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Cost Benefit Analysis of Source Water Protection Beneficial Management Practices: A Case Study in the Region of Waterloo, Ontario

FINAL REPORT

Prepared for: Ontario Ministry of the Environment

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EXECUTIVE SUMMARY

The purpose of this study was to examine the agronomic and environmental effectiveness, and the economic efficiency of beneficial management practices (BMPs) used to protect groundwater resources by reducing the amount of nitrogen potentially available to leach into groundwater, based on the 1980-2008 time step. To do so, a nitrogen mass balance model (MBM) was developed and the results from nitrogen (N) budgets developed from actual cropping practices within the capture zone of a production well in Waterloo Region were used to estimate long-term potentially leachable nitrogen (N_{pl}). Five BMP scenarios were compared to determine: i) their potential effectiveness in reducing the amount of nitrogen available to leach from agricultural fields into groundwater and ii) their relative potential for ensuring groundwater obtained in the future at a production well in the Waterloo Region will meet the Ontario Drinking Water Standard (ODWS) for nitrogen (10 mg/L). Finally, the economic costs associated with the alternative BMPs were assessed.

Key Results:

1. The implementation of nitrogen BMP scenarios designed to enhance existing nitrogen management practices (BMP21 (soil N test), BMP22 (N balance) and BMP23 (max N balance)) or remove key sources of nitrogen (BMP24 (drop manure) and BMP25 (drop manure/corn)) in agricultural fields represent effective environmental strategies for ensuring groundwater obtained at the production well in the future will meet the Ontario Drinking Water Standard (ODWS) for nitrogen (10 mg/L).

2. The mean estimates of long-term N_{pl} for the BMP scenarios ranged from 19 to 38 kg N/ha/yr compared to the mean estimate of N_{pl} for the Base case (44 kg N/ha/yr) (1980-2008; n=29 yrs; Table 15). In percentage terms, the mean estimates of N_{pl} for the BMP scenarios were approximately 14 to 57% less than the mean estimate of N_{pl} for the Base case (Figure 6) i.e.,
   - 57% less N_{pl} under BMP24 (drop manure) and BMP25 (drop manure/corn);
   - 48% less N_{pl} under BMP23 (max N balance);
   - 34% less N_{pl} under BMP22 (N balance); and
   - 14% less N_{pl} under BMP21 (soil N test).

3. The relative estimate of mean annual N_{pl} generally decreased across the capture zone as the intensity of nitrogen management using BMPs increased from BMP21 (soil N test) to BMP22 (N balance) to BMP23 (max N balance) (Figure 7). The relative estimate of mean annual N_{pl} was generally lower for the remaining two BMP scenarios, which represented significant targeted external influences on producer N use i.e., BMP24 (drop manure) and BMP25 (drop manure/corn) (except for BMP24, which was similar to BMP23 toward the end of the study time step) (Figure 7).

4. In the example set of fields representing a livestock-based rotation (B9/B10/B12) there was a 70 to 80% reduction in estimated N_{pl} across the BMP22 (N balance), BMP23 (max N balance), BMP24 (drop manure), and BMP25 (drop manure and corn) scenarios. A 12% reduction in estimated N_{pl} occurred under BMP21 (soil N test) (Table 17).

5. In the example set of fields representing a cash crop-based rotation (D1-D4) there was a 0 to 23% reduction in N_{pl} across the BMP22 (N balance), BMP23 (max N balance), BMP24 (drop manure), and BMP25 (drop manure/corn) scenarios. A 28% reduction in estimated N_{pl} occurred under BMP21 (soil N test) although this value may overestimate the potential reduction achievable for this field group since the analysis resulted in a greater decline in N_{pl} relative to the other more intensive BMP scenarios (Table 17).

6. Those field groups where manure/biosolids were used during crop production (A1-A4; B9/B10/B12; