/yr**	**0**	**0**	**0**	**0**	**0**	**0**

Source: Model output

Notes:

308 The Nutrient Management Act (2002) includes a regulation that limits the per-hectare P application rate to less than 390kg/ha over per-hectare P removal (see note 16) over 5 years. The model takes the annual average of the regulation and translate it to an application limit of less than 78kg/ha/yr over the per-hectare P removal rate.

309 The lower application limit is 79% of the 89kg/ha/yr, reducing it to 15kg/ha/yr.

310 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield (see note 1). The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

311 Total P input is the sum of P input from manure and from fertilizer.

312 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

313 Soil P surplus is calculated as P input per hectare minus P removed per hectare (see notes 13 and 14).

314 P agronomic balance is calculated as P input per hectare minus P required per hectare (see notes 10 and 11).

Table 6.16a – Compliance cost of a large Ontario dairy farm under a more restrictive Nutrient Management Act (2002)[315]: 79% lower application limit[316].

Program Outputs	Units	Base Solution	Solution in regulated scenario	% change from base solution
Compliance Cost	**$/yr**		**$55,032**	
Net Return	**$**	**$232,236**	**$177,204**	**-24%**
Milking Herd Size[317]	cows	170	118.4	-30%
Total Land Used	ha	200	175.6	-12%
Shadow Value of Land	$/ha/yr	$619	$886	43%
Shadow Value of Barn	$/cow/yr	$638	$0	-100%
Total Manure Applied[318]	metric tons/yr	689.7	480.3	-30%
N fertilizer purchased	metric tons/yr	0	2.458	
P fertilizer purchased	metric tons/yr	0	0	
K fertilizer purchased	metric tons/yr	0	0	

Source: model output

Notes:

315 The Nutrient Management Act (2002) includes a regulation that limits the per-hectare P application rate to less than 390kg/ha over per-hectare P removal (see note 16) over 5 years. The model takes the annual average of the regulation and translate it to an application limit of less than 78kg/ha/yr over the per-hectare P removal rate.

316 The lower application limit is 79% of the 78kg/ha/yr, reducing it to 15kg/ha/yr

317 Milking herd size only counts the number of milking age cows. Models assume number of heifers equals number of milking age cows.

318 Total manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.16b – N balances of a large Ontario dairy farm under a more restrictive Nutrient Management Act (2002)[319]: 79% lower application limit[320].

Program Outputs	Units	Base Solution	Solution in regulated scenario	% change from base solution
N Balances				
Total N required[321,322]	metric tons/yr	44.67	36.50	-18%
Total N input[323]	**metric tons/yr**	**54.37**	**42.74**	**-21%**
from manure	metric tons/yr	23.19	16.15	-30%
from fertilizer	metric tons/yr	0	2.458	
from other sources[324]	metric tons/yr	31.18	24.13	-23%
Total N Removed[325,326]	metric tons/yr	46.23	36.55	-21%
Soil N surplus / ha[327]	**kg/ha/yr**	**40.72**	**35.27**	**-13%**
N agronomic balance / ha[328]	**kg/ha/yr**	**48.51**	**35.53**	**-27%**

Source: model output

Notes:

319 The Nutrient Management Act (2002) includes a regulation that limits the per-hectare P application rate to less than 390kg/ha over per-hectare P removal (see note 16) over 5 years. The model takes the annual average of the regulation and translate it to an application limit of less than 78kg/ha/yr over the per-hectare P removal rate.

320 The lower application limit is 79% of the 78kg/ha/yr, reducing it to 15kg/ha/yr

321 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

322 Total N required is the sum of the per-hectare N requirement of each crop (see note 2) times land used for production of each crop.

323 Total N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

324 N from other sources is calculated as the hectares of land used multiplied by the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

325 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

326 Total N removed is the sum of the per-hectare N removal rate (see note 8) of each crop times land used for production of each crop.

327 Soil N surplus is calculated as total N input minus total N removed (see notes 8 and 9), divided by total land use.

328 N agronomic balance is calculated as total N input minus total N required (see notes 4 and 5), divided by total land use.

Table 6.16c – P balances of a large Ontario dairy farm under a more restrictive Nutrient Management Act (2002)[329]: 79% lower application limit[330].

Program Outputs	Units	Base Solution	Solution in regulated scenario	% change from base solution
P Balances				
Total P Required[331,332]	metric tons/yr	16.00	13.80	-14%
Total P Input[333]	**metric tons/yr**	**19.82**	**13.80**	**-30%**
from manure	metric tons/yr	19.82	13.80	-30%
from fertilizer	metric tons/yr	0	0	
Total P Removed[334,335]	metric tons/yr	12.35	11.17	-10%
Soil P surplus / ha[336]	**kg/ha/yr**	**37.34**	**15.00**	**-60%**
P agronomic balance / ha[337]	**kg/ha/yr**	**19.09**	**0**	**-100%**

Source: model output

Notes:

329 The Nutrient Management Act (2002) includes a regulation that limits the per-hectare P application rate to less than 390kg/ha over per-hectare P removal (see note 16) over 5 years. The model takes the annual average of the regulation and translate it to an application limit of less than 78kg/ha/yr over the per-hectare P removal rate.

330 The lower application limit is 79% of the 78kg/ha/yr, reducing it to 15kg/ha/yr

331 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield. The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

332 Total P required is the sum of per-hectare P requirement of each crop (see note 12) times land used for production of each crop.

333 Total P input is the sum of P input from manure and from fertilizer

334 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

335 Total P removed is the sum of the per-hectare P removal rate (see note 15) of each crop times land used for production of each crop.

336 Soil P surplus is calculated as total P input minus total P removed (see notes 15 and 16), divided by total land use.

337 P agronomic balance is calculated as total P input minus total P required (see notes 12 and 13), divided by total land use.

reducing P fertilizer usage. Because there was no P fertilizer usage for the large farm in the unregulated scenario, the only way to reduce fertilizer input is to reduce the amount of manure generated by reducing the herd size. The per-hectare program output and nutrient balances for the medium farm under the more restrictive Nutrient Management Act (2002) are shown in Table 6.17, and show that, like the small and medium farm model, not all land allocated for alfalfa production is used, again due to the crop rotation constraint. Corn and corn silage yield did not increase. Due to the reduced land allocation to alfalfa hay production without increased N input for corn crops, soil N surplus actually decreased for the large farm model under this restrictive regulation, unlike the soil N surplus increase observed for the small and medium farm model.

When the stricter regulation is applied to the three farm models, assuming a lower soil P value (and therefore higher crop P requirement), infeasibility occurs for all models and all farm models report a net return of $0/yr. Because of the strict regulation, farms with low soil P test values will find crop P requirements larger than the regulatory limit based on crop P removal values, since nutrient removal values are independent of soil nutrient values. Compliance to highly restrictive crop P-removal based regulations will be impossible for farms with very low soil P to begin with because of the differences in how soil P removal and soil P requirement are calculated.

When the stricter regulation is applied to the three farm models assuming a higher soil P value (and therefore lower crop P requirement), the compliance cost of the small and medium farm models is still zero, while there is a positive compliance cost with the large farm model. Table 6.18 presents the model output and nutrient balances of the large farm model under the more restrictive application limit when modeled with a higher soil

Table 6.17a – Model outputs on a per-crop basis for the model of medium Ontario dairy farms under the Nutrient Management Act (2002)[338]: 79% more restrictive application limit[339]

Model Outputs by Crop			Crops					
		Units	Corn	Corn Silage	Alfalfa Hay	Alfalfa Haylage	Soybeans	Wheat
Land Used		**ha**	**35.39**	**39.61**	**14.01**	**36.56**	**25.00**	**25.00**
Yield[340]		**metric tons/ha/yr**	**6.437**	**10.763**	**10.89**	**10.2**	**2.5**	**4.8**
Crop Produced[341]		**metric tons/yr**	227.8	426.3	152.5	372.92	62.50	120.0
	% sold		22.71%		27.19%		100%	100%
	% fed		77.29%	100%	72.81%	100%		
Crop Purchased[342]		**metric tons/yr**	0	0	0	0	0	0
Manure Applied[343]		**metric tons/yr**	110.9	124.1	43.87	114.51	43.502	43.50
N fertilizer Applied		kg/yr	643.5	719.7	0	0	0	1095
P fertilizer Applied		kg/yr	0	0	0	0	0	0
K fertilizer Applied		kg/yr	0	0	0	0	0	0

Source: Model output

Notes:

338 The Nutrient Management Act (2002) includes a regulation that limits the per-hectare P application rate to less than 390kg/ha over per-hectare P removal (see note 16) over 5 years. The model takes the annual average of the regulation and translate it to an application limit of less than 78kg/ha/yr over the per-hectare P removal rate.

339 The lower application limit is 79% of the 89kg/ha/yr, reducing it to 15kg/ha/yr.

340 Yield of each crop is measured in metric tons of dry matter per hectare. Yield for alfalfa hay, alfalfa haylage, soybeans, and wheat are calibrated to 2008 yield estimates in Oxford County, referenced from the NMAN2 Software (OMAFRA, undated). Corn and corn silage yield is determined by a quadratic N-response yield function (see Chapter 5).

341 Crop produced is measured in metric tons of dry matter, and is calculated as the yield of each crop multiplied by land used for production for each crop. All corn silage and alfalfa haylage produced must be used for feed, and all soybeans and wheat produced must be sold.

342 Crop purchased is measured in metric tons of dry matter. Soybeans and wheat cannot be purchased.

343 Manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.17b – Per-hectare N balances on a per-crop basis for the model of medium Ontario dairy farms under the Nutrient Management Act (2002)[344]: 79% more restrictive application limit[345]

Nutrient Balance by Crop		Crops					
	Units	Corn	Corn Silage	Alfalfa Hay	Alfalfa Haylage	Soybeans	Wheat
N Balances by Crop							
N Requirement per ha[346]	kg/ha/yr	153.6	153.6	276.4	306.4	240.7	155.7
N input per ha[347]	**kg/ha/yr**	**153.6**	**153.6**	**374.4**	**404.4**	**291.9**	**155.7**
from manure	kg/ha/yr	105.33	105.33	105.33	105.33	58.52	58.52
from fertilizer	kg/ha/yr	18.18	18.17	0	0	0	43.78
from other input[348]	kg/ha/yr	30.07	30.07	269.1	299.1	233.4	53.40
N Removal per ha[349]	kg/ha/yr	111.6	204.3	351.0	319.0	161.0	156.0
N surplus per ha[350]	**kg/ha/yr**	**41.98**	**-50.72**	**23.40**	**85.40**	**130.9**	**-0.3000**
N Agronomic Balance per ha[351]	**kg/ha/yr**	**0**	**0**	**98.03**	**98.03**	**51.22**	**0**

Source: Model output

Notes:

344 The Nutrient Management Act (2002) includes a regulation that limits the per-hectare P application rate to less than 390kg/ha over per-hectare P removal (see note 16) over 5 years. The model takes the annual average of the regulation and translate it to an application limit of less than 78kg/ha/yr over the per-hectare P removal rate.

345 The lower application limit is 79% of the 89kg/ha/yr, reducing it to 15kg/ha/yr.

346 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

347 N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

348 N from other sources is the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

349 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

350 Soil N surplus is calculated as N input per hectare minus N removed per hectare (see note 8).

351 N agronomic balance is calculated as N input per hectare minus N required per hectare (see note 5).

Table 6.17c – Per-hectare P balances on a per-crop basis for the model of medium Ontario dairy farms under the Nutrient Management Act (2002)[352]: 79% more restrictive application limit[353]

Nutrient Balance by Crop	Units	Crops					
		Corn	Corn Silage	Alfalfa Hay	Alfalfa Haylage	Soybeans	Wheat
P Balances by Crop							
P Requirement per ha[354]	kg/ha/yr	90	90	90	90	50	50
P input per ha[355]	**kg/ha/yr**	90.00	90.00	90.00	90.00	50.00	50.00
from manure	kg/ha/yr	90.00	90.00	90.00	90.00	50.00	50.00
from fertilizer	kg/ha/yr	0	0	0	0	0	0
P Removal per ha[356]	kg/ha/yr	83.70	76.24	53.08	53.08	57.60	42.46
P surplus per ha[357]	**kg/ha/yr**	**6.299**	**13.76**	**36.92**	**36.92**	**-7.600**	**7.540**
P Agronomic Balance per ha[358]	**kg/ha/yr**	**0**	**0**	**0**	**0**	**0**	**0**

Source: Model output

Notes:

352 The Nutrient Management Act (2002) includes a regulation that limits the per-hectare P application rate to less than 390kg/ha over per-hectare P removal (see note 16) over 5 years. The model takes the annual average of the regulation and translate it to an application limit of less than 78kg/ha/yr over the per-hectare P removal rate.

353 The lower application limit is 79% of the 89kg/ha/yr, reducing it to 15kg/ha/yr.

354 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield (see note 1). The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

355 Total P input is the sum of P input from manure and from fertilizer.

356 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

357 Soil P surplus is calculated as P input per hectare minus P removed per hectare (see notes 13 and 14).

358 P agronomic balance is calculated as P input per hectare minus P required per hectare (see notes 10 and 11).

Table 6.18a – Compliance cost of a large Ontario dairy farm under a more restrictive Nutrient Management Act (2002)[359] at 79% lower application limit[360]: assuming higher soil P test values.

Program Outputs	Units	Base solution with higher P soil value[361] 10-12mg/L	Regulated scenario with higher P soil value[3] 10-12mg/L	% change from base solution with higher P soil value
Compliance Cost	**$/yr**		**$25,930**	
Net Return	**$/yr**	**$232,236**	**$206,306**	**-11%**
Milking Herd Size[362]	cows	170	132	-22%
Total Land Used	ha	200	200	0%
Shadow Value of Land	$/ha/yr	$619	$1,032	67%
Shadow Value of Barn	$/cow/yr	$638	$0	-100%
Total Manure Applied[363]	metric tons/yr	689.7	535.6	-22%
N fertilizer purchased	metric tons/yr	0	0	
P fertilizer purchased	metric tons/yr	0	0	
K fertilizer purchased	metric tons/yr	0	0.4994	

Source: model output

Notes:

[359] The Nutrient Management Act (2002) includes a regulation that limits the per-hectare P application rate to less than 390kg/ha over per-hectare P removal (see note 16) over 5 years. The model takes the annual average of the regulation and translate it to an application limit of less than 78kg/ha/yr over the per-hectare P removal rate.

[360] The lower application limit is 79% of the 78kg/ha/yr, reducing it to 15kg/ha/yr.

[361] Crops grown on soil with high soil P value have low per-hectare P requirements. See Table 5.10 for P requirement values associated with soil P values.

[362] Milking herd size only counts the number of milking age cows. Models assume number of heifers equals number of milking age cows.

[363] Total manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.18b – N balances of a large Ontario dairy farm under a more restrictive Nutrient Management Act (2002)[364] at 79% lower application limit[365]: assuming higher soil P test values.

Program Outputs	Units	Base solution with higher P soil value[366] 10-12mg/L	Regulated scenario with higher P soil value[3] 10-12mg/L	% change from base solution with higher P soil value
N Balances				
Total N required[367,368]	metric tons/yr	44.67	42.51	-5%
Total N input[369]	**metric tons/yr**	**54.37**	**48.84**	**-10%**
from manure	metric tons/yr	23.19	18.01	-22%
from fertilizer	metric tons/yr	0	0	
from other sources[370]	metric tons/yr	31.18	30.83	-1%
Total N Removed[371,372]	metric tons/yr	46.23	45.36	-2%
Soil N surplus / ha[373]	**kg/ha/yr**	**40.72**	**17.42**	**-57%**
N agronomic balance / ha[374]	**kg/ha/yr**	**48.51**	**31.67**	**-35%**

Source: model output

Notes:

364 The Nutrient Management Act (2002) includes a regulation that limits the per-hectare P application rate to less than 390kg/ha over per-hectare P removal (see note 16) over 5 years. The model takes the annual average of the regulation and translate it to an application limit of less than 78kg/ha/yr over the per-hectare P removal rate.

365 The lower application limit is 79% of the 78kg/ha/yr, reducing it to 15kg/ha/yr.

366 Crops grown on soil with high soil P value have low per-hectare P requirements. See Table 5.10 for P requirement values associated with soil P values.

367 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

368 Total N required is the sum of the per-hectare N requirement of each crop (see note 2) times land used for production of each crop.

369 Total N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

370 N from other sources is calculated as the hectares of land used multiplied by the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

371 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

372 Total N removed is the sum of the per-hectare N removal rate (see note 8) of each crop times land used for production of each crop.

373 Soil N surplus is calculated as total N input minus total N removed (see notes 8 and 9), divided by total land use.

374 N agronomic balance is calculated as total N input minus total N required (see notes 4 and 5), divided by total land use.

Table 6.18c – P balances of a large Ontario dairy farm under a more restrictive Nutrient Management Act (2002)[375] at 79% lower application limit[376]: assuming higher soil P test values.

Program Outputs	Units	Base solution with higher P soil value[377] 10-12mg/L	Regulated scenario with higher P soil value[3] 10-12mg/L	% change from base solution with higher P soil value
P Balances				
Total P Required[378,379]	metric tons/yr	7.25	7.25	0%
Total P Input[380]	**metric tons/yr**	**19.82**	**15.39**	**-22%**
from manure	metric tons/yr	19.82	15.39	-22%
from fertilizer	metric tons/yr	0	0	
Total P Removed[381,382]	metric tons/yr	12.35	12.39	0%
Soil P surplus / ha[383]	**kg/ha/yr**	**37.34**	**15.00**	**-60%**
P agronomic balance / ha[384]	**kg/ha/yr**	**62.84**	**40.70**	**-35%**

Source: model output

Notes:

375 The Nutrient Management Act (2002) includes a regulation that limits the per-hectare P application rate to less than 390kg/ha over per-hectare P removal (see note 16) over 5 years. The model takes the annual average of the regulation and translate it to an application limit of less than 78kg/ha/yr over the per-hectare P removal rate.

376 The lower application limit is 79% of the 78kg/ha/yr, reducing it to 15kg/ha/yr.

377 Crops grown on soil with high soil P value have low per-hectare P requirements. See Table 5.10 for P requirement values associated with soil P values.

378 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield. The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

379 Total P required is the sum of per-hectare P requirement of each crop (see note 12) times land used for production of each crop.

380 Total P input is the sum of P input from manure and from fertilizer

381 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

382 Total P removed is the sum of the per-hectare P removal rate (see note 15) of each crop times land used for production of each crop.

383 Soil P surplus is calculated as total P input minus total P removed (see notes 15 and 16), divided by total land use.

384 P agronomic balance is calculated as total P input minus total P required (see notes 12 and 13), divided by total land use.

P value, reducing the crop P requirement. The compliance cost in this case is $25,930, approximately 11% of the net return in the base model assuming a higher soil P. Under the stricter crop P-removal based regulation, a large farm with high soil P will have half the compliance cost if compared to a large farm with an average soil P. The smaller compliance cost occurs because in the high soil P situation, the lower P requirement means difference between P requirement and P removal for all crops is smaller reduction. As such, the contribution of soil P surplus through alfalfa production is mitigated, allowing the farm to utilize its entire land base for crop production. Herd size is still reduced to 132 heads of milking age cows to reduce the excess P from manure.

Manure export or land rental do not help reduce compliance costs for the small and medium farm models under the more restrictive Nutrient Management Act (2002) regulation. For both farm sizes, the amount of P in manure is small enough that the regulation does not force a reduction in herd size. Land rental does not reduce compliance costs for the small and medium farm models in this situation because the shadow values of land are lower than the rental value: the cost of renting additional land in this case, is higher than the addition return gained through additional crop sales.

Manure export and land rental reduce compliance costs for the large farm model under the more restrictive regulation. Table 6.19 presents the compliance cost of a large dairy farm under the more restrictive regulation when the farm is able to export manure at a cost 10% above the cost of manure application, or rent land at a cost of $300/ha up to 10% of the land base. Given an option to export manure, the large farm model is able to reduce the compliance cost to $35,416/yr, or 15% of the net return in the base solution. By exporting 149.3 metric tons of manure off the farm, the large farm model increases

Table 6.19a – Compliance cost of a large Ontario dairy farm under a more restrictive Nutrient Management Act (2002)[385] at 79% lower application limit[386]: allowing for manure export[387] or land rental[388].

Program Outputs	Units	Base Solution	Regulated scenario with manure export	% change from base solution	Regulated scenario with land rental	% change from base solution
Compliance Cost	**$/yr**		**$35,416**		**$43,312**	
Net Return	**$/yr**	**$232,236**	**$196,820**	**-15%**	**$188,924**	**-19%**
Milking Herd Size[389]	cows	170	153	-10%	130	-23%
Total Land Used	ha	200	172.1	-14%	193.1	-3%
Shadow Value of Land	$/ha/yr	$619	$984	59%	$886	43%
Shadow Value of Barn	$/cow/yr	$638	$0	-100%	$0	-100%
Total Manure Applied[390]	metric tons/yr	689.7	469.4	-32%	528.3	-23%
Total Manure Exported	metric tons/yr	0	149.3		0	
N fertilizer purchased	metric tons/yr	0	2.825		2.703	
P fertilizer purchased	metric tons/yr	0	0		0	
K fertilizer purchased	metric tons/yr	0	0		0	

Source: program output

Notes:

385 The Nutrient Management Act (2002) includes a regulation that limits the per-hectare P application rate to less than 390kg/ha over per-hectare P removal (see note 16) over 5 years. The model takes the annual average of the regulation and translate it to an application limit of less than 78kg/ha/yr over the per-hectare P removal rate.

386 The lower application limit is 75% of the 78kg/ha/yr, reducing it to 15kg/ha/yr.

387 Manure export allow the farm to remove manure from the farm at a cost of 10% above manure application cost

388 Land rental allows the farm to rent additional land at a cost of $300/ha, and is restricted to rent no more than 10% of its land base.

389 Milking herd size only counts the number of milking age cows. Models assume number of heifers equals number of milking age cows.

390 Total manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.19b – N balances of a large Ontario dairy farm under a more restrictive Nutrient Management Act (2002)[391] at 79% lower application limit[392]: allowing for manure export[393] or land rental[394].

Program Outputs	Units	Base Solution	Regulated scenario with manure export	% change from base solution	Regulated scenario with land rental	% change from base solution
N Balances						
Total N required[395,396]	metric tons/yr	44.67	36.22	-19%	40.15	-10%
Total N input[397]	**metric tons/yr**	**54.37**	**42.12**	**-23%**	**47.01**	**-14%**
from manure	metric tons/yr	23.19	15.79	-32%	17.77	-23%
from fertilizer	metric tons/yr	0	2.825		2.703	
from other sources[398]	metric tons/yr	31.18	23.51	-25%	26.54	-15%
Total N Removed[399,400]	metric tons/yr	46.23	36.06	-22%	40.20	-13%
Soil N surplus / ha[401]	**kg/ha/yr**	**40.72**	**35.22**	**-13%**	**35.27**	**-13%**
N agronomic balance / ha[402]	**kg/ha/yr**	**48.51**	**34.27**	**-29%**	**35.53**	**-27%**

Source: program output

Notes:

391 The Nutrient Management Act (2002) includes a regulation that limits the per-hectare P application rate to less than 390kg/ha over per-hectare P removal (see note 16) over 5 years. The model takes the annual average of the regulation and translate it to an application limit of less than 78kg/ha/yr over the per-hectare P removal rate.

392 The lower application limit is 75% of the 78kg/ha/yr, reducing it to 15kg/ha/yr.

393 Manure export allow the farm to remove manure from the farm at a cost of 10% above manure application cost

394 Land rental allows the farm to rent additional land at a cost of $300/ha, and is restricted to rent no more than 10% of its land base.

395 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

396 Total N required is the sum of the per-hectare N requirement of each crop (see note 2) times land used for production of each crop.

397 Total N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

398 N from other sources is calculated as the hectares of land used multiplied by the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

399 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

400 Total N removed is the sum of the per-hectare N removal rate (see note 8) of each crop times land used for production of each crop.

401 Soil N surplus is calculated as total N input minus total N removed (see notes 8 and 9), divided by total land use.

402 N agronomic balance is calculated as total N input minus total N required (see notes 4 and 5), divided by total land use.

Table 6.19c – P balances of a large Ontario dairy farm under a more restrictive Nutrient Management Act (2002)[403] at 79% lower application limit[404]: allowing for manure export[405] or land rental[406].

Program Outputs	Units	Base Solution	Regulated scenario with manure export	% change from base solution	Regulated scenario with land rental	% change from base solution
P Balances						
Total P Required[407,408]	metric tons/yr	7.25	13.49	86%	15.18	109%
Total P Input[409]	**metric tons/yr**	**19.82**	**13.49**	**-32%**	**15.18**	**-23%**
from manure	metric tons/yr	19.82	13.49	-32%	15.18	-23%
from fertilizer	metric tons/yr	0	0		0	
Total P Removed[410,411]	metric tons/yr	12.35	10.91	-12%	12.28	-1%
Soil P surplus / ha[412]	**kg/ha/yr**	**37.34**	**15.00**	**-60%**	**15.00**	**-60%**
P agronomic balance / ha[413]	**kg/ha/yr**	**19.09**	**0**	**-100%**	**0**	**-100%**

Source: program output

Notes:

403 The Nutrient Management Act (2002) includes a regulation that limits the per-hectare P application rate to less than 390kg/ha over per-hectare P removal (see note 16) over 5 years. The model takes the annual average of the regulation and translate it to an application limit of less than 78kg/ha/yr over the per-hectare P removal rate.

404 The lower application limit is 75% of the 78kg/ha/yr, reducing it to 15kg/ha/yr.

405 Manure export allow the farm to remove manure from the farm at a cost of 10% above manure application cost

406 Land rental allows the farm to rent additional land at a cost of $300/ha, and is restricted to rent no more than 10% of its land base.

407 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield. The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

408 Total P required is the sum of per-hectare P requirement of each crop (see note 12) times land used for production of each crop.

409 Total P input is the sum of P input from manure and from fertilizer

410 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

411 Total P removed is the sum of the per-hectare P removal rate (see note 15) of each crop times land used for production of each crop.

412 Soil P surplus is calculated as total P input minus total P removed (see notes 15 and 16), divided by total land use.

413 P agronomic balance is calculated as total P input minus total P required (see notes 12 and 13), divided by total land use.

it's milking herd size to 153 head of milking age cattle. Given the option to rent land, the large farm is also able to reduce the compliance cost of the regulation to $43.312/yr, or 19% of the base net return. The reduction in compliance cost is less if the farm chooses to rent land rather than exports manure, since the 10% increase in land base is not enough for the farm to spread manure of the herd size in the base scenario while staying within the regulatory limit.

Scenario 2: Clean Water Act (2007)

Scenario 2.1: N and P application less than crop requirement + 15%

Under the Clean Water Act (2007), the proposed regulation limits both N and P application per hectare to 115% of crop requirement. Under this regulation, the small farm model did not incur any compliance cost since the application rates for with N and P in the base solution are both within regulatory limits. The compliance cost of a medium farm under the requirement-based regulations is presented in Table 6.20. The N and P requirement-based regulation reduces the net return of the medium farm model by $587/yr, a 1% reduction compared to the base solution. There is no reduction in herd size or land used in order for the farm to reach compliance: manure application rates were changed on some crops to reduce N fertilizer usage. Table 6.21 shows the per-hectare model output and nutrient balances for the medium farm under the Clean Water Act (2007). In order to reach compliance, manure application is reduced on land used for alfalfa haylage production, and increased on land used by all other crops. The decrease in manure application in alfalfa haylage reduces the N agronomic balance for alfalfa haylage from 82.53kg/ha/yr in the base solution to 45.96kg/ha/yr, which lead to a reduction in the soil N surplus and the N agronomic balance. The increase in manure

Table 6.20a – Compliance cost of a medium Ontario dairy farm under the proposed Clean Water Act (2007)[414]: N and P application rate limited to less than 15% over crop requirement.

Program Outputs	Units	Base Solution	Solution in regulated scenario	% change from base solution
Compliance Cost	**$/yr**		**$587**	
Net Return	**$**	**$115,211**	**$114,624**	**-1%**
Milking Herd Size[415]	cows	70	70	0%
Total Land Used	ha	130	130	0%
Shadow Value of Land	$/ha/yr	$279	$425	52%
Shadow Value of Barn	$/cow/yr	$1,128	$847	-25%
Total Manure Applied[416]	metric tons/yr	284.0	284.0	0%
N fertilizer purchased	metric tons/yr	0.7115	0.5688	-20%
P fertilizer purchased	metric tons/yr	2.240	2.483	11%
K fertilizer purchased	metric tons/yr	0.8857	1.46345	65%

Source: model output

Notes:

414 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 4 and 12).

415 Milking herd size only counts the number of milking age cows. Models assume number of heifers equals number of milking age cows.

416 Total manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.20b – N balances of a medium Ontario dairy farm under the proposed Clean Water Act (2007)[417]: N and P application rate limited to less than 15% over crop requirement.

Program Outputs	Units	Base Solution	Solution in regulated scenario	% change from base solution
N Balances				
Total N required[418,419]	metric tons/yr	26.77	27.31	2%
Total N input[420]	**metric tons/yr**	**30.15**	**30.01**	**0%**
from manure	metric tons/yr	9.551	9.551	0%
from fertilizer	metric tons/yr	0.7115	0.5688	-20%
from other sources[421]	metric tons/yr	19.89	19.89	0%
Total N Removed[422,423]	metric tons/yr	29.07	29.13	0%
Soil N surplus / ha[424]	**kg/ha/yr**	**8.314**	**6.761**	**-19%**
N agronomic balance / ha[425]	**kg/ha/yr**	**26.05**	**21**	**-20%**

Source: model output

Notes:

417 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 4 and 12).

418 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

419 Total N required is the sum of the per-hectare N requirement of each crop (see note 2) times land used for production of each crop.

420 Total N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

421 N from other sources is calculated as the hectares of land used multiplied by the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

422 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

423 Total N removed is the sum of the per-hectare N removal rate (see note 8) of each crop times land used for production of each crop.

424 Soil N surplus is calculated as total N input minus total N removed (see notes 8 and 9), divided by total land use.

425 N agronomic balance is calculated as total N input minus total N required (see notes 4 and 5), divided by total land use.

Table 6.20c – P balances of a medium Ontario dairy farm under the proposed Clean Water Act (2007)[426]: N and P application rate limited to less than 15% over crop requirement.

Program Outputs	Units	Base Solution	Solution in regulated scenario	% change from base solution
P Balances				
Total P Required[427,428]	metric tons/yr	10.40	10.40	0%
Total P Input[429]	**metric tons/yr**	**10.40**	**10.64**	**2%**
from manure	metric tons/yr	8.160	8.160	0%
from fertilizer	metric tons/yr	2.240	2.4834	11%
Total P Removed[430,431]	metric tons/yr	8.038	8.082	1%
Soil P surplus / ha[432]	**kg/ha/yr**	**18.17**	**19.70**	**8%**
P agronomic balance / ha[433]	**kg/ha/yr**	**0**	**1.87**	

Source: model output

Notes:

426 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 4 and 12).

427 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield. The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

428 Total P required is the sum of per-hectare P requirement of each crop (see note 12) times land used for production of each crop.

429 Total P input is the sum of P input from manure and from fertilizer

430 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

431 Total P removed is the sum of the per-hectare P removal rate (see note 15) of each crop times land used for production of each crop.

432 Soil P surplus is calculated as total P input minus total P removed (see notes 15 and 16), divided by total land use.

433 P agronomic balance is calculated as total P input minus total P required (see notes 12 and 13), divided by total land use.

Table 6.21a – Model outputs on a per-crop basis for the model of medium Ontario dairy farms under the Clean Water Act (2007)[434]: N and P application rate limited to less than 15% over crop requirement.

Model Outputs by Crop			Crops					
		Units	Corn	Corn Silage	Alfalfa Hay	Alfalfa Haylage	Soybeans	Wheat
Land Used		**ha**	**25.12**	**23.64**	**27.13**	**21.62**	**16.25**	**16.25**
Yield[435]		**metric tons/ha/yr**	**6.379**	**10.66**	**10.89**	**10.20**	**2.500**	**4.800**
Crop Produced[436]		**metric tons/yr**	160.2	252.0	295.5	220.5	40.63	78.00
	% sold		35.01%		77.78%		100%	100%
	% fed		64.99%	100%	22.22%	100%		
Crop Purchased[437]		**metric tons/yr**	0	0	0	0		
Manure Applied[438]		**metric tons/yr**	80.89	76.04	39.34	34.23	20.97	32.52
N fertilizer Applied		kg/yr	0	0	0	0	0	568.8
P fertilizer Applied		kg/yr	0	0	1312	961.9	209.8	0
K fertilizer Applied		kg/yr	0	0	856.1	607.4	0	0

Source: Model output

Notes:

434 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 4 and 12).

435 Yield of each crop is measured in metric tons of dry matter per hectare. Yield for alfalfa hay, alfalfa haylage, soybeans, and wheat are calibrated to 2008 yield estimates in Oxford County, referenced from the NMAN2 Software (OMAFRA, undated). Corn and corn silage yield is determined by a quadratic N-response yield function (see Chapter 5).

436 Crop produced is measured in metric tons of dry matter, and is calculated as the yield of each crop multiplied by land used for production for each crop. All corn silage and alfalfa haylage produced must be used for feed, and all soybeans and wheat produced must be sold.

437 Crop purchased is measured in metric tons of dry matter. Soybeans and wheat cannot be purchased.

438 Manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.21b – Per-hectare N balances on a per-crop basis for the model of medium Ontario dairy farms under the Clean Water Act (2007)[439]: N and P application rate limited to less than 15% over crop requirement.

Nutrient Balance by Crop		Crops					
	Units	Corn	Corn Silage	Alfalfa Hay	Alfalfa Haylage	Soybeans	Wheat
N Balances by Crop							
N Requirement per ha[440]	kg/ha/yr	138.4	138.3	276.4	306.4	240.7	155.7
N input per ha[441]	**kg/ha/yr**	**138.4**	**138.3**	**317.8**	**352.3**	**276.8**	**155.7**
from manure	kg/ha/yr	108.3	108.2	48.76	53.26	43.41	67.30
from fertilizer	kg/ha/yr	0	0	0	0	0	35.00
from other input[442]	kg/ha/yr	30.07	30.07	269.1	299.1	233.4	53.40
N Removal per ha[443]	kg/ha/yr	110.6	202.4	351.0	319.0	161.0	156.0
N surplus per ha[444]	**kg/ha/yr**	**27.79**	**-64.16**	**-33.17**	**33.33**	**115.81**	**-0.3000**
N Agronomic Balance per ha[445]	**kg/ha/yr**	**0.00**	**0.00**	**41.46**	**45.96**	**36.105**	**0**

Source: Model output

Notes:

439 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 4 and 12).

440 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

441 N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

442 N from other sources is the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

443 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

444 Soil N surplus is calculated as N input per hectare minus N removed per hectare (see note 8).

445 N agronomic balance is calculated as N input per hectare minus N required per hectare (see note 5).

Table 6.21c – Per-hectare P balances on a per-crop basis for the model of medium Ontario dairy farms under the Clean Water Act (2007)[446]: N and P application rate limited to less than 15% over crop requirement.

Nutrient Balance by Crop	Units	Crops					
		Corn	Corn Silage	Alfalfa Hay	Alfalfa Haylage	Soybeans	Wheat
P Balances by Crop							
P Requirement per ha[447]	kg/ha/yr	90	90	90	90	50	50
P input per ha[448]	**kg/ha/yr**	92.55	92.45	90.00	90.00	50.00	57.50
from manure	kg/ha/yr	92.55	92.45	41.66	45.50	37.09	57.50
from fertilizer	kg/ha/yr	0	0	48.34	44.50	12.91	0
P Removal per ha[449]	kg/ha/yr	82.94	75.54	53.08	53.08	57.60	42.46
P surplus per ha[450]	**kg/ha/yr**	**9.603**	**16.91**	**36.92**	**36.92**	**-7.60**	**15.04**
P Agronomic Balance per ha[451]	**kg/ha/yr**	**2.546**	**2.447**	**0**	**0**	**0**	**7.5**

Source: Model output

Notes:

446 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 4 and 12).

447 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield (see note 1). The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

448 Total P input is the sum of P input from manure and from fertilizer.

449 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

450 Soil P surplus is calculated as P input per hectare minus P removed per hectare (see notes 13 and 14).

451 P agronomic balance is calculated as P input per hectare minus P required per hectare (see notes 10 and 11).

application on corn and corn silage land is enough to eliminate the P fertilizer application for corn and corn silage production, which also leads to a higher P agronomic balance and soil P surplus. The increased manure application on wheat land also contributes to the increased P agronomic and soil P surplus.

The large farm model is greatly impacted by the Clean Water Act (2007). The compliance cost of a large farm under the more restrictive regulation is presented in Table 6.22. The Clean Water Act (2007) regulation reduces the net return of the medium farm model by $50,046/yr, a 22% reduction compared to the base solution. While the entire land base is used for crop production, the milking herd size is decrease by approximately 55 heads. There is also a large reduction for the N and P nutrient balances. Table 6.23 shows the per-hectare model output and nutrient balances for the large farm under the Clean Water Act (2007), and it shows a shift from corn silage land into corn production. Some alfalfa haylage land is also shifted to alfalfa hay production. Along with this, there is also a decrease in manure application on corn silage, alfalfa haylage, soybeans and wheat land, and an increase in manure application on corn and alfalfa hay land. The change in manure application on crops reduces the N agronomic balance on alfalfa hay land and alfalfa haylage land by over 50% compared to the base scenario, it also reduced the P agronomic balance on corn land and corn silage land by less than 50%, and reduced the P agronomic balance on wheat land by 80%. The reduction in soil N surplus is mainly attributed to a reduction in manure application on alfalfa haylage land, and the reduction in soil P surplus is contributed mainly through a reduction in manure application on wheat land.

Table 6.22a – Compliance cost of a large Ontario dairy farm under the proposed Clean Water Act (2007)[452]: N and P application rate limited to less than 15% over crop requirement.

Program Outputs	Units	Base Solution	Solution in regulated scenario	% change from base solution
Compliance Cost	**$/yr**		**$50,046**	
Net Return	**$**	**$232,236**	**$182,189**	**-22%**
Milking Herd Size[453]	cows	170	115	-32%
Total Land Used	ha	200	200	0%
Shadow Value of Land	$/ha/yr	$619	$911	47%
Shadow Value of Barn	$/cow/yr	$638	$0	-100%
Total Manure Applied[454]	metric tons/yr	689.7	465.9	-32%
N fertilizer purchased	metric tons/yr	0	0.8751	
P fertilizer purchased	metric tons/yr	0	3.812	
K fertilizer purchased	metric tons/yr	0	2.244	

Source: model output

Notes:

452 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 4 and 12).

453 Milking herd size only counts the number of milking age cows. Models assume number of heifers equals number of milking age cows.

454 Total manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.22b – N balances of a large Ontario dairy farm under the proposed Clean Water Act (2007)[455]: N and P application rate limited to less than 15% over crop requirement.

Program Outputs	Units	Base Solution	Solution in regulated scenario	% change from base solution
N Balances				
Total N required[456,457]	metric tons/yr	44.67	43.04	-4%
Total N input[458]	**metric tons/yr**	**54.37**	**47.21**	**-13%**
from manure	metric tons/yr	23.19	15.67	-32%
from fertilizer	metric tons/yr	0	0.8751	
from other sources[459]	metric tons/yr	31.18	30.67	-2%
Total N Removed[460,461]	metric tons/yr	46.23	45.04	-3%
Soil N surplus / ha[462]	**kg/ha/yr**	**40.72**	**10.87**	**-73%**
N agronomic balance / ha[463]	**kg/ha/yr**	**48.51**	**20.86**	**-57%**

Source: model output

Notes:

455 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 4 and 12).

456 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

457 Total N required is the sum of the per-hectare N requirement of each crop (see note 2) times land used for production of each crop.

458 Total N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

459 N from other sources is calculated as the hectares of land used multiplied by the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

460 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

461 Total N removed is the sum of the per-hectare N removal rate (see note 8) of each crop times land used for production of each crop.

462 Soil N surplus is calculated as total N input minus total N removed (see notes 8 and 9), divided by total land use.

463 N agronomic balance is calculated as total N input minus total N required (see notes 4 and 5), divided by total land use.

Table 6.22c – P balances of a large Ontario dairy farm under the proposed Clean Water Act (2007)[464]: N and P application rate limited to less than 15% over crop requirement.

Program Outputs	Units	Base Solution	Solution in regulated scenario	% change from base solution
P Balances				
Total P Required[465,466]	metric tons/yr	16.00	16.00	0%
Total P Input[467]	**metric tons/yr**	**19.82**	**17.20**	**-13%**
from manure	metric tons/yr	19.82	13.39	-32%
from fertilizer	metric tons/yr	0	3.812	
Total P Removed[468,469]	metric tons/yr	12.35	12.47	1%
Soil P surplus / ha[470]	**kg/ha/yr**	**37.34**	**23.66**	**-37%**
P agronomic balance / ha[471]	**kg/ha/yr**	**19.09**	**6.000**	**-69%**

Source: model output

Notes:

464 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 4 and 12).

465 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield. The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

466 Total P required is the sum of per-hectare P requirement of each crop (see note 12) times land used for production of each crop.

467 Total P input is the sum of P input from manure and from fertilizer

468 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

469 Total P removed is the sum of the per-hectare P removal rate (see note 15) of each crop times land used for production of each crop.

470 Soil P surplus is calculated as total P input minus total P removed (see notes 15 and 16), divided by total land use.

471 P agronomic balance is calculated as total P input minus total P required (see notes 12 and 13), divided by total land use.

Table 6.23a – Model outputs on a per-crop basis for the model of large Ontario dairy farms under the Clean Water Act (2007)[472]: N and P application rate limited to less than 15% over crop requirement.

Model Outputs by Crop			Crops					
		Units	Corn	Corn Silage	Alfalfa Hay	Alfalfa Haylage	Soybeans	Wheat
Land Used		**ha**	**36.54**	**38.46**	**39.53**	**35.47**	**25.00**	**25.00**
Yield[473]		**metric tons/ha/yr**	**6.431**	**10.75**	**10.89**	**10.2**	**2.500**	**4.800**
Crop Produced[474]		**metric tons/yr**	235.0	413.5	430.5	361.8	62.50	120.00
	% sold		27.31%		74.98%		100%	100%
	% fed		72.69%	100%	25.02%	100%		
Crop Purchased[475]		**metric tons/yr**	0	0	0	0	0	0
Manure Applied[476]		**metric tons/yr**	131.62	138.5	57.32	56.16	32.27	50.03
N fertilizer Applied		kg/yr	0	0	0	0	0	875.1
P fertilizer Applied		kg/yr	0	0	1911	1578	322.8	0
K fertilizer Applied		kg/yr	0	0	1247	996.5	0	0

Source: Model output

Notes:

472 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 4 and 12).

473 Yield of each crop is measured in metric tons of dry matter per hectare. Yield for alfalfa hay, alfalfa haylage, soybeans, and wheat are calibrated to 2008 yield estimates in Oxford County, referenced from the NMAN2 Software (OMAFRA, undated). Corn and corn silage yield is determined by a quadratic N-response yield function (see Chapter 5).

474 Crop produced is measured in metric tons of dry matter, and is calculated as the yield of each crop multiplied by land used for production for each crop. All corn silage and alfalfa haylage produced must be used for feed, and all soybeans and wheat produced must be sold.

475 Crop purchased is measured in metric tons of dry matter. Soybeans and wheat cannot be purchased.

476 Manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.23b – Per-hectare N balances on a per-crop basis for the model of large Ontario dairy farms under the Clean Water Act (2007)[477]: N and P application rate limited to less than 15% over crop requirement.

Nutrient Balance by Crop		Crops					
	Units	Corn	Corn Silage	Alfalfa Hay	Alfalfa Haylage	Soybeans	Wheat
N Balances by Crop							
N Requirement per ha[478]	kg/ha/yr	151.2	151.2	276.4	306.4	240.7	155.7
N input per ha[479]	**kg/ha/yr**	**151.2**	**151.2**	**317.8**	**352.3**	**276.8**	**155.7**
from manure	kg/ha/yr	121.1	121.1	48.76	53.26	43.41	67.30
from fertilizer	kg/ha/yr	0	0	0	0	0	35.00
from other input[480]	kg/ha/yr	30.07	30.07	269.1	299.1	233.4	53.40
N Removal per ha[481]	kg/ha/yr	111.5	204.1	351.0	319.0	161.0	156.0
N surplus per ha[482]	**kg/ha/yr**	**39.71**	**-52.89**	**-33.17**	**33.33**	**115.8**	**-0.3000**
N Agronomic Balance per ha[483]	**kg/ha/yr**	**0**	**0**	**41.46**	**45.96**	**36.1**	**0**

Source: Model output

Notes:

477 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 4 and 12).

478 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

479 N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

480 N from other sources is the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

481 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

482 Soil N surplus is calculated as N input per hectare minus N removed per hectare (see note 8).

483 N agronomic balance is calculated as N input per hectare minus N required per hectare (see note 5).

Table 6.23c – Per-hectare P balances on a per-crop basis for the model of large Ontario dairy farms under the Clean Water Act (2007)[484]: N and P application rate limited to less than 15% over crop requirement.

Nutrient Balance by Crop	Units	Crops					
		Corn	Corn Silage	Alfalfa Hay	Alfalfa Haylage	Soybeans	Wheat
P Balances by Crop							
P Requirement per ha[485]	kg/ha/yr	90	90	90	90	50	50
P input per ha[486]	**kg/ha/yr**	103.5	103.5	90.00	90.00	50.00	57.50
from manure	kg/ha/yr	103.5	103.5	41.66	45.50	37.09	57.50
from fertilizer	kg/ha/yr	0	0	48.34	44.50	12.91	0
P Removal per ha[487]	kg/ha/yr	83.62	76.16	53.08	53.08	57.60	42.46
P surplus per ha[488]	**kg/ha/yr**	**19.88**	**27.34**	**36.92**	**36.92**	**-7.600**	**15.04**
P Agronomic Balance per ha[489]	**kg/ha/yr**	**13.50**	**13.50**	**0**	**0**	**0**	**7.500**

Source: Model output

Notes:

484 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 4 and 12).

485 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield (see note 1). The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

486 Total P input is the sum of P input from manure and from fertilizer.

487 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

488 Soil P surplus is calculated as P input per hectare minus P removed per hectare (see notes 13 and 14).

489 P agronomic balance is calculated as P input per hectare minus P required per hectare (see notes 10 and 11).

When the Clean Water Act (2007) regulation is applied to the three farm models assuming a lower soil P test value (and therefore higher crop P requirement), compliance cost is reduced or eliminated. For the small and medium farm models with high soil P,there are no compliance costs if they are regulated under the Clean Water Act (2007). The compliance cost of the large farm model under the Clean Water Act (2007) regulations are presented in Table 6.24, and the compliance cost is $36,891/yr, or a 17% reduction compared to the base model assuming a lower soil P test value, and no land use reduction reported. In order to reach compliance, the farm model reduces manure output by reducing the milking herd size by 21%. This reduction in herd size is less than when modeled with the base soil P test value of 6-7mg/L. Lower soil P test values under the Clean Water Act (2007) regulations has an opposite affect on compliance costs compared to the Nutrient Management Act (2002) regulations. This is because the regulations under the Clean Water Act (2007) limit nutrient application based on nutrient requirement values. Therefore, farms with low soil P values have higher crop P requirement, meaning that the Clean Water Act (2007) regulation will allow these farms to apply more P compared to farms with low soil P test values. Whereas in under the Nutrient Management Act (2002) regulations, farms with low soil P test values have higher crop P requirements, which forces these farms to apply more P than what the Nutrient Management Act (2002) regulations allow, making compliance more difficult.

When the Clean Water Act (2007) regulation is applied to the three farm models assuming higher soil P test values, all farm models incur a higher compliance cost. Table 6.25 presents the model output and nutrient balances of the small farm model under the Clean Water Act (2007) regulation when modeled with higher soil P test values. The

Table 6.24a – Compliance cost of a large Ontario dairy farm under the proposed Clean Water Act (2007)[490]: N and P application rate limited to less than 15% over crop requirement: assuming lower soil P test values

Program Outputs	Units	Base solution with lower P soil value[491] 0-3mg/L	Regulated scenario with lower P soil value[2] 0-3mg/L	% change from base solution with lower P soil value
Compliance Cost	**$/yr**		**$36,891**	
Net Return	**$**	**$219,996**	**$183,105**	**-17%**
Milking Herd Size[492]	cows	170	135	-21%
Total Land Used	ha	200	200	0%
Shadow Value of Land	$/ha/yr	$362	$916	153%
Shadow Value of Barn	$/cow/yr	$868	$0	-100%
Total Manure Applied[493]	metric tons/yr	689.7	547.8	-21%
N fertilizer purchased	metric tons/yr	0	0.1685	
P fertilizer purchased	metric tons/yr	6.142	11.31	84%
K fertilizer purchased	metric tons/yr	0	2.222	

Source: model output

Notes:

490 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 5 and 13).

491 Crops grown on soil with high soil P value have low per-hectare P requirements. See Table 5.10 for P requirement values associated with soil P values.

492 Milking herd size only counts the number of milking age cows. Models assume number of heifers equals number of milking age cows.

493 Total manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.24b – N balances of a large Ontario dairy farm under the proposed Clean Water Act (2007)[494]: N and P application rate limited to less than 15% over crop requirement: assuming lower soil P test values

Program Outputs	Units	Base solution with lower P soil value[495] 0-3mg/L	Regulated scenario with lower P soil value[2] 0-3mg/L	% change from base solution with lower P soil value
N Balances				
Total N required[496,497]	metric tons/yr	44.12	45.25	3%
Total N input[498]	**metric tons/yr**	**54.37**	**49.45**	**-9%**
from manure	metric tons/yr	23.19	18.42	-21%
from fertilizer	metric tons/yr	0	0.1685	
from other sources[499]	metric tons/yr	31.18	30.86	-1%
Total N Removed[500,501]	metric tons/yr	46.22	45.47	-2%
Soil N surplus / ha[502]	**kg/ha/yr**	**40.75**	**19.86**	**-51%**
N agronomic balance / ha[503]	**kg/ha/yr**	**51.26**	**21.00**	**-59%**

Source: model output

Notes:

494 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 5 and 13).

495 Crops grown on soil with high soil P value have low per-hectare P requirements. See Table 5.10 for P requirement values associated with soil P values.

496 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

497 Total N required is the sum of the per-hectare N requirement of each crop (see note 2) times land used for production of each crop.

498 Total N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

499 N from other sources is calculated as the hectares of land used multiplied by the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

500 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

501 Total N removed is the sum of the per-hectare N removal rate (see note 8) of each crop times land used for production of each crop.

502 Soil N surplus is calculated as total N input minus total N removed (see notes 8 and 9), divided by total land use.

503 N agronomic balance is calculated as total N input minus total N required (see notes 4 and 5), divided by total land use.

Table 6.24c – P balances of a large Ontario dairy farm under the proposed Clean Water Act (2007)[504]: N and P application rate limited to less than 15% over crop requirement: assuming lower soil P test values

Program Outputs		Units	Base solution with lower P soil value[505] 0-3mg/L	Regulated scenario with lower P soil value[2] 0-3mg/L	% change from base solution with lower P soil value
P Balances					
Total P Required[506,507]		metric tons/yr	25.55	25.55	0%
Total P Input[508]		**metric tons/yr**	**25.96**	**27.05**	**4%**
	from manure	metric tons/yr	19.82	15.74	-21%
	from fertilizer	metric tons/yr	6.142	11.31	84%
Total P Removed[509,510]		metric tons/yr	12.35	12.42	1%
Soil P surplus / ha[511]		**kg/ha/yr**	**68.08**	**73.15**	**7%**
P agronomic balance / ha[512]		**kg/ha/yr**	**2.05**	**7.519**	**267%**

Source: model output

Notes:

504 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 5 and 13).

505 Crops grown on soil with high soil P value have low per-hectare P requirements. See Table 5.10 for P requirement values associated with soil P values.

506 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield. The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

507 Total P required is the sum of per-hectare P requirement of each crop (see note 12) times land used for production of each crop.

508 Total P input is the sum of P input from manure and from fertilizer

509 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

510 Total P removed is the sum of the per-hectare P removal rate (see note 15) of each crop times land used for production of each crop.

511 Soil P surplus is calculated as total P input minus total P removed (see notes 15 and 16), divided by total land use.

512 P agronomic balance is calculated as total P input minus total P required (see notes 12 and 13), divided by total land use.

Table 6.25a – Compliance cost of a small Ontario dairy farm under the proposed Clean Water Act (2007)[513]: N and P application rate limited to less than 15% over crop requirement: assuming higher soil P test values

Program Outputs	Units	Base solution with higher P soil value[514] 10-12mg/L	Regulated scenario with higher P soil value[2] 10-12mg/L	% change from base solution with higher P soil value
Compliance Cost	**$/yr**		**$165**	
Net Return	**$**	**$51,877**	**$51,712**	**0%**
Milking Herd Size[515]	cows	30	30	0%
Total Land Used	ha	60	60	0%
Shadow Value of Land	$/ha/yr	$418	$429	3%
Shadow Value of Barn	$/cow/yr	$894	$865	-3%
Total Manure Applied[516]	metric tons/yr	165.4	165.4	0%
N fertilizer purchased	metric tons/yr	1.494	1.428	-4%
P fertilizer purchased	metric tons/yr	0.05572	0.000	-100%
K fertilizer purchased	metric tons/yr	0	0.2321	

Source: model output

Notes:

513 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 5 and 13).

514 Crops grown on soil with high soil P value have low per-hectare P requirements. See Table 5.10 for P requirement values associated with soil P values.

515 Milking herd size only counts the number of milking age cows. Models assume number of heifers equals number of milking age cows.

516 Total manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.25b – N balances of a small Ontario dairy farm under the proposed Clean Water Act (2007)[517]: N and P application rate limited to less than 15% over crop requirement: assuming higher soil P test values

Program Outputs	Units	Base solution with lower P soil value[518] 0-3mg/L	Regulated scenario with lower P soil value[2] 0-3mg/L	% change from base solution with lower P soil value
N Balances				
Total N required[519,520]	metric tons/yr	11.91	11.91	0%
Total N input[521]	**metric tons/yr**	**12.56**	**12.50**	**-1%**
from manure	metric tons/yr	1.911	1.911	0%
from fertilizer	metric tons/yr	1.494	1.428	-4%
from other sources[522]	metric tons/yr	9.160	9.160	0%
Total N Removed[523,524]	metric tons/yr	13.30	13.30	0%
Soil N surplus / ha[525]	**kg/ha/yr**	**-12.28**	**-13.38**	**9%**
N agronomic balance / ha[526]	**kg/ha/yr**	**10.97**	**9.882**	**-10%**

Source: model output

Notes:

517 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 5 and 13).

518 Crops grown on soil with high soil P value have low per-hectare P requirements. See Table 5.10 for P requirement values associated with soil P values.

519 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

520 Total N required is the sum of the per-hectare N requirement of each crop (see note 2) times land used for production of each crop.

521 Total N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

522 N from other sources is calculated as the hectares of land used multiplied by the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

523 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

524 Total N removed is the sum of the per-hectare N removal rate (see note 8) of each crop times land used for production of each crop.

525 Soil N surplus is calculated as total N input minus total N removed (see notes 8 and 9), divided by total land use.

526 N agronomic balance is calculated as total N input minus total N required (see notes 4 and 5), divided by total land use.

Table 6.25c – P balances of a small Ontario dairy farm under the proposed Clean Water Act (2007)[527]: N and P application rate limited to less than 15% over crop requirement: assuming higher soil P test values

Program Outputs	Units	Base solution with higher P soil value[528] 10-12mg/L	Regulated scenario with higher P soil value[2] 10-12mg/L	% change from base solution with higher P soil value
P Balances				
Total P Required[529,530]	metric tons/yr	2.175	2.175	0%
Total P Input[531]	**metric tons/yr**	**2.413**	**2.357**	**-2%**
from manure	metric tons/yr	2.357	2.357	0%
from fertilizer	metric tons/yr	0.05572	0.000	-100%
Total P Removed[532,533]	metric tons/yr	3.664	3.664	0%
Soil P surplus / ha[534]	**kg/ha/yr**	**-20.86**	**-21.79**	**4%**
P agronomic balance / ha[535]	**kg/ha/yr**	**3.961**	**3.033**	**-23%**

Source: model output

Notes:

[527] The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 5 and 13).

[528] Crops grown on soil with high soil P value have low per-hectare P requirements. See Table 5.10 for P requirement values associated with soil P values.

[529] P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield. The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

[530] Total P required is the sum of per-hectare P requirement of each crop (see note 12) times land used for production of each crop.

[531] Total P input is the sum of P input from manure and from fertilizer

[532] P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

[533] Total P removed is the sum of the per-hectare P removal rate (see note 15) of each crop times land used for production of each crop.

[534] Soil P surplus is calculated as total P input minus total P removed (see notes 15 and 16), divided by total land use.

[535] P agronomic balance is calculated as total P input minus total P required (see notes 12 and 13), divided by total land use.

Table 6.26a – Compliance cost of a medium Ontario dairy farm under the proposed Clean Water Act (2007)[536]: N and P application rate limited to less than 15% over crop requirement: assuming higher soil P test values

Program Outputs	Units	Base solution with higher P soil value[537] 10-12mg/L	Regulated scenario with higher P soil value[2] 10-12mg/L	% change from base solution with higher P soil value
Compliance Cost	**$/yr**		**$22,570**	
Net Return	**$**	**$120,112**	**$97,542**	**-19%**
Milking Herd Size[538]	cows	70	46.488	-34%
Total Land Used	ha	130	130	0%
Shadow Value of Land	$/ha/yr	$441	$750	70%
Shadow Value of Barn	$/cow/yr	$897	$0	-100%
Total Manure Applied[539]	metric tons/yr	284.0	188.6	-34%
N fertilizer purchased	metric tons/yr	0	1.760	
P fertilizer purchased	metric tons/yr	0	0	
K fertilizer purchased	metric tons/yr	1.432	1.852	29%

Source: model output

Notes:

536 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 5 and 13).

537 Crops grown on soil with high soil P value have low per-hectare P requirements. See Table 5.10 for P requirement values associated with soil P values.

538 Milking herd size only counts the number of milking age cows. Models assume number of heifers equals number of milking age cows.

539 Total manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.26b – N balances of a medium Ontario dairy farm under the proposed Clean Water Act (2007)[540]: N and P application rate limited to less than 15% over crop requirement: assuming higher soil P test values

Program Outputs	Units	Base solution with lower P soil value[541] 0-3mg/L	Regulated scenario with lower P soil value[2] 0-3mg/L	% change from base solution with lower P soil value
N Balances				
Total N required[542,543]	metric tons/yr	11.91	11.91	0%
Total N input[544]	**metric tons/yr**	**12.56**	**12.50**	**-1%**
from manure	metric tons/yr	1.911	1.911	0%
from fertilizer	metric tons/yr	1.494	1.428	-4%
from other sources[545]	metric tons/yr	9.160	9.160	0%
Total N Removed[546,547]	metric tons/yr	13.30	13.30	0%
Soil N surplus / ha[548]	**kg/ha/yr**	**-12.28**	**-13.38**	**9%**
N agronomic balance / ha[549]	**kg/ha/yr**	**10.97**	**9.882**	**-10%**

Source: model output

Notes:

540 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 5 and 13).

541 Crops grown on soil with high soil P value have low per-hectare P requirements. See Table 5.10 for P requirement values associated with soil P values.

542 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

543 Total N required is the sum of the per-hectare N requirement of each crop (see note 2) times land used for production of each crop.

544 Total N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

545 N from other sources is calculated as the hectares of land used multiplied by the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

546 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

547 Total N removed is the sum of the per-hectare N removal rate (see note 8) of each crop times land used for production of each crop.

548 Soil N surplus is calculated as total N input minus total N removed (see notes 8 and 9), divided by total land use.

549 N agronomic balance is calculated as total N input minus total N required (see notes 4 and 5), divided by total land use.

Table 6.26c – P balances of a medium Ontario dairy farm under the proposed Clean Water Act (2007)[550]: N and P application rate limited to less than 15% over crop requirement: assuming higher soil P test values

Program Outputs	Units	Base solution with higher P soil value[551] 10-12mg/L	Regulated scenario with higher P soil value[2] 10-12mg/L	% change from base solution with higher P soil value
P Balances				
Total P Required[552,553]	metric tons/yr	4.71	4.71	0%
Total P Input[554]	**metric tons/yr**	**8.16**	**5.42**	**-34%**
from manure	metric tons/yr	8.160	5.419	-34%
from fertilizer	metric tons/yr	0	0	
Total P Removed[555,556]	metric tons/yr	8.038	7.986	-1%
Soil P surplus / ha[557]	**kg/ha/yr**	**0.94**	**-19.74**	**-2193%**
P agronomic balance / ha[558]	**kg/ha/yr**	**26.51**	**5.438**	**-79%**

Source: model output

Notes:

550 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 5 and 13).

551 Crops grown on soil with high soil P value have low per-hectare P requirements. See Table 5.10 for P requirement values associated with soil P values.

552 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield. The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

553 Total P required is the sum of per-hectare P requirement of each crop (see note 12) times land used for production of each crop.

554 Total P input is the sum of P input from manure and from fertilizer

555 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

556 Total P removed is the sum of the per-hectare P removal rate (see note 15) of each crop times land used for production of each crop.

557 Soil P surplus is calculated as total P input minus total P removed (see notes 15 and 16), divided by total land use.

558 P agronomic balance is calculated as total P input minus total P required (see notes 12 and 13), divided by total land use.

compliance cost in this case is $165/yr, with no herd size or land use reduction reported. Table 6.26 presents the model output and nutrient balances of the medium farm model under the Clean Water Act (2007) regulation when modeled with a higher soil P test values. For the medium farm, the compliance cost is $22,570/yr, or approximately 19% of the net return in the base model assuming a higher soil P, with a corresponding 34% drop in herd size and no land use reduction reported. Table 6.27 presents the model output and nutrient balances of the large farm model under the Clean Water Act (2007) regulation, when modeled with a higher soil P test values, and reports a compliance cost of $82,171/yr, or 35% lower than the net return of the base model assuming a higher soil P. In order for large farms with high soil P test values to reach compliance, herd size is reduced by 58%. Higher soil P test values under the Clean Water Act (2007) regulations also has an opposite affect on compliance costs compared to the Nutrient Management Act (2002) regulations. Farms with high soil P values have lower crop P requirement, meaning that the Clean Water Act (2007) regulations will allow these farms to apply less P compared to farms with high soil P test values. Whereas, under the Nutrient Management Act (2002) regulations, farms with high soil P test values have lower crop P requirements, force these farms to apply more P than what the Nutrient Management Act (2002) regulations allow. Farms with high soil P test values will find the Clean Water Act (2007) regulations easier to comply with compared to the Nutrient Management Act (2002) regulations.

Manure export does not reduce the cost of complying with the Clean Water Act (2007) for the medium farm model, since compliance to the Clean Water Act (2007) does not force a reduction in herd size. Land rental is effective in reducing compliance cost.

Table 6.27a – Compliance cost of a large Ontario dairy farm under the proposed Clean Water Act (2007)[559]: N and P application rate limited to less than 15% over crop requirement: assuming higher soil P test values

Program Outputs	Units	Base solution with higher P soil value[560] 10-12mg/L	Regulated scenario with higher P soil value[2] 10-12mg/L	% change from base solution with higher P soil value
Compliance Cost	**$/yr**		**$82,171**	
Net Return	**$**	**$232,236**	**$150,065**	**-35%**
Milking Herd Size[561]	cows	170	72	-58%
Total Land Used	ha	200	200	0%
Shadow Value of Land	$/ha/yr	$619	$750	21%
Shadow Value of Barn	$/cow/yr	$638	$0	-100%
Total Manure Applied[562]	metric tons/yr	689.7	290.2	-58%
N fertilizer purchased	metric tons/yr	0	2.708	
P fertilizer purchased	metric tons/yr	0	0	
K fertilizer purchased	metric tons/yr	0	2.849	

Source: model output

Notes:

559 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 5 and 13).

560 Crops grown on soil with high soil P value have low per-hectare P requirements. See Table 5.10 for P requirement values associated with soil P values.

561 Milking herd size only counts the number of milking age cows. Models assume number of heifers equals number of milking age cows.

562 Total manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.27b – N balances of a large Ontario dairy farm under the proposed Clean Water Act (2007)[563]: N and P application rate limited to less than 15% over crop requirement: assuming higher soil P test values

Program Outputs	Units	Base solution with lower P soil value[564] 0-3mg/L	Regulated scenario with lower P soil value[2] 0-3mg/L	% change from base solution with lower P soil value
N Balances				
Total N required[565,566]	metric tons/yr	44.67	39.43	-12%
Total N input[567]	**metric tons/yr**	**54.37**	**42.73**	**-21%**
from manure	metric tons/yr	23.19	9.76	-58%
from fertilizer	metric tons/yr	0	2.708	
from other sources[568]	metric tons/yr	31.18	30.27	-3%
Total N Removed[569,570]	metric tons/yr	46.23	43.74	-5%
Soil N surplus / ha[571]	**kg/ha/yr**	**40.72**	**-5.02**	**-112%**
N agronomic balance / ha[572]	**kg/ha/yr**	**48.51**	**16.54**	**-66%**

Source: model output

Notes:

563 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 5 and 13).

564 Crops grown on soil with high soil P value have low per-hectare P requirements. See Table 5.10 for P requirement values associated with soil P values.

565 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

566 Total N required is the sum of the per-hectare N requirement of each crop (see note 2) times land used for production of each crop.

567 Total N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

568 N from other sources is calculated as the hectares of land used multiplied by the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

569 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

570 Total N removed is the sum of the per-hectare N removal rate (see note 8) of each crop times land used for production of each crop.

571 Soil N surplus is calculated as total N input minus total N removed (see notes 8 and 9), divided by total land use.

572 N agronomic balance is calculated as total N input minus total N required (see notes 4 and 5), divided by total land use.

Table 6.27c – P balances of a large Ontario dairy farm under the proposed Clean Water Act (2007)[573]: N and P application rate limited to less than 15% over crop requirement: assuming higher soil P test values

Program Outputs	Units	Base solution with higher P soil value[574] 10-12mg/L	Regulated scenario with higher P soil value[2] 10-12mg/L	% change from base solution with higher P soil value
P Balances				
Total P Required[575,576]	metric tons/yr	7.250	7.250	0%
Total P Input[577]	**metric tons/yr**	**19.82**	**8.338**	**-58%**
from manure	metric tons/yr	19.82	8.338	-58%
from fertilizer	metric tons/yr	0.000	0.00	
Total P Removed[578,579]	metric tons/yr	12.35	12.29	-1%
Soil P surplus / ha[580]	**kg/ha/yr**	**37.34**	**-19.74**	**-153%**
P agronomic balance / ha[581]	**kg/ha/yr**	**62.84**	**5.438**	**-91%**

Source: model output

Notes:

573 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 5 and 13).

574 Crops grown on soil with high soil P value have low per-hectare P requirements. See Table 5.10 for P requirement values associated with soil P values.

575 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield. The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

576 Total P required is the sum of per-hectare P requirement of each crop (see note 12) times land used for production of each crop.

577 Total P input is the sum of P input from manure and from fertilizer

578 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

579 Total P removed is the sum of the per-hectare P removal rate (see note 15) of each crop times land used for production of each crop.

580 Soil P surplus is calculated as total P input minus total P removed (see notes 15 and 16), divided by total land use.

581 P agronomic balance is calculated as total P input minus total P required (see notes 12 and 13), divided by total land use.

Table 6.28a – Compliance cost of a medium Ontario dairy farm under the proposed Clean Water Act (2007)[582]: N and P application rate limited to less than 15% over crop requirement: allowing for manure export[583] or land rental[584].

Program Outputs	Units	Base Solution	Regulated scenario with manure export	% change from base solution	Regulated scenario with land rental	% change from base solution
Compliance Cost	**$/yr**		**$587**		**$164**	
Net Return	**$/yr**	**$115,211**	**$114,624**	**-1%**	**$115,047**	**0%**
Milking Herd Size[585]	cows	70	70	0%	70	0%
Total Land Used	ha	130	130	0%	135.084	4%
Shadow Value of Land	$/ha/yr	$279	$425	52%	$300	7%
Shadow Value of Barn	$/cow/yr	$1,128	$847	-25%	$1,086	-4%
Total Manure Applied[586]	metric tons/yr	284.0	284.0	0%	284.0	0%
Total Manure Exported	metric tons/yr	0	0		0	
N fertilizer purchased	metric tons/yr	0.7115	0.5688	-20%	0.739	4%
P fertilizer purchased	metric tons/yr	2.240	2.483	11%	2.647	18%
K fertilizer purchased	metric tons/yr	0.8857	1.463	65%	1.524	72%

Source: program output

Notes:

582 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 6 and 14).

583 Manure export allow the farm to remove manure from the farm at a cost of 10% above manure application cost

584 Land rental allows the farm to rent additional land at a cost of $300/ha, and is restricted to rent no more than 10% of its land base.

585 Milking herd size only counts the number of milking age cows. Models assume number of heifers equals number of milking age cows.

586 Total manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.28b – N balances of a medium Ontario dairy farm under the proposed Clean Water Act (2007)[587]: N and P application rate limited to less than 15% over crop requirement: allowing for manure export[588] or land rental[589].

Program Outputs	Units	Base Solution	Regulated scenario with manure export	% change from base solution	Regulated scenario with land rental	% change from base solution
N Balances						
Total N required[590,591]	metric tons/yr	26.77	27.31	2%	28.20	5%
Total N input[592]	**metric tons/yr**	**30.15**	**30.01**	**0%**	**30.93**	**3%**
from manure	metric tons/yr	9.551	9.551	0%	9.551	0%
from fertilizer	metric tons/yr	0.7115	0.5688	-20%	0.739	4%
from other sources[593]	metric tons/yr	19.89	19.89	0%	20.64	4%
Total N Removed[594,595]	metric tons/yr	29.07	29.13	0%	30.20	4%
Soil N surplus / ha[596]	**kg/ha/yr**	**8.314**	**6.761**	**-19%**	**5.44**	**-35%**
N agronomic balance / ha[597]	**kg/ha/yr**	**26.05**	**20.81**	**-20%**	**20.24**	**-22%**

Source: program output

Notes:

587 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 6 and 14).

588 Manure export allow the farm to remove manure from the farm at a cost of 10% above manure application cost

589 Land rental allows the farm to rent additional land at a cost of $300/ha, and is restricted to rent no more than 10% of its land base.

590 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

591 Total N required is the sum of the per-hectare N requirement of each crop (see note 2) times land used for production of each crop.

592 Total N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

593 N from other sources is calculated as the hectares of land used multiplied by the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

594 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

595 Total N removed is the sum of the per-hectare N removal rate (see note 8) of each crop times land used for production of each crop.

596 Soil N surplus is calculated as total N input minus total N removed (see notes 8 and 9), divided by total land use.

597 N agronomic balance is calculated as total N input minus total N required (see notes 4 and 5), divided by total land use.

Table 6.28c – P balances of a medium Ontario dairy farm under the proposed Clean Water Act (2007)[598]: N and P application rate limited to less than 15% over crop requirement: allowing for manure export[599] or land rental[600].

Program Outputs	Units	Base Solution	Regulated scenario with manure export	% change from base solution	Regulated scenario with land rental	% change from base solution
P Balances						
Total P Required[601,602]	metric tons/yr	10.40	10.40	0%	10.81	4%
Total P Input[603]	**metric tons/yr**	**10.40**	**10.64**	**2%**	**10.81**	**4%**
from manure	metric tons/yr	8.160	8.160	0%	8.160	0%
from fertilizer	metric tons/yr	2.240	2.483	11%	2.646	18%
Total P Removed[604,605]	metric tons/yr	8.038	8.082	1%	8.394	4%
Soil P surplus / ha[606]	**kg/ha/yr**	**18.17**	**19.70**	**8%**	**17.86**	**-2%**
P agronomic balance / ha[607]	**kg/ha/yr**	**0**	**1.874**		**0**	

Source: program output

Notes:

598 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 6 and 14).

599 Manure export allow the farm to remove manure from the farm at a cost of 10% above manure application cost

600 Land rental allows the farm to rent additional land at a cost of $300/ha, and is restricted to rent no more than 10% of its land base.

601 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield. The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

602 Total P required is the sum of per-hectare P requirement of each crop (see note 12) times land used for production of each crop.

603 Total P input is the sum of P input from manure and from fertilizer

604 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

605 Total P removed is the sum of the per-hectare P removal rate (see note 15) of each crop times land used for production of each crop.

606 Soil P surplus is calculated as total P input minus total P removed (see notes 15 and 16), divided by total land use.

607 P agronomic balance is calculated as total P input minus total P required (see notes 12 and 13), divided by total land use.

Table 6.28 presents the compliance cost of a medium dairy farm under the Clean Water Act (2007) when the farm is able to export manure at a cost 10% above the cost of manure application, or rent land at a cost of $300/ha for up to 10% of the land base. The medium farm model reports no manure export even when the option to export manure is given, and the medium farm's compliance cost remains at $587/yr. Given the option to rent land, the large farm is also able to reduce the compliance cost of the regulation to $164/yr.

For the large farm model, both manure export and land rental are able to reduce compliance cost, and land rental is a more effective method in reducing compliance cost. Table 6.29 presents the compliance cost of a medium dairy farm under the Clean Water Act (2007) when the farm is able to export manure at a cost 10% above the cost of manure application, or rent land at a cost of $300/ha up to 10% of the land base. Given the option to export manure, the compliance cost of the large farm model is reduced to $13,698/yr, a 6% reduction of the net return in base solution. Given the option to export manure, the large farm model no longer has to reduce its herd size in order to comply with the regulations. Given the option to rent land, the compliance cost is lowered to $37,828, a 16% reduction of the net return in base solution. Note that when the medium farm model is allowed to rent land, there is a slightly greater reduction in soil N surplus and soil P surplus. There is little change to the nutrient balance in the large farm model under the Clean Water Act (2007) regulations when the model is allowed to export manure, and no change at all when the large farm is allowed to rent extra land.

Table 6.29a – Compliance cost of a large Ontario dairy farm under the proposed Clean Water Act (2007)[608]: N and P application rate limited to less than 15% over crop requirement: allowing for manure export[609] or land rental[610].

Program Outputs	Units	Base Solution	Regulated scenario with manure export	% change from base solution	Regulated scenario with land rental	% change from base solution
Compliance Cost	**$/yr**		**$13,698**		**$37,828**	
Net Return	**$/yr**	**$232,236**	**$218,538**	**-6%**	**$194,408**	**-16%**
Milking Herd Size[611]	cows	170	170	0%	126.328	-26%
Total Land Used	ha	200	200	0%	220	10%
Shadow Value of Land	$/ha/yr	$619	$553	-11%	$911	47%
Shadow Value of Barn	$/cow/yr	$638	$635	0%	$0	-100%
Total Manure Applied[612]	metric tons/yr	689.7	468.2	-32%	512.5	-26%
Total Manure Exported	metric tons/yr	0	221.5		0	
N fertilizer purchased	metric tons/yr	0	0.8751		0.9626	
P fertilizer purchased	metric tons/yr	0	3.747		4.193	
K fertilizer purchased	metric tons/yr	0	2.185		2.468	

Source: program output

Notes:

608 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 6 and 14).

609 Manure export allow the farm to remove manure from the farm at a cost of 10% above manure application cost

610 Land rental allows the farm to rent additional land at a cost of $300/ha, and is restricted to rent no more than 10% of its land base.

611 Milking herd size only counts the number of milking age cows. Models assume number of heifers equals number of milking age cows.

612 Total manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.29b – N balances of a large Ontario dairy farm under the proposed Clean Water Act (2007)[613]: N and P application rate limited to less than 15% over crop requirement: allowing for manure export[614] or land rental[615].

Program Outputs	Units	Base Solution	Regulated scenario with manure export	% change from base solution	Regulated scenario with land rental	% change from base solution
N Balances						
Total N required[616,617]	metric tons/yr	44.67	43.55	-3%	47.35	6%
Total N input[618]	**metric tons/yr**	**54.37**	**47.80**	**-12%**	**51.93**	**-4%**
from manure	metric tons/yr	23.19	15.75	-32%	17.24	-26%
from fertilizer	metric tons/yr	0	0.8751		0.9626	
from other sources[619]	metric tons/yr	31.18	31.18	0%	33.74	8%
Total N Removed[620,621]	metric tons/yr	46.23	46.20	0%	49.54	7%
Soil N surplus / ha[622]	**kg/ha/yr**	**40.72**	**7.986**	**-80%**	**10.87**	**-73%**
N agronomic balance / ha[623]	**kg/ha/yr**	**48.51**	**21.24**	**-56%**	**20.86**	**-57%**

Source: program output

Notes:

613 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 6 and 14).

614 Manure export allow the farm to remove manure from the farm at a cost of 10% above manure application cost

615 Land rental allows the farm to rent additional land at a cost of $300/ha, and is restricted to rent no more than 10% of its land base.

616 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

617 Total N required is the sum of the per-hectare N requirement of each crop (see note 2) times land used for production of each crop.

618 Total N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

619 N from other sources is calculated as the hectares of land used multiplied by the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

620 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

621 Total N removed is the sum of the per-hectare N removal rate (see note 8) of each crop times land used for production of each crop.

622 Soil N surplus is calculated as total N input minus total N removed (see notes 8 and 9), divided by total land use.

623 N agronomic balance is calculated as total N input minus total N required (see notes 4 and 5), divided by total land use.

Table 6.29c – P balances of a large Ontario dairy farm under the proposed Clean Water Act (2007)[624]: N and P application rate limited to less than 15% over crop requirement: allowing for manure export[625] or land rental[626].

Program Outputs	Units	Base Solution	Regulated scenario with manure export	% change from base solution	Regulated scenario with land rental	% change from base solution
P Balances						
Total P Required[627,628]	metric tons/yr	16.00	16.00	0%	17.60	10%
Total P Input[629]	**metric tons/yr**	**19.82**	**17.20**	**-13%**	**18.92**	**-5%**
from manure	metric tons/yr	19.82	13.45	-32%	14.73	-26%
from fertilizer	metric tons/yr	0	3.747		4.193	
Total P Removed[630,631]	metric tons/yr	12.35	12.33	0%	13.71	11%
Soil P surplus / ha[632]	**kg/ha/yr**	**37.34**	**24.35**	**-35%**	**23.66**	**-37%**
P agronomic balance / ha[633]	**kg/ha/yr**	**19.09**	**6.000**	**-69%**	**6.000**	**-69%**

Source: program output

Notes:

624 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 6 and 14).

625 Manure export allow the farm to remove manure from the farm at a cost of 10% above manure application cost

626 Land rental allows the farm to rent additional land at a cost of $300/ha, and is restricted to rent no more than 10% of its land base.

627 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield. The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

628 Total P required is the sum of per-hectare P requirement of each crop (see note 12) times land used for production of each crop.

629 Total P input is the sum of P input from manure and from fertilizer

630 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

631 Total P removed is the sum of the per-hectare P removal rate (see note 15) of each crop times land used for production of each crop.

632 Soil P surplus is calculated as total P input minus total P removed (see notes 15 and 16), divided by total land use.

633 P agronomic balance is calculated as total P input minus total P required (see notes 12 and 13), divided by total land use.

Scenario 2.2: N and P application less than crop requirement + 10%

A second regulatory scenario modeling the Clean Water Act (2007) with a stricter regulation is applied for all farms. In this sub-scenario, the proposed regulation limits both N and P application per hectare to 110% of the crop requirements. This reduction in application limit is arbitrarily chosen to simulate a hypothetical situation where N and P application in groundwater protection zones and surface water intake protection zones were considered to be a higher threat to drinking water quality than previously thought. Under this regulation, the small farm model still does not incur any compliance cost. The compliance cost of a medium farm under the more restrictive regulation is presented in Table 6.30. The N and P requirement-based regulation reduces the net return of the medium farm model by $6072/yr, a 5% reduction compared to the base solution. Compliance is reached by a small reduction in herd size of 4 milking age cows with no reduction in land used. There is a reduction in the soil N balance and the N agronomic balance, and a slight increase in the soil P balance and P agronomic balance. Table 6.31 shows the per-hectare model output and nutrient balances for the medium farm under the Clean Water Act (2007). Under the Clean Water Act (2007), manure application is also reduced on land used for alfalfa haylage production, and increased on land used for all other crops. The increase in manure application on corn and corn silage land is enough to eliminate the P fertilizer application for corn and corn silage production, which results in a higher P agronomic balance and soil P surplus. The increased manure application on wheat land also contributes to the increased P agronomic balance and soil P surplus.

The large farm model is greatly impacted by the stricter Clean Water Act (2007) regulations. The compliance cost of a large farm under the more restrictive regulation is

Table 6.30a – Compliance cost of a medium Ontario dairy farm under a more restrictive proposed Clean Water Act (2007)[634]: N and P application rate limited to less than 10% over crop requirement.

Program Outputs	Units	Base Solution	Solution in regulated scenario	% change from base solution
Compliance Cost	**$/yr**		**$6,072**	
Net Return	**$**	**$115,211**	**$109,139**	**-5%**
Milking Herd Size[635]	cows	70	66	-6%
Total Land Used	ha	130	130	0%
Shadow Value of Land	$/ha/yr	$279	$840	201%
Shadow Value of Barn	$/cow/yr	$1,128	$0	-100%
Total Manure Applied[636]	metric tons/yr	284.0	266.7	-6%
N fertilizer purchased	metric tons/yr	0.7115	0.6164	-13%
P fertilizer purchased	metric tons/yr	2.240	3.257	45%
K fertilizer purchased	metric tons/yr	0.8857	2.105	138%

Source: model output

Notes:

634 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 4 and 12).

635 Milking herd size only counts the number of milking age cows. Models assume number of heifers equals number of milking age cows.

636 Total manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.30b – N balances of a medium Ontario dairy farm under a more restrictive proposed Clean Water Act (2007)[637]: N and P application rate limited to less than 10% over crop requirement.

Program Outputs	Units	Base Solution	Solution in regulated scenario	% change from base solution
N Balances				
Total N required[638,639]	metric tons/yr	26.77	27.64	3%
Total N input[640]	**metric tons/yr**	**30.15**	**29.44**	**-2%**
from manure	metric tons/yr	9.551	8.968	-6%
from fertilizer	metric tons/yr	0.7115	0.6164	-13%
from other sources[641]	metric tons/yr	19.89	19.85	0%
Total N Removed[642,643]	metric tons/yr	29.07	29.07	0%
Soil N surplus / ha[644]	**kg/ha/yr**	**8.314**	**2.812**	**-66%**
N agronomic balance / ha[645]	**kg/ha/yr**	**26.05**	**13.84**	**-47%**

Source: model output

Notes:

637 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 4 and 12).

638 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

639 Total N required is the sum of the per-hectare N requirement of each crop (see note 2) times land used for production of each crop.

640 Total N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

641 N from other sources is calculated as the hectares of land used multiplied by the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

642 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

643 Total N removed is the sum of the per-hectare N removal rate (see note 8) of each crop times land used for production of each crop.

644 Soil N surplus is calculated as total N input minus total N removed (see notes 8 and 9), divided by total land use.

645 N agronomic balance is calculated as total N input minus total N required (see notes 4 and 5), divided by total land use.

Table 6.30c – P balances of a medium Ontario dairy farm under a more restrictive proposed Clean Water Act (2007)[646]: N and P application rate limited to less than 10% over crop requirement.

Program Outputs		Units	Base Solution	Solution in regulated scenario	% change from base solution
P Balances					
Total P Required[647,648]		metric tons/yr	10.40	10.40	0%
Total P Input[649]		**metric tons/yr**	**10.40**	**10.92**	**5%**
	from manure	metric tons/yr	8.160	7.663	-6%
	from fertilizer	metric tons/yr	2.240	3.257	45%
Total P Removed[650,651]		metric tons/yr	8.038	8.115	1%
Soil P surplus / ha[652]		**kg/ha/yr**	**18.17**	**21.58**	**19%**
P agronomic balance / ha[653]		**kg/ha/yr**	**0**	**4.000**	

Source: model output

Notes:

646 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 4 and 12).

647 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield. The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

648 Total P required is the sum of per-hectare P requirement of each crop (see note 12) times land used for production of each crop.

649 Total P input is the sum of P input from manure and from fertilizer

650 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

651 Total P removed is the sum of the per-hectare P removal rate (see note 15) of each crop times land used for production of each crop.

652 Soil P surplus is calculated as total P input minus total P removed (see notes 15 and 16), divided by total land use.

653 P agronomic balance is calculated as total P input minus total P required (see notes 12 and 13), divided by total land use.

Table 6.31a – Model outputs on a per-crop basis for the model of medium Ontario dairy farms under the Clean Water Act (2007)[654]: N and P application rate limited to less than 10% over crop requirement.

Model Outputs by Crop			Crops					
		Units	Corn	Corn Silage	Alfalfa Hay	Alfalfa Haylage	Soybeans	Wheat
Land Used		**ha**	**26.68**	**22.07**	**28.45**	**20.30**	**16.25**	**16.25**
Yield[655]		**metric tons/ha/yr**	**6.413**	**10.723**	**10.89**	**10.2**	**2.5**	**4.8**
Crop Produced[656]		**metric tons/yr**	171.09	236.7	309.8	207.1	40.63	78.00
	% sold		42.85%		80.10%		100%	100%
	% fed		57.15%	100%	19.90%	100%		
Crop Purchased[657]		**metric tons/yr**	0	0	0	0	0	0
Manure Applied[658]		**metric tons/yr**	91.91	76.05	29.56	22.90	15.16	31.10
N fertilizer Applied		kg/yr	0	0	0	0	0	616.4
P fertilizer Applied		kg/yr	0	0	1711	1169	376.9	0
K fertilizer Applied		kg/yr	0	0	1200	809.2	95.96	0

Source: Model output

Notes:

654 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 4 and 12).

655 Yield of each crop is measured in metric tons of dry matter per hectare. Yield for alfalfa hay, alfalfa haylage, soybeans, and wheat are calibrated to 2008 yield estimates in Oxford County, referenced from the NMAN2 Software (OMAFRA, undated). Corn and corn silage yield is determined by a quadratic N-response yield function (see Chapter 5).

656 Crop produced is measured in metric tons of dry matter, and is calculated as the yield of each crop multiplied by land used for production for each crop. All corn silage and alfalfa haylage produced must be used for feed, and all soybeans and wheat produced must be sold.

657 Crop purchased is measured in metric tons of dry matter. Soybeans and wheat cannot be purchased.

658 Manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.31b – Per-hectare N balances on a per-crop basis for the model of medium Ontario dairy farms under the Clean Water Act (2007)[659]: N and P application rate limited to less than 10% over crop requirement.

Nutrient Balance by Crop		Crops					
	Units	Corn	Corn Silage	Alfalfa Hay	Alfalfa Haylage	Soybeans	Wheat
N Balances by Crop							
N Requirement per ha[660]	kg/ha/yr	145.9	145.9	276.4	306.4	240.7	155.7
N input per ha[661]	**kg/ha/yr**	**145.9**	**145.9**	**304.0**	**337.0**	**264.8**	**155.7**
from manure	kg/ha/yr	115.87	115.87	34.94	37.94	31.37	64.37
from fertilizer	kg/ha/yr	0	0	0	0	0	37.93
from other input[662]	kg/ha/yr	30.07	30.07	269.1	299.1	233.4	53.40
N Removal per ha[663]	kg/ha/yr	111.2	203.5	351.0	319.0	161.0	156.0
N surplus per ha[664]	**kg/ha/yr**	**34.75**	**-57.60**	**-46.99**	**18.01**	**103.8**	**-0.3000**
N Agronomic Balance per ha[665]	**kg/ha/yr**	**0**	**0**	**27.64**	**30.64**	**24.07**	**0**

Source: Model output

Notes:

659 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 4 and 12).

660 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

661 N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

662 N from other sources is the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

663 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

664 Soil N surplus is calculated as N input per hectare minus N removed per hectare (see note 8).

665 N agronomic balance is calculated as N input per hectare minus N required per hectare (see note 5).

Table 6.31c – Per-hectare P balances on a per-crop basis for the model of medium Ontario dairy farms under the Clean Water Act (2007)[666]: N and P application rate limited to less than 10% over crop requirement.

Nutrient Balance by Crop		Crops					
	Units	Corn	Corn Silage	Alfalfa Hay	Alfalfa Haylage	Soybeans	Wheat
P Balances by Crop							
P Requirement per ha[667]	kg/ha/yr	90	90	90	90	50	50
P input per ha[668]	**kg/ha/yr**	99.00	99.00	90.00	90.00	50.00	55.00
from manure	kg/ha/yr	99.00	99.00	29.85	32.42	26.80	55.00
from fertilizer	kg/ha/yr	0	0	60.15	57.59	23.20	0.00
P Removal per ha[669]	kg/ha/yr	83.39	75.95	53.08	53.08	57.60	42.46
P surplus per ha[670]	**kg/ha/yr**	**15.61**	**23.05**	**36.92**	**36.92**	**-7.600**	**12.54**
P Agronomic Balance per ha[671]	**kg/ha/yr**	**9.000**	**9.000**	**0**	**0**	**0**	**5.000**

Source: Model output

Notes:

666 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 4 and 12).

667 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield (see note 1). The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

668 Total P input is the sum of P input from manure and from fertilizer.

669 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

670 Soil P surplus is calculated as P input per hectare minus P removed per hectare (see notes 13 and 14).

671 P agronomic balance is calculated as P input per hectare minus P required per hectare (see notes 10 and 11).

presented in Table 6.32. The Clean Water Act (2007) regulation reduces the net return of the medium farm model by $50,046/yr, a 22% reduction compared to the base solution. In order to reach compliance, the milking herd size is decrease by approximately 55 heads, a 41% reduction compared to the base solution, with no reduction in land used. There is also a large reduction for the N and P nutrient balances. Table 6.33 shows the per-hectare model output and nutrient balances for the large under the Clean Water Act (2007), and it shows a shift from corn silage land into corn production. Some alfalfa haylage land is also shifted to alfalfa hay production. Along with this, there is also a decrease in manure application on corn silage, alfalfa haylage, soybeans and wheat land, and an increase in manure application on corn and alfalfa hay land. The change in manure application on crops reduces the N agronomic balance on alfalfa hay land and alfalfa haylage land by over 50% compared to the base scenario, reduced the P agronomic balance on corn land and corn silage land by less than 50%, and reduced the P agronomic balance on wheat land by 80%. The reduction in soil N surplus is mainly attributed to a reduction in manure application on alfalfa haylage land, and the reduction in soil P surplus is contributed mainly through a reduction in manure application on wheat land.

When the stricter Clean Water Act (2007) regulation is applied to the three farm models assuming a lower soil P test values (and therefore higher crop P requirement), compliance cost is reduced or eliminated. For the small and medium farm models with high soil P, there are no compliance costs in this scenario. The compliance cost of the large farm model under the stricter Clean Water Act (2007) regulation is presented in Table 6.34, and the compliance cost is $51,372/yr, or a 23% reduction compared to the base solution assuming a lower soil P. To reach compliance, the large farm model with

Table 6.32a – Compliance cost of a large Ontario dairy farm under a more restrictive proposed Clean Water Act (2007)[672]: N and P application rate limited to less than 10% over crop requirement.

Program Outputs	Units	Base Solution	Solution in regulated scenario	% change from base solution
Compliance Cost	**$/yr**		**$64,330**	
Net Return	**$**	**$232,236**	**$167,906**	**-28%**
Milking Herd Size[673]	cows	170	101	-41%
Total Land Used	ha	200	200	0%
Shadow Value of Land	$/ha/yr	$619	$840	36%
Shadow Value of Barn	$/cow/yr	$638	$0	-100%
Total Manure Applied[674]	metric tons/yr	689.7	410.3	-41%
N fertilizer purchased	metric tons/yr	0	0.9483	
P fertilizer purchased	metric tons/yr	0	5.011	
K fertilizer purchased	metric tons/yr	0	3.238	

Source: model output

Notes:

672 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 4 and 12).

673 Milking herd size only counts the number of milking age cows. Models assume number of heifers equals number of milking age cows.

674 Total manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.32b – N balances of a large Ontario dairy farm under a more restrictive proposed Clean Water Act (2007)[675]: N and P application rate limited to less than 10% over crop requirement.

Program Outputs	Units	Base Solution	Solution in regulated scenario	% change from base solution
N Balances				
Total N required[676,677]	metric tons/yr	44.67	42.52	-5%
Total N input[678]	**metric tons/yr**	**54.37**	**45.29**	**-17%**
from manure	metric tons/yr	23.19	13.80	-41%
from fertilizer	metric tons/yr	0	0.9483	
from other sources[679]	metric tons/yr	31.18	30.54	-2%
Total N Removed[680,681]	metric tons/yr	46.23	44.73	-3%
Soil N surplus / ha[682]	**kg/ha/yr**	**40.72**	**2.812**	**-93%**
N agronomic balance / ha[683]	**kg/ha/yr**	**48.51**	**13.84**	**-71%**

Source: model output

Notes:

675 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 4 and 12).

676 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

677 Total N required is the sum of the per-hectare N requirement of each crop (see note 2) times land used for production of each crop.

678 Total N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

679 N from other sources is calculated as the hectares of land used multiplied by the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

680 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

681 Total N removed is the sum of the per-hectare N removal rate (see note 8) of each crop times land used for production of each crop.

682 Soil N surplus is calculated as total N input minus total N removed (see notes 8 and 9), divided by total land use.

683 N agronomic balance is calculated as total N input minus total N required (see notes 4 and 5), divided by total land use.

Table 6.32c – P balances of a large Ontario dairy farm under a more restrictive proposed Clean Water Act (2007)[684]: N and P application rate limited to less than 10% over crop requirement.

Program Outputs	Units	Base Solution	Solution in regulated scenario	% change from base solution
P Balances				
Total P Required[685,686]	metric tons/yr	16.00	16.00	0%
Total P Input[687]	**metric tons/yr**	**19.82**	**16.80**	**-15%**
from manure	metric tons/yr	19.82	11.79	-41%
from fertilizer	metric tons/yr	0	5.01	
Total P Removed[688,689]	metric tons/yr	12.35	12.48	1%
Soil P surplus / ha[690]	**kg/ha/yr**	**37.34**	**21.58**	**-42%**
P agronomic balance / ha[691]	**kg/ha/yr**	**19.089**	**4.000**	**-79%**

Source: model output

Notes:

684 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 4 and 12).

685 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield. The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

686 Total P required is the sum of per-hectare P requirement of each crop (see note 12) times land used for production of each crop.

687 Total P input is the sum of P input from manure and from fertilizer

688 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

689 Total P removed is the sum of the per-hectare P removal rate (see note 15) of each crop times land used for production of each crop.

690 Soil P surplus is calculated as total P input minus total P removed (see notes 15 and 16), divided by total land use.

691 P agronomic balance is calculated as total P input minus total P required (see notes 12 and 13), divided by total land use.

Table 6.33a – Model outputs on a per-crop basis for the model of large Ontario dairy farms under the Clean Water Act (2007)[692]: N and P application rate limited to less than 10% over crop requirement.

Model Outputs by Crop		Crops					
	Units	Corn	Corn Silage	Alfalfa Hay	Alfalfa Haylage	Soybeans	Wheat
Land Used	**ha**	**41.04**	**33.96**	**43.77**	**31.23**	**25.00**	**25.00**
Yield[693]	**metric tons/ha/yr**	**6.413**	**10.72**	**10.89**	**10.20**	**2.500**	**4.800**
Crop Produced[694]	**metric tons/yr**	263.2	364.1	476.6	318.6	62.50	120.0
% sold		42.85%		80.10%		100%	100%
% fed		57.15%	100%	19.90%	100%		
Crop Purchased[695]	**metric tons/yr**	0	0	0	0	0	0
Manure Applied[696]	**metric tons/yr**	141.4	117.0	45.47	35.23	23.32	47.85
N fertilizer Applied	kg/yr	0	0	0	0	0	948.3
P fertilizer Applied	kg/yr	0	0	2633	1798	579.9	0
K fertilizer Applied	kg/yr	0	0	1846	1245	147.6	0

Source: Model output

Notes:

692 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 4 and 12).

693 Yield of each crop is measured in metric tons of dry matter per hectare. Yield for alfalfa hay, alfalfa haylage, soybeans, and wheat are calibrated to 2008 yield estimates in Oxford County, referenced from the NMAN2 Software (OMAFRA, undated). Corn and corn silage yield is determined by a quadratic N-response yield function (see Chapter 5).

694 Crop produced is measured in metric tons of dry matter, and is calculated as the yield of each crop multiplied by land used for production for each crop. All corn silage and alfalfa haylage produced must be used for feed, and all soybeans and wheat produced must be sold.

695 Crop purchased is measured in metric tons of dry matter. Soybeans and wheat cannot be purchased.

696 Manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.33b – Per-hectare N balances on a per-crop basis for the model of large Ontario dairy farms under the Clean Water Act (2007)[697]: N and P application rate limited to less than 10% over crop requirement.

Nutrient Balance by Crop	Units	Crops: Corn	Corn Silage	Alfalfa Hay	Alfalfa Haylage	Soybeans	Wheat
N Balances by Crop							
N Requirement per ha[698]	kg/ha/yr	145.9	145.9	276.4	306.4	240.7	155.7
N input per ha[699]	**kg/ha/yr**	**145.9**	**145.9**	**304.0**	**337.0**	**264.8**	**155.7**
from manure	kg/ha/yr	115.9	115.9	34.94	37.94	31.37	64.37
from fertilizer	kg/ha/yr	0	0	0	0	0	37.93
from other input[700]	kg/ha/yr	30.07	30.07	269.1	299.1	233.4	53.40
N Removal per ha[701]	kg/ha/yr	111.2	203.5	351.0	319.0	161.0	156.0
N surplus per ha[702]	**kg/ha/yr**	**34.75**	**-57.60**	**-46.99**	**18.01**	**103.8**	**-0.3000**
N Agronomic Balance per ha[703]	**kg/ha/yr**	**0**	**0**	**27.64**	**30.64**	**24.07**	**0**

Source: Model output

Notes:

697 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 4 and 12).

698 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

699 N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

700 N from other sources is the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

701 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

702 Soil N surplus is calculated as N input per hectare minus N removed per hectare (see note 8).

703 N agronomic balance is calculated as N input per hectare minus N required per hectare (see note 5).

Table 6.33c – Per-hectare P balances on a per-crop basis for the model of large Ontario dairy farms under the Clean Water Act (2007)[704]: N and P application rate limited to less than 10% over crop requirement.

Nutrient Balance by Crop		Crops					
	Units	Corn	Corn Silage	Alfalfa Hay	Alfalfa Haylage	Soybeans	Wheat
P Balances by Crop							
P Requirement per ha[705]	kg/ha/yr	90	90	90	90	50	50
P input per ha[706]	**kg/ha/yr**	99.00	99.00	90.00	90.00	50.00	55.00
from manure	kg/ha/yr	99.00	99.00	29.85	32.42	26.80	55.00
from fertilizer	kg/ha/yr	0	0	60.15	57.59	23.20	0
P Removal per ha[707]	kg/ha/yr	83.39	75.95	53.08	53.08	57.60	42.46
P surplus per ha[708]	**kg/ha/yr**	**15.61**	**23.05**	**36.92**	**36.92**	**-7.600**	**12.54**
P Agronomic Balance per ha[709]	**kg/ha/yr**	**9.000**	**9.000**	**0**	**0**	**0**	**5.000**

Source: Model output

Notes:

704 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 4 and 12).

705 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield (see note 1). The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

706 Total P input is the sum of P input from manure and from fertilizer.

707 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

708 Soil P surplus is calculated as P input per hectare minus P removed per hectare (see notes 13 and 14).

709 P agronomic balance is calculated as P input per hectare minus P required per hectare (see notes 10 and 11).

Table 6.34a – Compliance cost of a large Ontario dairy farm under a more restrictive Clean Water Act (2007)[710]: N and P application rate limited to less than 10% over crop requirement: assuming lower soil P test values

Program Outputs	Units	Base solution with lower P soil value[711] 0-3mg/L	Regulated scenario with lower P soil value[2] 0-3mg/L	% change from base solution with lower P soil value
Compliance Cost	**$/yr**		**$51,372**	
Net Return	**$/yr**	**$219,996**	**$168,624**	**-23%**
Milking Herd Size[712]	cows	170	120	-29%
Total Land Used	ha	200	200	0%
Shadow Value of Land	$/ha/yr	$362	$843	133%
Shadow Value of Barn	$/cow/yr	$868	$0	-100%
Total Manure Applied[713]	metric tons/yr	689.7	488.3	-29%
N fertilizer purchased	metric tons/yr	0	0.2724	
P fertilizer purchased	metric tons/yr	6.142	12.52	104%
K fertilizer purchased	metric tons/yr	0	3.224	

Source: model output

Notes:

710 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 5 and 13).

711 Crops grown on soil with high soil P value have low per-hectare P requirements. See Table 5.10 for P requirement values associated with soil P values.

712 Milking herd size only counts the number of milking age cows. Models assume number of heifers equals number of milking age cows.

713 Total manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.34b – N balances of a large Ontario dairy farm under a more restrictive Clean Water Act (2007)[714]: N and P application rate limited to less than 10% over crop requirement: assuming lower soil P test values

Program Outputs	Units	Base solution with lower P soil value[715] 0-3mg/L	Regulated scenario with lower P soil value[2] 0-3mg/L	% change from base solution with lower P soil value
N Balances				
Total N required[716,717]	metric tons/yr	44.12	44.63	1%
Total N input[718]	**metric tons/yr**	**54.37**	**47.42**	**-13%**
from manure	metric tons/yr	23.19	16.42	-29%
from fertilizer	metric tons/yr	0	0.2724	
from other sources[719]	metric tons/yr	31.18	30.72	-1%
Total N Removed[720,721]	metric tons/yr	46.22	45.18	-2%
Soil N surplus / ha[722]	**kg/ha/yr**	**40.75**	**11.18**	**-73%**
N agronomic balance / ha[723]	**kg/ha/yr**	**51.26**	**13.93**	**-73%**

Source: model output

Notes:

714 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 5 and 13).

715 Crops grown on soil with high soil P value have low per-hectare P requirements. See Table 5.10 for P requirement values associated with soil P values.

716 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

717 Total N required is the sum of the per-hectare N requirement of each crop (see note 2) times land used for production of each crop.

718 Total N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

719 N from other sources is calculated as the hectares of land used multiplied by the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

720 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

721 Total N removed is the sum of the per-hectare N removal rate (see note 8) of each crop times land used for production of each crop.

722 Soil N surplus is calculated as total N input minus total N removed (see notes 8 and 9), divided by total land use.

723 N agronomic balance is calculated as total N input minus total N required (see notes 4 and 5), divided by total land use.

Table 6.34c – P balances of a large Ontario dairy farm under a more restrictive Clean Water Act (2007)[724]: N and P application rate limited to less than 10% over crop requirement: assuming lower soil P test values

Program Outputs	Units	Base solution with lower P soil value[725] 0-3mg/L	Regulated scenario with lower P soil value[2] 0-3mg/L	% change from base solution with lower P soil value
P Balances				
Total P Required[726,727]	metric tons/yr	25.55	25.55	0%
Total P Input[728]	**metric tons/yr**	**25.96**	**26.55**	**2%**
from manure	metric tons/yr	19.82	14.03	-29%
from fertilizer	metric tons/yr	6.142	12.52	104%
Total P Removed[729,730]	metric tons/yr	12.35	12.47	1%
Soil P surplus / ha[731]	**kg/ha/yr**	**68.08**	**70.41**	**3%**
P agronomic balance / ha[732]	**kg/ha/yr**	**2.051**	**5.013**	**144%**

Source: model output

Notes:

724 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 5 and 13).

725 Crops grown on soil with high soil P value have low per-hectare P requirements. See Table 5.10 for P requirement values associated with soil P values.

726 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield. The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

727 Total P required is the sum of per-hectare P requirement of each crop (see note 12) times land used for production of each crop.

728 Total P input is the sum of P input from manure and from fertilizer

729 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

730 Total P removed is the sum of the per-hectare P removal rate (see note 15) of each crop times land used for production of each crop.

731 Soil P surplus is calculated as total P input minus total P removed (see notes 15 and 16), divided by total land use.

732 P agronomic balance is calculated as total P input minus total P required (see notes 12 and 13), divided by total land use.

lower oil P test values is forced to reduce its herd size by 29% with no change in land used. This herd size reduction is smaller compared with the base scenario when modeled with the base soil P test values.

When the stricter Clean Water Act regulations are applied to the three farm models assuming a higher soil P test values, all farm models incur a higher compliance cost. Table 6.35 presents the model output and nutrient balances of the small farm model under the stricter Clean Water Act (2007) regulation when modeled with a higher soil P test values. The compliance cost in this case is $165/yr, with no herd size or land use reduction reported. Table 6.36 presents the model output and nutrient balances of the medium farm model under the Clean Water Act (2007) regulation when modeled with higher soil P test values. For the medium farm, the compliance cost is $22,570/yr, or approximately 19% of the net return in the base model assuming a higher soil P, with a corresponding 34% drop in herd size and no reduction in land used. Table 6.37 presents the model output and nutrient balances of the large farm model under the Clean Water Act (2007) regulation when modeled with a higher soil P test values, and reports a compliance cost of $82,171/yr, or 35% lower than the net return of the base model assuming a higher soil P. In order for the large farm model with high soil P test values to reach compliance, it is forced to reduce its herd size by 61%, with no reduction in land.

Manure export does not reduce the cost of complying with the Clean Water Act (2007) for the medium farm model, since no reduction in herd size is reported, but land rental is effective in reducing compliance cost. Table 6.38 presents the compliance cost of a medium dairy farm under the Clean Water Act (2007) when the farm is able to export manure at a cost 10% above the cost of manure application, or rent land at a cost of $300/ha up to 10% of the land base. The medium farm model reports no manure

Table 6.35a – Compliance cost of a small Ontario dairy farm under a stricter Clean Water Act (2007)[733]: N and P application rate limited to less than 10% over crop requirement: assuming higher soil P test values

Program Outputs	Units	Base solution with higher P soil value[734] 10-12mg/L	Regulated scenario with higher P soil value[2] 10-12mg/L	% change from base solution with higher P soil value
Compliance Cost	**$/yr**		**$211**	
Net Return	**$/yr**	**$51,877**	**$51,666**	**0%**
Milking Herd Size[735]	cows	30	30	0%
Total Land Used	ha	60	60	0%
Shadow Value of Land	$/ha/yr	$418	$428	3%
Shadow Value of Barn	$/cow/yr	$894	$865	-3%
Total Manure Applied[736]	metric tons/yr	165.4	165.4	0%
N fertilizer purchased	metric tons/yr	1.494	1.401	-6%
P fertilizer purchased	metric tons/yr	0.05572	0	-100%
K fertilizer purchased	metric tons/yr	0	0.2895	

Source: model output

Notes:

[733] The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 5 and 13).

[734] Crops grown on soil with high soil P value have low per-hectare P requirements. See Table 5.10 for P requirement values associated with soil P values.

[735] Milking herd size only counts the number of milking age cows. Models assume number of heifers equals number of milking age cows.

[736] Total manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.35b – N balances of a small Ontario dairy farm under a stricter Clean Water Act (2007)[737]: N and P application rate limited to less than 10% over crop requirement: assuming higher soil P test values

Program Outputs	Units	Base solution with higher P soil value[738] 10-12mg/L	Regulated scenario with higher P soil value[2] 10-12mg/L	% change from base solution with higher P soil value
N Balances				
Total N required[739,740]	metric tons/yr	11.91	11.91	0%
Total N input[741]	**metric tons/yr**	**12.56**	**12.47**	**-1%**
from manure	metric tons/yr	1.911	1.911	0%
from fertilizer	metric tons/yr	1.494	1.401	-6%
from other sources[742]	metric tons/yr	9.160	9.160	0%
Total N Removed[743,744]	metric tons/yr	13.30	13.30	0%
Soil N surplus / ha[745]	**kg/ha/yr**	**-12.28**	**-13.83**	**13%**
N agronomic balance / ha[746]	**kg/ha/yr**	**10.97**	**9.426**	**-14%**

Source: model output

Notes:

737 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 5 and 13).

738 Crops grown on soil with high soil P value have low per-hectare P requirements. See Table 5.10 for P requirement values associated with soil P values.

739 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

740 Total N required is the sum of the per-hectare N requirement of each crop (see note 2) times land used for production of each crop.

741 Total N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

742 N from other sources is calculated as the hectares of land used multiplied by the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

743 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

744 Total N removed is the sum of the per-hectare N removal rate (see note 8) of each crop times land used for production of each crop.

745 Soil N surplus is calculated as total N input minus total N removed (see notes 8 and 9), divided by total land use.

746 N agronomic balance is calculated as total N input minus total N required (see notes 4 and 5), divided by total land use.

Table 6.35c – P balances of a small Ontario dairy farm under a stricter Clean Water Act (2007)[747]: N and P application rate limited to less than 10% over crop requirement: assuming higher soil P test values

Program Outputs	Units	Base solution with higher P soil value[748] 10-12mg/L	Regulated scenario with higher P soil value[2] 10-12mg/L	% change from base solution with higher P soil value
P Balances				
Total P Required[749,750]	metric tons/yr	2.175	2.175	0%
Total P Input[751]	**metric tons/yr**	**2.413**	**2.357**	**-2%**
from manure	metric tons/yr	2.357	2.357	0%
from fertilizer	metric tons/yr	0.05572	0	-100%
Total P Removed[752,753]	metric tons/yr	3.664	3.664	0%
Soil P surplus / ha[754]	**kg/ha/yr**	**-20.86**	**-21.79**	**4%**
P agronomic balance / ha[755]	**kg/ha/yr**	**3.961**	**3.033**	**-23%**

Source: model output

Notes:

747 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 5 and 13).

748 Crops grown on soil with high soil P value have low per-hectare P requirements. See Table 5.10 for P requirement values associated with soil P values.

749 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield. The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

750 Total P required is the sum of per-hectare P requirement of each crop (see note 12) times land used for production of each crop.

751 Total P input is the sum of P input from manure and from fertilizer

752 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

753 Total P removed is the sum of the per-hectare P removal rate (see note 15) of each crop times land used for production of each crop.

754 Soil P surplus is calculated as total P input minus total P removed (see notes 15 and 16), divided by total land use.

755 P agronomic balance is calculated as total P input minus total P required (see notes 12 and 13), divided by total land use.

Table 6.36a – Compliance cost of a medium Ontario dairy farm under a stricter Clean Water Act (2007)[756]: N and P application rate limited to less than 10% over crop requirement: assuming higher soil P test values

Program Outputs	Units	Base solution with higher P soil value[757] 10-12mg/L	Regulated scenario with higher P soil value[2] 10-12mg/L	% change from base solution with higher P soil value
Compliance Cost	**$/yr**		**$26,275**	
Net Return	**$/yr**	**$120,112**	**$93,837**	**-22%**
Milking Herd Size[758]	cows	70	43	-39%
Total Land Used	ha	130	130	0%
Shadow Value of Land	$/ha/yr	$441	$722	64%
Shadow Value of Barn	$/cow/yr	$897	$0	-100%
Total Manure Applied[759]	metric tons/yr	284.0	172.7	-39%
N fertilizer purchased	metric tons/yr	0	1.922	
P fertilizer purchased	metric tons/yr	0	0.05724	
K fertilizer purchased	metric tons/yr	1.432	2.125	48%

Source: model output

Notes:

756 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 5 and 13).

757 Crops grown on soil with high soil P value have low per-hectare P requirements. See Table 5.10 for P requirement values associated with soil P values.

758 Milking herd size only counts the number of milking age cows. Models assume number of heifers equals number of milking age cows.

759 Total manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.36b – N balances of a medium Ontario dairy farm under a stricter Clean Water Act (2007)[760]: N and P application rate limited to less than 10% over crop requirement: assuming higher soil P test values

Program Outputs	Units	Base solution with higher P soil value[761] 10-12mg/L	Regulated scenario with higher P soil value[2] 10-12mg/L	% change from base solution with higher P soil value
N Balances				
Total N required[762,763]	metric tons/yr	26.77	25.59	-4%
Total N input[764]	**metric tons/yr**	**29.44**	**27.37**	**-7%**
from manure	metric tons/yr	9.551	5.809	-39%
from fertilizer	metric tons/yr	0	1.922	
from other sources[765]	metric tons/yr	19.89	19.64	-1%
Total N Removed[766,767]	metric tons/yr	29.07	28.35	-2%
Soil N surplus / ha[768]	**kg/ha/yr**	**2.841**	**-7.523**	**-365%**
N agronomic balance / ha[769]	**kg/ha/yr**	**20.58**	**13.68**	**-34%**

Source: model output

Notes:

760 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 5 and 13).

761 Crops grown on soil with high soil P value have low per-hectare P requirements. See Table 5.10 for P requirement values associated with soil P values.

762 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

763 Total N required is the sum of the per-hectare N requirement of each crop (see note 2) times land used for production of each crop.

764 Total N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

765 N from other sources is calculated as the hectares of land used multiplied by the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

766 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

767 Total N removed is the sum of the per-hectare N removal rate (see note 8) of each crop times land used for production of each crop.

768 Soil N surplus is calculated as total N input minus total N removed (see notes 8 and 9), divided by total land use.

769 N agronomic balance is calculated as total N input minus total N required (see notes 4 and 5), divided by total land use.

Table 6.36c – P balances of a medium Ontario dairy farm under a stricter Clean Water Act (2007)[770]: N and P application rate limited to less than 10% over crop requirement: assuming higher soil P test values

Program Outputs	Units	Base solution with higher P soil value[771] 10-12mg/L	Regulated scenario with higher P soil value[2] 10-12mg/L	% change from base solution with higher P soil value
P Balances				
Total P Required[772,773]	metric tons/yr	4.71	4.71	0%
Total P Input[774]	**metric tons/yr**	**8.16**	**5.02**	**-38%**
from manure	metric tons/yr	8.160	4.963	-39%
from fertilizer	metric tons/yr	0	0.05724	
Total P Removed[775,776]	metric tons/yr	8.038	7.996	-1%
Soil P surplus / ha[777]	**kg/ha/yr**	**0.94**	**-22.89**	**-2526%**
P agronomic balance / ha[778]	**kg/ha/yr**	**26.51**	**2.369**	**-91%**

Source: model output

Notes:

770 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 5 and 13).

771 Crops grown on soil with high soil P value have low per-hectare P requirements. See Table 5.10 for P requirement values associated with soil P values.

772 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield. The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

773 Total P required is the sum of per-hectare P requirement of each crop (see note 12) times land used for production of each crop.

774 Total P input is the sum of P input from manure and from fertilizer

775 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

776 Total P removed is the sum of the per-hectare P removal rate (see note 15) of each crop times land used for production of each crop.

777 Soil P surplus is calculated as total P input minus total P removed (see notes 15 and 16), divided by total land use.

778 P agronomic balance is calculated as total P input minus total P required (see notes 12 and 13), divided by total land use.

Table 6.37a – Compliance cost of a large Ontario dairy farm under a more restrictive Clean Water Act (2007)[779]: N and P application rate limited to less than 10% over crop requirement: assuming higher soil P test values

Program Outputs	Units	Base solution with higher P soil value[780] 10-12mg/L	Regulated scenario with higher P soil value[2] 10-12mg/L	% change from base solution with higher P soil value
Compliance Cost	**$/yr**		**$87,872**	
Net Return	**$/yr**	**$232,236**	**$144,364**	**-38%**
Milking Herd Size[781]	cows	170	66	-61%
Total Land Used	ha	200	200	0%
Shadow Value of Land	$/ha/yr	$619	$722	17%
Shadow Value of Barn	$/cow/yr	$638	$0	-100%
Total Manure Applied[782]	metric tons/yr	689.7	265.7	-61%
N fertilizer purchased	metric tons/yr	0	2.957	
P fertilizer purchased	metric tons/yr	0	0.08806	
K fertilizer purchased	metric tons/yr	0	3.269	

Source: model output

Notes:

779 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 5 and 13).

780 Crops grown on soil with high soil P value have low per-hectare P requirements. See Table 5.10 for P requirement values associated with soil P values.

781 Milking herd size only counts the number of milking age cows. Models assume number of heifers equals number of milking age cows.

782 Total manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.37b – N balances of a large Ontario dairy farm under a more restrictive Clean Water Act (2007)[783]: N and P application rate limited to less than 10% over crop requirement: assuming higher soil P test values

Program Outputs	Units	Base solution with higher P soil value[784] 10-12mg/L	Regulated scenario with higher P soil value[2] 10-12mg/L	% change from base solution with higher P soil value
N Balances				
Total N required[785,786]	metric tons/yr	44.67	39.37	-12%
Total N input[787]	**metric tons/yr**	**54.37**	**42.11**	**-23%**
from manure	metric tons/yr	23.19	8.94	-61%
from fertilizer	metric tons/yr	0	2.957	
from other sources[788]	metric tons/yr	31.18	30.21	-3%
Total N Removed[789,790]	metric tons/yr	46.23	43.61	-6%
Soil N surplus / ha[791]	**kg/ha/yr**	**40.72**	**-7.523**	**-118%**
N agronomic balance / ha[792]	**kg/ha/yr**	**48.51**	**13.68**	**-72%**

Source: model output

Notes:

783 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 5 and 13).

784 Crops grown on soil with high soil P value have low per-hectare P requirements. See Table 5.10 for P requirement values associated with soil P values.

785 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

786 Total N required is the sum of the per-hectare N requirement of each crop (see note 2) times land used for production of each crop.

787 Total N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

788 N from other sources is calculated as the hectares of land used multiplied by the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

789 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

790 Total N removed is the sum of the per-hectare N removal rate (see note 8) of each crop times land used for production of each crop.

791 Soil N surplus is calculated as total N input minus total N removed (see notes 8 and 9), divided by total land use.

792 N agronomic balance is calculated as total N input minus total N required (see notes 4 and 5), divided by total land use.

Table 6.37c – P balances of a large Ontario dairy farm under a more restrictive Clean Water Act (2007)[793]: N and P application rate limited to less than 10% over crop requirement: assuming higher soil P test values

Program Outputs	Units	Base solution with higher P soil value[794] 10-12mg/L	Regulated scenario with higher P soil value[2] 10-12mg/L	% change from base solution with higher P soil value
P Balances				
Total P Required[795,796]	metric tons/yr	7.250	7.250	0%
Total P Input[797]	**metric tons/yr**	**19.82**	**7.724**	**-61%**
from manure	metric tons/yr	19.82	7.636	-61%
from fertilizer	metric tons/yr	0.000	0.08805	
Total P Removed[798,799]	metric tons/yr	12.35	12.30	0%
Soil P surplus / ha[800]	**kg/ha/yr**	**37.34**	**-22.89**	**-161%**
P agronomic balance / ha[801]	**kg/ha/yr**	**62.84**	**2.369**	**-96%**

Source: model output

Notes:

793 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 5 and 13).

794 Crops grown on soil with high soil P value have low per-hectare P requirements. See Table 5.10 for P requirement values associated with soil P values.

795 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield. The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

796 Total P required is the sum of per-hectare P requirement of each crop (see note 12) times land used for production of each crop.

797 Total P input is the sum of P input from manure and from fertilizer

798 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

799 Total P removed is the sum of the per-hectare P removal rate (see note 15) of each crop times land used for production of each crop.

800 Soil P surplus is calculated as total P input minus total P removed (see notes 15 and 16), divided by total land use.

801 P agronomic balance is calculated as total P input minus total P required (see notes 12 and 13), divided by total land use.

Table 6.38a – Compliance cost of a medium Ontario dairy farm under a more restrictive Clean Water Act (2007)[802]: N and P application rate limited to less than 10% over crop requirement: allowing for manure export[803] or land rental[804].

Program Outputs	Units	Base Solution	Regulated scenario with manure export	% change from base solution	Regulated scenario with land rental	% change from base solution
Compliance Cost	**$/yr**		**$3,046**		**$960**	
Net Return	**$/yr**	**$115,211**	**$112,165**	**-3%**	**$114,251**	**-1%**
Milking Herd Size[805]	cows	70	70	0%	70	0%
Total Land Used	ha	130	130	0%	143	10%
Shadow Value of Land	$/ha/yr	$279	$481	72%	$416	49%
Shadow Value of Barn	$/cow/yr	$1,128	$709	-37%	$838	-26%
Total Manure Applied[806]	metric tons/yr	284.0	266.8	-6%	284.0	0%
Total Manure Exported	metric tons/yr	0	17.19		0	
N fertilizer purchased	metric tons/yr	0.7115	0.5688	-20%	0.739	4%
P fertilizer purchased	metric tons/yr	2.240	2.483	11%	2.647	18%
K fertilizer purchased	metric tons/yr	0.8857	1.463	65%	1.524	72%

Source: program output

Notes:

802 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 6 and 14).

803 Manure export allow the farm to remove manure from the farm at a cost of 10% above manure application cost

804 Land rental allows the farm to rent additional land at a cost of $300/ha, and is restricted to rent no more than 10% of its land base.

805 Milking herd size only counts the number of milking age cows. Models assume number of heifers equals number of milking age cows.

806 Total manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.38b – N balances of a medium Ontario dairy farm under a more restrictive Clean Water Act (2007)[807]: N and P application rate limited to less than 10% over crop requirement: allowing for manure export[808] or land rental[809].

Program Outputs	Units	Base Solution	Regulated scenario with manure export	% change from base solution	Regulated scenario with land rental	% change from base solution
N Balances						
Total N required[810,811]	metric tons/yr	26.77	27.68	3%	30.07	12%
Total N input[812]	**metric tons/yr**	**30.15**	**29.48**	**-2%**	**32.04**	**6%**
from manure	metric tons/yr	9.551	8.972	-6%	9.551	0%
from fertilizer	metric tons/yr	0.7115	0.6164	-13%	0.6780	-5%
from other sources[813]	metric tons/yr	19.89	19.89	0%	21.82	10%
Total N Removed[814,815]	metric tons/yr	29.07	29.16	0%	31.91	10%
Soil N surplus / ha[816]	**kg/ha/yr**	**8.314**	**2.453**	**-70%**	**0.9694**	**-88%**
N agronomic balance / ha[817]	**kg/ha/yr**	**26.05**	**13.87**	**-47%**	**13.83**	**-47%**

Source: program output

Notes:

807 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 6 and 14).

808 Manure export allow the farm to remove manure from the farm at a cost of 10% above manure application cost

809 Land rental allows the farm to rent additional land at a cost of $300/ha, and is restricted to rent no more than 10% of its land base.

810 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

811 Total N required is the sum of the per-hectare N requirement of each crop (see note 2) times land used for production of each crop.

812 Total N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

813 N from other sources is calculated as the hectares of land used multiplied by the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

814 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

815 Total N removed is the sum of the per-hectare N removal rate (see note 8) of each crop times land used for production of each crop.

816 Soil N surplus is calculated as total N input minus total N removed (see notes 8 and 9), divided by total land use.

817 N agronomic balance is calculated as total N input minus total N required (see notes 4 and 5), divided by total land use.

Table 6.38c – P balances of a medium Ontario dairy farm under a more restrictive Clean Water Act (2007)[818]: N and P application rate limited to less than 10% over crop requirement: allowing for manure export[819] or land rental[820].

Program Outputs	Units	Base Solution	Regulated scenario with manure export	% change from base solution	Regulated scenario with land rental	% change from base solution
P Balances						
Total P Required[821,822]	metric tons/yr	10.40	10.40	0%	11.44	10%
Total P Input[823]	**metric tons/yr**	**10.40**	**10.92**	**5%**	**11.74**	**13%**
from manure	metric tons/yr	8.160	7.666	-6%	8.160	0%
from fertilizer	metric tons/yr	2.240	3.254	45%	3.585	60%
Total P Removed[824,825]	metric tons/yr	8.038	8.104	1%	8.914	11%
Soil P surplus / ha[826]	**kg/ha/yr**	**18.17**	**21.66**	**19%**	**19.80**	**9%**
P agronomic balance / ha[827]	**kg/ha/yr**	**0**	**4.000**		**2.133**	

Source: program output

Notes:

818 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 6 and 14).

819 Manure export allow the farm to remove manure from the farm at a cost of 10% above manure application cost

820 Land rental allows the farm to rent additional land at a cost of $300/ha, and is restricted to rent no more than 10% of its land base.

821 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield. The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

822 Total P required is the sum of per-hectare P requirement of each crop (see note 12) times land used for production of each crop.

823 Total P input is the sum of P input from manure and from fertilizer

824 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

825 Total P removed is the sum of the per-hectare P removal rate (see note 15) of each crop times land used for production of each crop.

826 Soil P surplus is calculated as total P input minus total P removed (see notes 15 and 16), divided by total land use.

827 P agronomic balance is calculated as total P input minus total P required (see notes 12 and 13), divided by total land use.

export (even when the option to export manure is given) and the medium farm's compliance cost remains at $587/yr, with no change in herd size and land used compared to the regulated situation when manure export is not an option. Given the option to rentland, the large farm is also able to reduce the compliance cost of the regulation to $164/yr.

For the large farm model, both manure export and land rental are able to reduce compliance cost, though land rental is a more effective method in reducing compliance cost. Table 6.39 presents the compliance cost of a medium dairy farm under the Clean Water Act (2007) when the farm is able to export manure at a cost 10% above the cost of manure application, or rent land at a cost of $300/ha up to 10% of the land base. Given the option to export manure, the compliance cost of the large farm model is reduced to $31,204/yr, a 13% reduction of the net return in base solution. Compliance is reached without reducing herd size or land use when given the option to export manure. Given the option to rent land, the compliance cost is lowered to $52,749, a 23% reduction of the net return in base solution. Compliance is reached with no change in land use and a 22% reduction in herd size, much lower than the 66% herd size reduction when manure export is not an option. Note that when the medium farm is allowed to rent land, there is a slightly greater reduction in soil N surplus and soil P surplus. There is little change to the nutrient balance in the large farm model under the Clean Water Act (2007) regulations when the model is allowed to export manure, and no change at all when the large farm is allowed to rent extra land.

Table 6.39a – Compliance cost of a large Ontario dairy farm under a more restrictive Clean Water Act (2007)[828]: N and P application rate limited to less than 10% over crop requirement: allowing for manure export[829] or land rental[830].

Program Outputs	Units	Base Solution	Regulated scenario with manure export	% change from base solution	Regulated scenario with land rental	% change from base solution
Compliance Cost	**$/yr**		**$31,204**		**$52,749**	
Net Return	**$/yr**	**$232,236**	**$201,031**	**-13%**	**$179,487**	**-23%**
Milking Herd Size[831]	cows	170	170	0%	132	-22%
Total Land Used	ha	200	200	0%	220	10%
Shadow Value of Land	$/ha/yr	$619	$467	-25%	$843	36%
Shadow Value of Barn	$/cow/yr	$638	$633	-1%	$0	-100%
Total Manure Applied[832]	metric tons/yr	689.7	480.3	-30%	537.2	-22%
Total Manure Exported	metric tons/yr	0	209.4		0	
N fertilizer purchased	metric tons/yr	0	0.2724		0.2996	
P fertilizer purchased	metric tons/yr	0	12.48		13.77	
K fertilizer purchased	metric tons/yr	0	3.189		3.547	

Source: program output

Notes:

828 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 6 and 14).

829 Manure export allow the farm to remove manure from the farm at a cost of 10% above manure application cost

830 Land rental allows the farm to rent additional land at a cost of $300/ha, and is restricted to rent no more than 10% of its land base.

831 Milking herd size only counts the number of milking age cows. Models assume number of heifers equals number of milking age cows.

832 Total manure applied is measured in metric tons of dry matter per year. The models assume manure from the milking herd and heifers are stored and applied as a single manure source. Milking herd produces solid manure in tie-stall barns and liquid manure in free-stall barns. See Table 5.8 for nutrient content of each type of manure. The nutrient contents of manure are referenced from the NMAN2 Software (OMAFRA, undated).

Table 6.39b – N balances of a large Ontario dairy farm under a more restrictive Clean Water Act (2007)[833]: N and P application rate limited to less than 10% over crop requirement: allowing for manure export[834] or land rental[835].

Program Outputs	Units	Base Solution	Regulated scenario with manure export	% change from base solution	Regulated scenario with land rental	% change from base solution
N Balances						
Total N required[836,837]	metric tons/yr	44.67	44.77	0%	49.09	10%
Total N input[838]	**metric tons/yr**	**54.37**	**47.61**	**-12%**	**52.16**	**-4%**
from manure	metric tons/yr	23.19	16.15	-30%	18.06	-22%
from fertilizer	metric tons/yr	0	0.2724		0.2996	
from other sources[839]	metric tons/yr	31.18	31.18	0%	33.79	8%
Total N Removed[840,841]	metric tons/yr	46.23	46.23	0%	49.70	7%
Soil N surplus / ha[842]	**kg/ha/yr**	**40.72**	**6.873**	**-83%**	**11.18**	**-73%**
N agronomic balance / ha[843]	**kg/ha/yr**	**48.51**	**14.16**	**-71%**	**13.93**	**-71%**

Source: program output

Notes:

833 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 6 and 14).

834 Manure export allow the farm to remove manure from the farm at a cost of 10% above manure application cost

835 Land rental allows the farm to rent additional land at a cost of $300/ha, and is restricted to rent no more than 10% of its land base.

836 N requirement is defined as the minimum amount of N input per hectare a crop needs in order to produce a specified per-hectare yield. For wheat, the per-hectare N requirement values are referenced from the NMAN2 Software (OMAFRA, undated). For alfalfa hay, alfalfa haylage, and soybeans, the N requirement per ha equal the sum of N per hectare input from atmospheric deposition, non-symbiotic N fixation and symbiotic N fixation, as well as the N credit from previous year's crop residue. For corn and corn silage, the per-hectare N requirement value equals the per-hectare N application rate, determined by a quadratic N-response yield function.

837 Total N required is the sum of the per-hectare N requirement of each crop (see note 2) times land used for production of each crop.

838 Total N input is the sum of N from manure, from fertilizer, and from other sources (see note 7).

839 N from other sources is calculated as the hectares of land used multiplied by the sum of per-hectare N input from atmospheric deposition, non-symbiotic N fixation, symbiotic N fixation in soil for legume crops, as well as Total N input from crop residue from previous year's crop. The values for each crop are presented in Table 5.9.

840 N removal is defined as the amount of N in the harvested portion of the crops. The per-hectare N removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

841 Total N removed is the sum of the per-hectare N removal rate (see note 8) of each crop times land used for production of each crop.

842 Soil N surplus is calculated as total N input minus total N removed (see notes 8 and 9), divided by total land use.

843 N agronomic balance is calculated as total N input minus total N required (see notes 4 and 5), divided by total land use.

Table 6.39c – P balances of a large Ontario dairy farm under a more restrictive Clean Water Act (2007)[844]: N and P application rate limited to less than 10% over crop requirement: allowing for manure export[845] or land rental[846].

Program Outputs	Units	Base Solution	Regulated scenario with manure export	% change from base solution	Regulated scenario with land rental	% change from base solution
P Balances						
Total P Required[847,848]	metric tons/yr	16.00	25.55	60%	28.11	76%
Total P Input[849]	**metric tons/yr**	**19.82**	**26.28**	**33%**	**29.21**	**47%**
from manure	metric tons/yr	19.82	13.80	-30%	15.43	-22%
from fertilizer	metric tons/yr	0	12.48		13.77	
Total P Removed[850,851]	metric tons/yr	12.35	12.35	0%	13.72	11%
Soil P surplus / ha[852]	**kg/ha/yr**	**37.34**	**69.67**	**87%**	**70.41**	**89%**
P agronomic balance / ha[853]	**kg/ha/yr**	**19.09**	**3.665**	**-81%**	**5.013**	**-74%**

Source: program output

Notes:

844 The Clean Water Act includes a regulation that limits the per-hectare N and P application rate to less than 15% over per-hectare N and P crop requirement (see notes 6 and 14).

845 Manure export allow the farm to remove manure from the farm at a cost of 10% above manure application cost

846 Land rental allows the farm to rent additional land at a cost of $300/ha, and is restricted to rent no more than 10% of its land base.

847 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield. The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

848 Total P required is the sum of per-hectare P requirement of each crop (see note 12) times land used for production of each crop.

849 Total P input is the sum of P input from manure and from fertilizer

850 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

851 Total P removed is the sum of the per-hectare P removal rate (see note 15) of each crop times land used for production of each crop.

852 Soil P surplus is calculated as total P input minus total P removed (see notes 15 and 16), divided by total land use.

853 P agronomic balance is calculated as total P input minus total P required (see notes 12 and 13), divided by total land use.

Table 6.40a – Compliance cost under different regulatory scenarios of the Nutrient Management Act (2002) for the models of small, medium, and large Ontario dairy farms.

	Small[854]		Medium[1]		Large[1]	
	Compliance Cost ($/yr)	% of Net Income	Compliance Cost ($/yr)	% of Net Income	Compliance Cost ($/yr)	% of Net Income
Scenario 1 : Nutrient Management Act (2002)						
Application Limit: P application(kg P/ha/yr) < crop removed P[855] + 78kg/ha/yr						
1.1 Herd Size Trigger (>170 head of milking age cattle)						
Original soil P test values: 6-7 mg/L	Not Applicable		Not Applicable		$0	0%
Lower soil P Value[856]: 0-3mg/L	Not Applicable		Not Applicable		$0	0%
Higher soil P Value: 10-12mg/L	Not Applicable		Not Applicable		$0	0%
1.2 Barn Expansion Trigger (Barn Capacity + 10%)						
Original soil P test values: 6-7 mg/L	$0	0%	$0	0%	$0	0%
Lower soil P Value: 0-3mg/L	$0	0%	$0	0%	$0	0%
Higher soil P Value: 10-12mg/L	$0	0%	$0	0%	$0	0%
1.3 Stricter Application Limit: P application (kg P/ha/yr) < crop removed P + 19.5kg/ha/yr						
Original soil P test values: 6-7 mg/L	$0	0%	$0	0%	$22,565	10%
Lower soil P Value: 0-3mg/L	Infeasible		Infeasible		Infeasible	
Higher soil P Value: 10-12mg/L	$0	0%	$0	0%	$19,786	9%
Manure export	Not Applicable		Not Applicable		$3,393	1%
Land rental	Not Applicable		Not Applicable		$7,598	3%
1.4 Stricter Application Limit: P application (kg P/ha/yr) < crop removed P + 15kg/ha/yr						
Original soil P test values: 6-7 mg/L	$3,388	7%	$6,104	5%	$55,032	24%
Lower soil P Value: 0-3mg/L	Infeasible		Infeasible		Infeasible	
Higher soil P Value: 10-12mg/L	$0	0%	$0	0%	$25,930	11%
Manure export	$3,388	7%	$6,104	5%	$35,416	15%
Land rental	$3,388	7%	$6,104	5%	$43,312	19%

Source: program output (see table 6.9 to 6.39)

Notes:

854 The model of small farm houses its herd in a tie-stall barn, and the medium and the large farms each house its herd in a free-stall barn. See note 3 for the implication of farm type on the type of manure the milking herd produces.

855 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

856 Crops grown on soil with low soil P value have high per-hectare P requirements, and low per-hectare P requirements in soil with high soil P values. See Table 5.10 for P requirement values associated with soil P values.

Table 6.40b – Compliance cost under different regulatory scenarios of the Clean Water Act (2007) for the models of small, medium, and large Ontario dairy farms.

	Small[857]		Medium[1]		Large[1]	
	Compliance Cost ($/yr)	% of Net Income	Compliance Cost ($/yr)	% of Net Income	Compliance Cost ($/yr)	% of Net Income
Scenario 2: Clean Water Act (2007)						
Application Limit: N and P application (kg/ha/yr) < crop requirement[858],[859] + 15%						
2.1: Proposed N and P application Limit						
Original soil P test values: 6-7 mg/L	$0	0%	$587	1%	$50,046	22%
Lower soil P Value: 0-3mg/L	$0	0%	$0	0%	$36,891	17%
Higher soil P Value: 10-12mg/L	$165	0%	$22,570	19%	$82,171	35%
Manure export	Not Applicable		$587	1%	$13,698	6%
Land rental	Not Applicable		$164	0%	$37,828	16%
2.2: Stricter Application Limit: N and P application (kg/ha/yr) < crop requirement + 10%						
Original soil P test values: 6-7 mg/L	$0	0%	$6,072	5%	$64,330	28%
Lower soil P Value: 0-3mg/L	$0	0%	$0	0%	$51,372	23%
Higher soil P Value: 10-12mg/L	$221	0%	$26,257	22%	$87,872	38%
Manure export	Not Applicable		$3,046	3%	$31,204	13%
Land rental	Not Applicable		$960	1%	$52,749	23%

Source: program output (see table 6.9 to 6.39)

Notes:

857 The model of small farm houses its herd in a tie-stall barn, and the medium and the large farms each house its herd in a free-stall barn. See note 3 for the implication of farm type on the type of manure the milking herd produces.

858 P removal is defined as the amount of P in the harvested portion of the crops. The per-hectare P removal value is based on the per-hectare yield for each crop. The calculation is explained in Table 5.11.

859 P requirement is defined as the minimum amount of P input per hectare a crop needs in order to produce a specified per-hectare yield. The per-hectare P requirement for each crop is based on soil P values (see Table 5.10). For all crops, the per-hectare P requirement values are referenced from the NMAN2 Software (OMAFRA, undated), and the soil P value is assumed to be 6-7mg/L.

Summary of Compliance Costs under Different Regulatory Scenarios

Table 6.40a and 6.40b summarizes the compliance cost for the small, medium, and large Ontario dairy farm models under different regulatory scenarios. With the current configuration of the Nutrient Management Act (2002), under either the herd size or barn expansion trigger (sub-scenario 1.1 and 1.2) there are no compliance costs for all three farm models, because none of the models has a soil P surplus exceeding 78kg/ha/yr (the annual average of the five-year regulatory limit). When the regulatory is reduced by 75%, limiting the soil P surplus to below 19.5kg/ha/yr in sub-scenario 1.3, farms with low soil P test values cannot comply to the stricter regulations, since the higher P requirements for the crops exceed the regulatory limit. With the average soil P test values of 6-7mg/L, only the large farm incurs compliance cost. This cost is slightly lower for large farms with a higher soil P test values, since crops grown on soil with high P value have lower P requirement. Both manure export and land rental are able to reduce the compliance cost, and manure export provided a larger reduction in compliance cost for the large farm under the stricter Nutrient Management Act (2002) regulation. When the Nutrient Management Act (2002) regulation is made even more restrictive in sub-scenario 1.4, all farm models incur a compliance cost. For the large farm model, the compliance cost under this stricter regulation is more strict than in sub-scenario 1.3. For all farms modeled with a low soil P test values, compliance costs reach 100% of net return. Under a higher soil P test values, compliance cost is lower for large farm models and zero for small and medium farms. The small and medium farm models did not export manure or rent land to reduce their compliance cost, even when the options were given.

The large farm model did reduce compliance cost when it was given the option to export manure or rent land.

Scenario 2.1 simulates the conditions of the Clean Water Act (2007) regulations. Under the proposed Clean Water Act (2007) regulation, the small farm model does not incur any compliance cost, but both the medium and large farm model incurred compliance costs. When modeled with higher soils P test values, the small farm and medium farm both did not incur any compliance cost, and the compliance cost for the large farm model was lower. When modeled with a lower soil P test values, each of the farms incurred a higher compliance cost. Manure export is able to reduce compliance cost for the large farm models, and land rental is able to reduce the compliance cost of the Clean Water Act (2007) regulations for both the medium and the large farm models.

In Scenario 2.2, where the Clean Water Act (2007) regulations are made stricter, the small farm model also does not incur any compliance cost. The medium and the large farm models both incur compliance costs higher than in Scenario 2.1. When modeled with a lower soil P test values, both the small farm and medium farm do not incur any compliance costs, while the large farm model incurs a lower compliance cost. Modeling with a higher soil P test values raises the compliance cost for all three farm models. Manure export and land rental are able to reduce compliance costs for the medium and the large farm models.

Comparison between Nutrient Management Act (2002) and Clean Water Act (2007)

There are several important differences between the regulations within the Nutrient Management Act (2002) and the Clean Water Act (2007). The most important difference is that the Nutrient Management Act (2002) restricts P application based on phosphate removed through crop harvest, whereas the Clean Water Act (2007) restricts N and P application based on the amount crop requires for production. This is an important distinction because it affects how the farmers need to change their production activities to bring their farms into compliance.

Under the current Nutrient Management Act standards, where P application is limited to 78kg/ha/yr above crop removal, the study found that the Nutrient Management Act (2002) is not able to reduce the nutrient application rate of the small, medium, and large dairy farm models and they do not incur any compliance costs. This is as a result of the P application rates for these farms being much lower than what the standard allows. However, if the standard for the Nutrient Management Act (2002) was to be lowered by 75% to limit P application to below 19.5kg/ha/yr, farms with low soil P test values will see compliance costs reaching 100% of their net return. This is because P application rates are driven by P crop requirements, which are in turn driven by soil P test value, but P removal rates are not affected by soil P test value. By regulating P application based on removal rates, farms with high soil P test values cannot comply to a strict P-removal based regulation and meet the high P requirements of crops at the same time. In reality, it is not likely that any dairy farms will incur a compliance cost 100% of their net return, since it is unlikely that a farm will have soil P test values of 0-3mg/L for its entire land base. Lauzon *et al.* (2005) sampled the soil P test values on 23 farm fields across southern and eastern Ontario, and found that the range of soil test P value is between 1mg/L to 315mg/L, with the average soil P test value of these fields ranging between 8.5mg/L to 71mg/L. Also, Cowan (undated) suggested that soil P test values have increased for

Ontario soil. Therefore, it is likely that the cost of complying to Nutrient Management Act (2007) regulations is likely to be lower in the future than the values reported in this report.

The problems caused by the stricter Nutrient Management Act (2002) standards do not occur under the proposed Clean Water Act (2007) regulations, where N and P application must be less than 115% of crop requirement. In this case, soil P test values have an opposite effect on compliance costs for all farms. Under the Nutrient Management Act (2002), farms with low soil P test values have higher compliance costs and farms with high soil P have lower compliance costs, whereas under the Clean Water Act (2007), farms with high soil P test values have higher compliance costs and farms with low soil test values have lower compliance costs. This occurs because under a requirement-based regulation, farms with high soil P test values (meaning low P crop requirements) are allowed to apply less P on their land, whereas farms with low soil P test values (meaning high P crop requirements) are allowed to apply more P on their land. The problem under a more restrictive Nutrient Management Act (2002) faced by farms with high soil P test values, where it was impossible for these farms to meet crop P requirement and comply with the regulation at the same time, is eliminated under the Clean Water Act (2007) regulations.

The Clean Water Act (2007) regulations also tend to be costlier for large dairy farms to comply with, compared to the Nutrient Management Act. This is the case because large dairy farms tend to have high N and P agronomic balances; in general, P is over applied in relation to crop requirement for corn, corn silage, and wheat, whereas N is generally over applied in relation to crop requirement for alfalfa hay, alfalfa haylage and soybeans. This application pattern occurs when manure is the main source of nutrients used to meet crop requirement: corn, corn silage and wheat have lower P requirement than what the manure provides, and alfalfa hay, alfalfa haylage, and soybeans have lower N requirement than what the manure provides. Therefore, the only way for large farms to comply with the Clean Water Act regulations is to reduce manure application onto the land. However, cost of complying to the Clean Water Act (2007) is also likely to be lower than suggested by this research, since it is not likely that groundwater protection zones or surface water intake protection zones apply to the entire land base of a farm.

If manure export is not an option available for the large farms, then the only way of compliance is to reduce their herd size, which is a major source of compliance cost. This is also why manure export is a better option for large farms to reduce compliance cost: manure export means that not all manure generated is applied on land. Therefore by removing manure off the farm, the large farm can sustain a larger herd size even when regulated under the Clean Water Act (2007).

It is uncertain how many dairy farms will be regulated under the Clean Water Act (2007) regulations. Currently, the size and location groundwater protection zones and the surface water intake protection zones are still being determined. Since most surface water treatment facilities are likely located near urban areas, dairy farms close to urban areas are likely to be regulated. Also, if soil P test values have been increasing in Ontario as Cowan has suggested, then the cost of complying with the Clean Water Act (2007) is likely to be higher than the values reported in this study.

Furthermore, for some cases where the model predicts a reduction in herd size may in reality lead to an increase in the demand for land. In the model, because land base was set as a binding constraint, the only way for the model to meet regulations was to reduce herd size. In reality, if land were available for purchase or rental, a farm would want to increase its land base to support the herd size it already has. This means that binding nutrient regulations will increase the demand for agricultural land, which will drive up land prices. Furthermore, because the dairy industry in Ontario is supply managed, the cost of complying to nutrient management regulations will likely be transferred over to the consumer in the form of higher milk prices.

Chapter 7 – Conclusion

Summary

The purpose of the research was to measure the compliance cost of the current and future configurations of the nutrient management regulations on Ontario dairy farms. Three optimization models, each simulating a small, a medium, and a large net-return-maximizing Ontario dairy farms, were solved under two sets of regulatory scenarios simulating variations of the Nutrient Management Act (2002) and the Clean Water Act (2007). The Nutrient Management Act (2002) restricts P application to be some amount above P removed through crop harvest, whereas the Clean Water Act (2007) restricts N and P application to be some amount above crop requirements. Compliance costs for each variation of the two regulatory scenarios were measured as the difference in net return between the regulated scenario and the base solution. Compliance costs were also measured for the three farm models when soil P test values were increased or decreased. Lastly, the models were given an option to export manure or rent land at a cost to measure whether these management practices are effective in reducing the cost of complying with the both sets of nutrient management regulations.

Principal Findings

Five principal findings are listed below:

1. Under the current Nutrient Management Act (2002), small, medium and large Ontario dairy farms of do not incur compliance costs. This is because in all cases, P application is lower than the maximum amount allowed by the application.

2. If the P application limit under the Nutrient Management Act (2002) were more restrictive, small farms would still incur no compliance cost, while large farms would see their annual net return reduced by 10% to 24% and may be forced to reduce their herd size. Dairy farms with low soil P, regardless of size, will incur a

reduction in net return of 100% because the amount of P required for crop production would be higher than the amount allowed by these regulations. Farms with higher soil P would incur a lower compliance cost.

3. Medium and large dairy farms will incur compliance costs under the proposed Clean Water Act (2007) regulations. Large farms may also be forced to reduce their herd size. For the large farms with high soil P, compliance costs can be up to a 35% reduction in annual net return. Small farms will not incur any compliance costs under the Clean Water Act (2007) unless soil P test values are high. Manure export and land rental can reduce compliance costs for the Clean Water Act (2007) regulations. If regulations in the Clean Water Act (2007) were made stricter, medium and large farms will see an increase in compliance costs.

4. The Clean Water Act (2007) reduces soil N surplus and N agronomic balance for medium and large farms, but will not always reduce soil P surplus. Since the N application restriction is the binding constraint for the regulated farms, when farms are forced to comply with the Clean Water Act (2007) regulations, farms tend to increase manure application on corn land that has high N requirement and low P removal.

5. Manure export and land rental can reduce, but not eliminate, compliance costs to the Clean Water Act (2007) regulations and stricter Nutrient Management Act (2002) regulations. For large farms, the reduction in compliance cost is higher when the farm exports manure as opposed to renting more land.

Policy Implication

The analysis shows a serious problem in the current nutrient management regulations: if the current regulations from the Nutrient Management Act (2002) were to be made stricter, some farms may find compliance with the regulations impossible, since the regulatory limit for P application may be lower than crop requirement for farms with land that have low soil P test values. Switching to a requirement-based regulation would solve this problem, but regulated farms would incur a much higher compliance cost. If the goal of nutrient management regulation is to reduce nutrient pollution in ground water and surface water, then regulators need to review the relationships between nutrient pollution, soil nutrient surplus and nutrient agronomic balance. It is unclear why the current Nutrient Management Act (2002) regulations allow large amounts of P to be applied over the crop P removal rate. More up-to-date research on crop yield response to nutrients, as well as nutrient uptake and removal specific to Ontario are needed for the development of more effective Ontario-specific nutrient management regulations.

The results suggest that current nutrient management regulations will not negatively impact the Ontario dairy industry. However, if Nutrient Management Act standards were to change in the future, or if dairy farms were to be regulated under the proposed Clean Water Act (2007) regulations, there may be a large impact on the profitability and milk output of large dairy farms regulated under either Act. It may be important for the industry to see whether these farms are situated in groundwater protection areas to get a better grasp on the impact of the Clean Water Act (2007) on the industry. Industry should also encourage manure export as a way to reduce compliance cost over land expansion.

Suggestions for Further Research

The optimization model used in this research could be expanded from a static, one-year model to a multi-year or dynamic model to examine the cost of nutrient management regulations over time, especially if soil P test values over time can be related to P application in previous years. Variations in environmental conditions such as soil type, heat units, and precipitation may affect crop yield, nutrient uptake and removal values, and should be taken into consideration if this model were to be applied to a study of the effect of nutrient management in areas outside Ontario. In the current model, only corn and corn silage is modeled with a N yield-response function: the soil nutrient balances may be more accurate if all crops were modeled with N and P yield response functions. The model developed by this research may also be extended to other agricultural sectors, and even other sectors of production, to study the compliance costs of nutrient management regulations for other industries as well.

Furthermore, the location-specific regulatory triggers of the Clean Water Act (2007) suggest that spatial components are important parameters as well. Location specific information on which farms are affected by the Clean Water Act (2007), as well as how large the groundwater and surface water intake protection zones are needed for further research.

Lastly, the Ontario dairy sector is only one of many livestock sectors that are regulated by the nutrient management regulations. In particular, hog and beef cattle producers will likely incur high compliance costs with both the Nutrient Management Act (2002) and the Clean Water Act (2007). The model developed in this thesis can be adopted to simulate the production parameters of hog and beef cattle operations in order to measure the compliance costs to of the current and possible future configurations of nutrient management regulations in Ontario. The model can also be recalibrated to measure the compliance costs of livestock operations in other provinces and countries as well.

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Appendix A – Model Equations

Table A.1 - Summary of the conceptual model for analyzing the compliance cost of nutrient management regulations for Ontario dairy farms.

Objective Function

$$
\begin{aligned}
&\max\left(\sum_{c=1}^{6}(P_c Q_c^s) + P^{mn} Q^m\right) \\
&-\sum_{c=1}^{6} C_c A_c - \sum_{c=1}^{6} A_c (P^n n_c^f + P^p p_c^f + P^k k_c^f) \\
&-\sum_{c=1}^{6} A_c (C^s m_c^s + C^l m_c^l) - \sum_{a=1}^{2} (C_a Q_a) \\
&-\sum_{c=1}^{1} P_1^{fd} Q_1^{fd} - \sum_{c=3}^{3} P_3^{fd} Q_3^{fd} - \sum_{a=1}^{2} (P_a^{sp} Q_a^{sp}) \\
&-C^{sx} M^{sx} - C^{lx} M^{lx} - C^r A^r - wL
\end{aligned}
\tag{4.1}
$$

Subject to…

$$Q_c = Q_c^s + Q_c^f \in c = \{1,3\} \tag{4.2}$$

$$Q_c = Q_c^f \in c = \{2,4\} \tag{4.3}$$

$$Q_c = Q_c^s \in c = \{5,6\} \tag{4.4}$$

$$Q_c = A_c + Y_c(n_c, p_c, k_c) \tag{4.5}$$

$$Y_c = Y_c^{\max} \cdot \left(1 - \exp[-\beta_c^n (n^s + n_c)]\right) \cdot \left(1 - \exp[-\beta_c^p (p^s + p_c)]\right) \tag{4.6}$$

$$Q^m = m Q_a \in a = 1 \tag{4.7}$$

$$P^{mn} = P^m - \left(\frac{iP^q}{365}\right) - C^m \tag{4.8}$$

$$\sum_{c=1}^{6}(A_c M_c^{sa}) + M^{sx} = \sum_{a=1}^{2} Q_a M_a^s \tag{4.9}$$

$$\sum_{c=1}^{6}(A_c M_c^{la}) + M^{lx} = \sum_{a=1}^{2} Q_a M_a^l \tag{4.10}$$

$$L = \sum_{c=1}^{6} A_c \alpha_c + \sum_{a=1}^{2} \gamma_a Q_a \quad (4.11)$$

$$\sum_{c=1}^{2} A_c \le \frac{T_{corn}}{\overline{T}} A^T \quad (4.12a)$$

$$\sum_{c=3}^{4} A_c \le \frac{T_{alfalfa}}{\overline{T}} A^T \quad (4.12b)$$

$$A_c \le \frac{T_{soy}}{\overline{T}} A^T \in c = 5 \quad (4.12c)$$

$$A_c \le \frac{T_{wheat}}{\overline{T}} A^T \in c = 6 \quad (4.12d)$$

$$A^T = \overline{A} + A^r \quad (4.13)$$

$$A^r \le 0.1 \cdot \overline{A} \quad (4.14)$$

$$Q_a \le B \in a = 1 \quad (4.15)$$

$$n_c \ge n_c^r \quad (4.16a)$$

$$p_c \ge p_c^r \quad (4.16b)$$

$$k_c \ge k_c^r \quad (4.16c)$$

$$n_c = (\theta^s M_c^{sa} + \theta^l M_c^{la} + n_c^f + n_c^{cred}) + (\varsigma_c + \eta + \mu) \quad (4.17a)$$

$$p_c = \varphi^s M_c^{sa} + \varphi^l M_c^{la} + p_c^f \quad (4.17b)$$

$$k_c = \phi^s M_c^{sa} + \phi^l M_c^{la} + k_c^f \quad (4.17c)$$

$$Q_c^f + Q_c^{fd} \ge \sum_{a=1}^{2} Q_a R_{a,c} \in c = \{1,3\} \quad (4.18a)$$

$$Q_c^f \ge \sum_{a=1}^{2} Q_a R_{a,c} \in c = \{2,4\} \quad (4.18b)$$

$$Q_a^{sp} \ge \sum_{a=1}^{2} Q_a R_a^{sp} \quad (4.18c)$$

$$Spls^N = \sum_{c=1}^{6} A_c (n_c - n_c^{rmvl}) \quad (4.19a)$$

$$Spls^P = \sum_{c=1}^{6} A_c (p_c - p_c^{rmvl}) \quad (4.19b)$$

$$Agro_c^N = n_c - n_c^r \quad (4.20a)$$

$$Agro_c^P = p_c - p_c^r \quad (4.20b)$$

where...

c is the index denoting each of the six crops grown on farm: corn (c=1), corn silage (c=2), alfalfa hay (c=3), alfalfa silage (c=4), soybeans (c=5), and wheat (c=6),

a is the index denoting the two cohorts of livestock on the farm: milking age cow (c=1), replacement heifers (c=2). Replacement heifers are defined as cows that have not yet calved,

p_c is the per-metric-ton price of crop c

Q_c^s is the quantity (in metric tons of dry matter) of crop c sold

P^{mn} is the net price per hectoliter (HL) of milk

Q^m is the total quality of milk (measured in HL) produced on farm and sold

C_c is the crop establishment cost that are unrelated to yield

A_c is the workable hectares of land devoted to producing crop c

P^n is the per-kg price of N fertilizer plus the cost of application

n_c^f is the N fertilizer application rate on crop c in kg/ha

P^p is the per-kg price of P fertilizer plus the cost of application

p_c^f is the P fertilizer application rate on crop c in kg/ha

P^k is the per-kg price of K fertilizer plus the cost of application

k_c^f is the K fertilizer application rate on crop c in kg/ha

C^{sm} is the cost of applying one metric ton of solid manure

M_c^{sa} is the solid manure application rate on crop c in kg/ha

C^{lm} is the cost of applying one metric ton of liquid manure

M_c^{la} is the liquid manure application rate on crop c in kg/ha

C_a is the cost of raising and maintaining 1 animal in cohort *a*

Q_a is the number of animals in cohort *a*

P_c^{fd} is the cost per metric ton of purchasing additional feed crop *c*,

Q_c^{fd} is the amount of feed crop *f* purchased in metric tons

P_a^{sp} is the cost per metric ton of purchasing feed supplements for cohort *a*

Q_a^{sp} is the amount of feed supplements purchased for cohort *a* in metric tons

C^{sx} is the cost of exporting 1 metric ton of solid manure off farm

M^{sx} is the amount of solid manure being exported off farm

C^{lx} is the cost of exporting 1 metric ton of liquid manure off farm

M^{lx} is the amount of liquid manure being exported off farm

C^r is the rental price of one hectare of land

A^r is the hectare of land rented at C^r

w is the hourly wage rate

L is the number of labour hours required for farm operation in one year

Q_c is the total quantity (in metric tons) of crop *c* produced on farm

Q_c^f is the quantity (in metric tons) of crop *c* used as cattle feed

Y_c is the metric-ton per hectare yield function of crop *c*

n_c is the per-hectare application rate of N in kilograms per hectare

p_c is the per-hectare application rate of P in kilograms per hectare

k_c is the per-hectare application rate of K in kilograms per hectare

$Y_c^{\max}$ is the maximum yield obtained per hectare when both nitrate and phosphate inputs are in excess

β_c^n is an estimated parameter that relates N input to crop yield

n^s is the N content in soil in kg per hectare

β_c^p is an estimated parameter that relates N input to crop yield

p^s is the P content in soil in kg per hectare

m is the annual milk production per milking cow

Q_a is the number of animals in cohort a

P^m is the per hectoliter market price of milk that a producer would receive given a fixed proportion of butter fat, proteins, and other solids

i is the estimated rental value of butter fat quota

P^q is the current price of one daily butterfat quota, converted to a per-hectoliter price

C^m is the cost associated with quantity of milk produced, such as transportation and marketing costs

M_c^{sa} is the metric ton per hectare application rate of solid manure on crop c

M_a^s is the metric tons of solid manure generated by one animal in cohort a in one year

M_c^{la} is the metric ton per hectare application rate of solid manure on crop c

M_a^l is the metric tons of liquid manure generated by one animal in cohort a in one year

α_c is the number of hours required to tend to one hectare of cropland

γ_a is the number of labour hours required to tend to one animal in cohort a each period

T_{corn} is the number of years corn crops are grown on a hectare of land for one crop rotation cycle

$\overline{T}$ is total number of years of one crop rotation cycle

A_T is the total hectares of workable land

$T_{alfalfa}$ is the number of years alfalfa crops are grown on a hectare of land for one crop rotation cycle

T_{soy} is the number of years soybeans are grown on a hectare of land for one crop rotation cycle

T_{wheat} is the number of years wheat is grown on a hectare of land for one crop rotation cycle

$\overline{A}$ is land base that the farm owns.

n_c^r is the kg/ha of N crop c requires to yield a specific yield

p_c^r is the kg/ha of P crop c requires to yield a specific yield

k_c^r is the kg/ha of K crop c requires to yield a specific yield

B is the maximum number of milking dairy cows the barn can accommodate

θ^s is the kg of N per metric ton of solid manure

θ^l is the kg of N per metric ton of liquid manure

n_c^{cred} is the kg of N left for crop c from the crop residue of previous year's crop

ς_c is the symbiotic N fixation in kilograms of N for crop c

η is the non-symbiotic N fixation in kilograms of N per hectare

μ is the atmospheric deposition in kilograms of N per hectare

φ^s is the kg of P in one metric-ton of solid manure

φ^l is the kg of P in one metric-ton of liquid manure

ϕ^s is the kg of K in one metric-ton of solid manure

ϕ^l is the kg of K in one metric-ton of liquid manure

$R_{a,c}$ is the metric ton of crop c an animal in cohort a requires as feed in a year

R_a^{sp} is the metric ton of supplement an animal in cohort a requires as feed in a year

$Spls^N$ is the total amount of soil N surplus of the farm in kg

n_c^{rmvl} is the kg of N removed by crop c through harvest per hectare

$Spls^P$ is the total amount of soil P surplus of the farm in kg

p_c^{rmvl} is the kg of P removed by crop c through harvest per hectare

$Agro_c^N$ is the N agronomic balance in kg/ha for crop c

$Agro_c^P$ is the P agronomic balance in kg/ha for crop c

Appendix B – GAMs model codes

```
OPTION NLP = MINOS;

Parameter
* Scenario or farm type choices
* Farm size
*1 = small, 2 = medium, 3 = large
size    /3/

* Allow / disallow manure export
*1 = yes (Pman = Cman*1.1), 2 = no (Pman = $999/metric ton)
allowxpt /2/

* Allow / disallow land rental
*1 = yes (Prent = $300/ha), 2 = no (Pman = $1000/ha)
allowrnt /2/

* Allow / disallow barn expansion
*1 = yes, 2 = no
plsB    /2/

*Regulatory constraint*
*NMA constraint
Prent   per hectare cost of land rental
        /300/

Rlim    limiting the amount of land that can be rented (as % of land base)
*       0 = 0%, 0.1 = 10%, etc
        /0.2/

Plim    additonal phosphate allowed to be applied on top of crop removal balance
        /78/

*CWA constraints
Palim   additonal times of phosphate allowed above P requirements (1 = 100% above P
requirement)
        /1/

Nalim   additonal times nitrogen allowed abover N requirements (1 = 100% above N
requirement)
        /1/
;
```

```
Sets
      c merged index for crops & feed              /1*7/

*subindices / subsets
      crp(c)      subindex for all crops             /1*6/
      crn(crp)    subindex for all corn              /1,2/
      alf(crp)    subindex for all alfalfa           /3,4/
      soy(crp)    subindex for soy                   /5/
      wht(crp)    subindex for winter wheat          /6/
      notcrn(crp)   subindex for supplements + all crops grown except corn /3*6/

      fd(c)       subindex for crop and supplement going to feed    /1,2,3,4,7/
      cfd(crp)    subindex for crops going to feed    /1,2,3,4/
      ntfd(crp)   subindex for crops not going to feed   /5,6/
      mkt(crp)    subindex for crops sold to market   /1,3,5,6/
      ntmkt(crp)  subindex for crops not sold to market   /2,4/
      fdmk(crp)   subindex for crops going to market and for feed /1,3/
      supp(c)     subindex for feed supplement       /7/

$ontext
      Index c definitions
      1=high moisture and grain corn  2=silage corn
      3=alfalfa                    4=alfalfa haylage
      5=soybeans                   6=winter wheat
      7=protein and mineral suppliments
$offtext
;

Parameters

*production constraints*
      Abar    cropland holdings hectare
                /200/
      B       barn capaity milkage age cow
                /170/
      Lmax    Maximum hired Labour endowment (hrs)
                /10000/
      W       Wage for hired labour
                /18.85/

*CROP ENTERPRISE*

*Crop Rotation specifications*
      cprtyr  number of years for 1 crop rotation cycle
      alfyr   number of years for continuous alfalfa in crop rotation
                /3/
      crnyr   number of years for continuous corn in crop rotation
                /3/
      soyyr   number of years for continuous soybeans in crop rotation
                /1/
      whtyr   number of years for continuous winter wheat in crop rotation
                /1/
```

```
*Prices*
    Pc(mkt) Market price for each crop
*           $ per metric ton (dry matter basis)
*           Source: OMAFRA Cost of Production Enterprise: Jan 09
*           corn price converted from $/bu (85% dry matter content)
*           alfalfa price converted from $/tonne (90.71% dry matter content)
*           Soybeans and wheat prices in as-is weight (with moisture), conferted from $/bu
*           For wheat, only grains are sold and (straws are used for bedding)
                /1  207.51
                 3  121.27
                 5  512.06
                 6  277.84
                /

    Pf(fd)  Price of feed or input (per bushel or per metric ton)
*           Suplement prices back-calculated from feed requirements and farm visit data
*           allow purchasing of HM corn and alfalfa hay as additional feed
                /1  189
                 2  999
                 3  122
                 4  999
                 7  830/
    Pn      Price of ammonium nitrate fertilizer ($ per kg)
*           based on OMAFRA Cost of Production Enterprise: Jan 09*
*               /1.867/
*           plus cost of application ($0.13 per kg)
                /2/

    Pp      Price of phosphate fertilizer ($ per kg)
*           based on OMAFRA Cost of Production Enterprise: Jan 09*
*               /1.852/
*           plus cost of application ($0.13 per kg)
                /1.98/

    Pk      Price of potash fertilizer ($ per kg)
*           based on OMAFRA Cost of Production Enterprise: Jan 09*
*               /1.62/
*           plus cost of application ($0.13 per kg)
                /1.75/

    Cland(crp)      Cost of seeding establishing and harvesting crop ($ per ha)
*               Source: OMAFRA crop enterprise budgets
*               excluding labour, fertilizer application cost
                /1  671.55
                 2  629.04
                 3  582.40
                 4  582.40
                 5  546.21
                 6  455.48
                /

    Csman           Cost of applying solid manure from heifers ($ per metric ton of dry matter)
*               Converted from $3 per ton, with dry matter content of 40%
*               Source: OMAFRA survey (1997 to 2000)
                /8.27/
```

Clman Cost of applying liquid manure from adult cows ($ per metric ton of dry matter)
* Converted from $8 per gallon, with dry matter content of %9.1%
* Sou rce: OMAFRA survey (1997 to 2000)
/23.22/
Cman Cost of applying a metric ton of manure

Lc(crp) Hours of labour required for each ha of land for crop c
* estimated at an average wage rate of $18.85/hr
/1 1.750
2 3.749
3 4.627
4 4.627
5 1.258
6 2.635
/

Yield Specifications
Yield(c) fixed metric ton per hectare yield for each crop
* 0 for corn (1,2) since yield is based on N response function
* Alfalfa hay and haylage yield in dry matter basis
* Alfalfa hay yield converted from as-is weight basis (90.71% dry matter)
* Source: OMAFRA estimates*
/1 0
2 0
3 10.89
4 10.2
5 2.5
6 4.8
7 0
/

*Yield function coefficient
* Calculated from Beauchamp (1987). Reduced yield to match Oxford Yield estimates from OMAFRA
* Converted yield function to give yield in dry matter basis (6.4 metric ton dry matter per ha for corn)
beta1 First Parameters for yield functions for corn (yield in metric ton per ha)
/3.827/
beta2 Second Parameters for yield functions for corn (yield in metric ton per ha)
/0.0316/
beta3 First Parameters for yield functions for corn (yield in metric ton per ha)
/0.0000951/

coeff(crn) Yield coefficent for corn and corn silage
* dry matter yield of kg of corn silage 1.672 times higher than equivalent dry matter grain corn yield
* Assume 85% dry matter content for grain corn, 35% dry matter content for corn silage
* Estimate of grain corn and corn silage yield based on NMAN2 yield estimates for Oxford County
/1 1
2 1.672
/

```
      nreq(c) Nitrogen application requirements (kg per hectare) for non-corn crops
*           Based on NMAN2 numbers
                 /1  166
                  2  166
                  3  276.37
                  4  306.37
                  5  240.7
                  6  155.7
                 /

      preq(c) Phosphate application requirements (kg per hectare) for each crop
*           Based on NMAN workbooks estimates
$ontext
*      assume  soil test for sodium bi carbonate phosphorus soil test of 0-3mg/L
                 /1  110
                  2  110
                  3  180
                  4  180
                  5  81
                  6  71
                  7  0
                 /
$offtext
*$ontext
*      assume  soil test for sodium bi carbonate phosphorus soil test of 6-7mg/L
                 /1  90
                  2  90
                  3  90
                  4  90
                  5  50
                  6  50
                  7  0
                 /
*$offtext
$ontext
*      assume  soil test for sodium bi carbonate phosphorus soil test of 10-12mg/L
                 /1  50
                  2  50
                  3  30
                  4  30
                  5  30
                  6  20
                  7  0
                 /
$offtext

kreq(c) potassium required per crop
*      assume  soil test of 101-120 mg/L
                 /1  30
                  2  30
                  3  69
                  4  69
                  5  30
                  6  20
                  7  0
                 /
```

BsYld(crp) Base yield (metric ton per ha) used to calculate N and P removal for each crop
* based on NMAN2, yield converted to dry matter basis
/1 6.46
2 10.8
3 10.89
4 10.2
5 2.5
6 4.8
/

bsNrmvl(crp) nitrogen removed (kg per ha) based on BsYld for each crop
* Based on NMAN2 estimates associated with the above base yields
/1 112
2 205
3 351
4 319
5 161
6 156
/

bsPrmvl(crp) phosphate removed (kg per ha) based on BsYld for each crop
* Based on NMAN2 estimates associated with the above base yields
/1 84
2 76.50
3 53.08
4 53.08
5 57.60
6 42.46
/

bsKrmvl(crp) potassium removed (kg per ha) based on BsYld for each crop
* Based on NMAN2 estimates associated with the above base yields
/1 39
2 191
3 359
4 305
5 58
6 131
/

LIVESTOCK ENTERPRISE
R(fd) Annual Feed Requirements per Milking Age Cow for feed f(metric ton or bu per milking age cow)
* Assume 10 month lactation, 2 month dry, constant 1:1 milking age cows to heifer ratio
* Based on numbers from the Elora Dairy Research Centre
* Feed requirement in dry matter basis
/1 1.4874
2 3.6007
3 0.9381
4 3.15
7 1.679/

Lm   Hours of labour required per adult milking cow
*   Hours per milking cow calcuated from number from farm visit: at 30.5hr/adult milking age cow
*   Hours per heifer obtained from OMAFRA factsheet: at 12.5hr/heifer.
/38.125/

*Prices
Pm   Milk Price (per Hectolitre (HL)) net or gross?
*   Based on DFO website , May'08 numbers, cost of transportation and cow maintenance included
/47.99/

Pman   Per metric-ton (in dry matter) cost of manure export off farm
*production coefficients

m   Annual milk production per adult milking cow (in HL)
*   Based on OMAFRA and DFO estimates
/85/

sman   annual solid manure production per milking age cow (metric ton per milking age cow)
*   Based on NMAN2 Software, Manure Pack Holstein heifers with straw bedding
*   metric tons in dry matter basis assuming 40% dry matter
/1.599/

lman   annual liquid manure production per milking age cow (1000L per milking age cow)
*   Based on NMAN2 Software, Free Stall Holstein
*   metric tons in dry matter basis assuming 9.1% dry matter
/2.458/

*Manure nutrient profile
*Nitrogen content
aNsman kg of available nitrate per metric ton of solid manure
*   Dry matter estimate through NMAN2 Manure nutrient database
/12.176/

aNlman kg of available nitrate per 1000L of liquid manure
*   Dry matter estimate through NMAN2 Manure nutrient database
/47.586/

Natm   atmospheric deposition of nitrogen (kg N per ha)
*   value taken from van Ham thesis
/18.4/

Nnonsym Non-symbiotic nitrogen fixation (kg N per ha)
*   value taken from van Ham thesis
/5/

Nsym(crp) Symbiotic nitrogen fixation for legume crops (kg N per ha)
*   Based on Nitrogen fixation values found in van Ham's thesis
/1 0
2 0
3 170
4 200
5 100
6 0/

```
        Ncred(crp) Nitrogen Credit from previous crop based on crop rotation
*           from NMAN2 estimates
                /1  6.67
                 2  6.67
                 3  75.67
                 4  75.67
                 5  110
                 6  30
                /

*Phosphate content
        aPsman   kg of available phosphate per metric ton of solid manure
*           NMAN2 estimates per metric ton of dry matter. Assume phosphate = 92% of total P
                /15.346/

        aPlman   kg of available phosphate per metric ton of liquid manure dry matter
*           NMAN2 estimates per metric ton of dry matter. Assume phosphate = 92% of total P
                /37.444/

*Potassium content
        aKsman   kg of available potassium oxide per metric ton of solid manure
*           NMAN2 estimates per metric ton of dry matter. Assume phosphate = 92% of total P
                /21.708/

        aKlman   kg of available potassium oxide per metric ton of liquid manure dry matter
*           NMAN2 estimates per metric ton of dry matter. Assume phosphate = 92% of total P
                /28.512/

        man      metric tons of manure (dry matter) produced per cow
        aNman   kg of available N per metric ton dry matter of manure
        aPman   kg of available P per metric ton dry matter of manure
        aKman   kg of available k per metric ton dry matter of manure
;

if ((size eq 1),
        Abar = 60;
        B = 30;
        lman =3.915;
        Clman=8.27;
        aNlman =11.3;
        aPlman =13.8;
        aKlman =25.27;
else
        if ((size eq 2),
        Abar = 130;
        B = 70;
);
);

if ((allowxpt eq 2),
        Pman = 35;
);
if ((allowrnt eq 2),
        Prent = 1000;
);
```

```
if ((plsB eq 1),
      B = B*1.1;
);

*total crop rotation year is the sum of all years of crop
cprtyr = alfyr + crnyr + soyyr + whtyr;

Variables
      Pi            Total Profit
      L             Total labour (hrs)

*CROP ENTERPRISE
* Production variables
      Y(c)          per-hectare yield
      Atotal        Total Land (workable + rented)

* Crop quantity produced, sold, or used as feed
      Qc(c)         Amount of crops c produced

* Fertilizer purchase and application
* Nitrogen
      nfert         kg of nitrogen fertilizer purchased
      nph(c)        kg per hectare of nitrogen applied to crop c from all sources

* Phosphate
      pfert         kg of phosphate fertilizer applied
      pph(c)        kg oer hectare of phosphate applied to crop c from all sources

* Potassium
      kfert         kg of potassium oxide fertilizer applied
      kph(c)        kg oer hectare of potassium oxide applied to crop c from all sources

*LIVESTOCK ENTERPRISE
* Production variables
      Qa            Number of milking age cows on Farm
      Qm            Total milk produced

* Manure production
      tman          Total manure produced in metric tons (dry matter basis)

* Manure application
      mapp(crp)     metric ton (dry matter) per ha of manure applied per crop

* Total allowable excess P
      Pallow        Total kg of excess P allowed
      Pallow2(crp)  kg per ha excess of preg allowed
      Nallow2(crp)  kg per ha excess of nreg allowed

* Crop removal of N and P
      Nrmvl(crp)    kg per ha of nitrogen removed by each crop through harvest
      Prmvl(crp)    kg per ha of phosphate removed by each crop through harvest
      Krmvl(crp)    kg per ha of potassium removed by each crop through harvest
```

```
* Soil N and P balance
      Nblnc(crp)     Nitrogen balance in kg per ha
      Pblnc(crp)     Phosphate balance in kg per ha
      Kblnc(crp)     Potassium balance in kg per ha
      Nblnc2(crp)    Nitrogen agro balance in kg per ha (above nreq)
      Pblnc2(crp)    Phosphate agro balance in kg per ha (above preq)
;

Positive variables
*CROP ENTERPRISE
* Production variables
      A(c)           Hectares used for each crop
      Arent          Hectares of rented land

* Crop quantity produced, sold, or used as feed
      Qcs(crp)       Amount of crops c sold
      Qcf(crp)       Amount of crop c for feed c

* Quantity of feed purchased and used
      Qf(c)          Amount of feed purchased
      Qfeed(c)       Amount of feed used

* Fertilizer purchase and application
      nfapp(crp)     kg per ha of nitrogen fertilizer applied to crop C
      pfapp(crp)     kg per ha of phosphate fertilizer applied to crop C
      kfapp(crp)     kg per ha of potassium oxide fertilizer applied to crop C

*LIVESTOCK ENTERPRISE
* Production variables
      Qa             Number of milking age cows on Farm

* Manure application
      mapp(crp)      metric ton (dry matter) per ha of manure applied per crop

* Manure export and Land Rental
      manxpt         metric tons of solid manure exported off farm
;

Equations

*objective function*
      profit         define objective function
      Rentlim        define limit on amount of land that can be rented

*crops
      crpprd(c)      define total metric tons produced for all non-corn crops
      crpyld(notcrn) define per metric ton per hectare yield of non-corn crops
      crnyld(crn)    define per metric ton per hectare yield of corn crops
      cropfate1(ntfd)
      cropfate2(ntmkt)
      cropfate3(fdmk)

*feeds
      feedtrans(cfd) define transfer from crop feed purchase
      suptrans(supp) define transfer of supplement purchase
      feedintk(fd)   define feed intake requirements
```

*livestock
    milkprod   define total milk production (in hectolitres)

*Manure production and fate of produced manure
    manprod   define total manure production (in cubic metre)
    manfate   define manure production application and export

*Nutrient requirement for crops
    Nrequired(crp) define nitrogen per ha required by crop c from fertilizer or manure
    Prequired(crp) define phosphate per ha required by crop c from fertilizer or manure
    Krequired(crp) define potassium oxid per ha required by crop c from fertilizer or manure

*Nutrient applied through fertilizr
    Nfertsum   define total nitrogen fertilizer applied and purchased
    Pfertsum   define total phosphate fertilizer applied and purchased
    Kfertsum   define total potassium oxide fertilizer applied and purchased

*Total nutrients applied from all sources
    ntotal(crp) define total nitrogen applied to crop c
    ptotal(crp) define total nitrogen applied to crop c
    ktotal(crp) define total postassium oxide applied to crop c

*Nutrients removed from crop harvest
    Nremove(crp) define actual amount of nitrogen removed through crop production
    Premove(crp) define actual amount of nitrogen removed through crop production
    Kremove(crp) define actual amount of potassium removed through crop production

*surplus balance of nutrients
    Nbalanc(crp) kg per ha balance of N (N input - N removed) for each crop
    Pbalanc(crp) kg per ha balance of P (P input - P removed) for each crop
    Kbalanc(crp) kg per ha balance of K (K input - K removed) for each crop

*Agronomic Balance of nutrients
    Nbalanc2(notcrn) kg per ha balance of N (N input - nreq) for each crop
    Pbalanc2(crp) kg per ha balance of P (P input - preq) for each crop

*Production constraints
*Land constraint by crops to simulate crop rotation
    alfrotn   define max land devoted to alfalfa to simulate crop rotation
    crnrotn   define max land devoted to corn to simulate crop rotation
    soyrotn   define max land devoted to soybeans to simulate crop rotation
    whtrotn   define max land devoted to winter wheat to simulate crop rotation
*Barn constraint
    barncons   define barn capacity constraint
    Landrent   define equation to rent land at a cost
*Labour constraint
    Labcons   define constraints for croplands
    Labttl   define constraints for croplands

```
*Regulatory constraints
       Pttl          define total allowable excess P
       Preg          define limiting nutrient application rates
       Pttl2(crp)    define total allowable excess P based on agro balance
       Nttl2(crp)    define total allowable excess N based on agro balance
       Preg2(crp)    define limiting nutrient application rate based on agro balance
       Nreg2(crp)    define limiting nutrient application rate based on agro balance
;

*Objective Function
       profit..             Pi =e= (Pm*Qm) + sum((mkt), (Pc(mkt)*Qcs(mkt))) -
(sum((fd),(Pf(fd)*Qf(fd))) + sum((crp),A(crp)*Cland(crp)) + (Pn*nfert) + (Pp*pfert) + (Pk*kfert) +
(Cman*tman) + (W*L) + (Pman*manxpt) + (Prent*Arent));

*Transfers
*Crop production
       crpprd(c)..          Qc(c) =e= A(c)*Y(c);
       crpyld(notcrn)..       Y(notcrn) =e= Yield(notcrn);
       crnyld(crn)..         Y(crn) =e= coeff(crn)*(beta1 + (beta2*nph(crn)) -
(beta3*nph(crn)*nph(crn)));

       ntotal(crp)..        nph(crp) =e= nfapp(crp) + (mapp(crp)*aNman) + Natm + Nnonsym +
Nsym(crp) + Ncred(Crp);
       ptotal(crp)..        pph(crp) =e= pfapp(crp) + (mapp(crp)*aPman);
       ktotal(crp)..        kph(crp) =e= kfapp(crp) + (mapp(crp)*aKman);

       nrequired(notcrn)..    nph(notcrn) =g= nreq(notcrn);
       prequired(crp)..      pph(crp) =g= preq(crp);
       krequired(crp)..      kph(crp) =g= kreq(crp);

       cropfate1(ntfd)..     Qc(ntfd) =e= Qcs(ntfd);
       cropfate2(ntmkt)..     Qc(ntmkt) =e= Qcf(ntmkt);
       cropfate3(fdmk)..      Qc(fdmk) =e= Qcs(fdmk) + Qcf(fdmk);

       feedtrans(cfd)..      Qfeed(cfd) =e= Qcf(cfd) + Qf(cfd);
       suptrans(supp)..       Qfeed(supp) =e= Qf(supp);
       feedintk(fd)..        Qfeed(fd) =e= R(fd)*Qa;

       milkprod..           Qm =e= Qa*m;

*      From cows to manure
       manprod..             (Qa*man) =e= tman;

*      From manure produced to application or export
       manfate..            tman =e= sum((crp), A(crp)*mapp(crp)) + manxpt;
       nfertsum..           nfert =e= sum((crp), A(crp)*nfapp(crp));
       pfertsum..           pfert =e= sum((crp), A(crp)*pfapp(crp));
       kfertsum..           kfert =e= sum((crp), A(crp)*kfapp(crp));
*Production constraints
*      Land rental condition
       Landrent..     Atotal =e= Abar + Arent;
       Rentlim..      Arent =l= Abar*Rlim;
```

```
*       land & crop rotation constraints
        alfrotn..     (alfyr/cprtyr)* (Atotal) =g= sum((alf),A(alf));
        crnrotn..     (crnyr/cprtyr)* (Atotal) =g= sum((crn),A(crn));
        soyrotn..     (soyyr/cprtyr)* (Atotal) =g= sum((soy),A(soy));
        whtrotn..     (whtyr/cprtyr)* (Atotal) =g= sum((wht),A(wht));

*Labour Constraint
        Labttl..      L =e= ((Qa*Lm) + sum((crp),A(crp)*Lc(crp)));
        Labcons..     Lmax =g= L;

*       barn constraint
        barncons..    B =g= Qa;

*Nutrient removal by each crop
        Nremove(crp)..  Nrmvl(crp) =e= (Y(crp)/BsYld(Crp))*bsNrmvl(crp);
        Premove(crp)..  Prmvl(crp) =e= (Y(crp)/BsYld(Crp))*bsPrmvl(crp);
        Kremove(crp)..  Krmvl(crp) =e= (Y(crp)/BsYld(Crp))*bsKrmvl(crp);

*Soil nutrient balance of each crop
        Nbalanc(crp)..  Nblnc(crp) =e= nph(crp)- Nrmvl(crp);
        Pbalanc(crp)..  Pblnc(crp) =e= pph(crp)- Prmvl(crp);
        Kbalanc(crp)..  Kblnc(crp) =e= kph(crp)- Krmvl(crp);

*Soil agro balance of each crop
        Nbalanc2(notcrn)..  Nblnc2(notcrn) =e= nph(notcrn)- nreq(notcrn);
        Pbalanc2(crp)..  Pblnc2(crp) =e= pph(crp)- preq(crp);

*nutrient regulation

*       NMA regulation
        Pttl..        Pallow =e= sum((crp),A(crp))*Plim;
        Preg..        Pallow =g= sum((crp),A(crp)*Pblnc(crp));

*       CWA regulation
        Pttl2(crp)..    Pallow2(crp) =e= preq(crp)*Palim;
        Nttl2(crp)..    Nallow2(crp) =e= nreq(crp)*Nalim;
        Preg2(crp)..    Pallow2(crp) =g= Pblnc2(crp);
        Nreg2(crp)..    Nallow2(crp) =g= Nblnc2(crp);

Model farm /all/;
solve farm using nlp maximizing Pi;
```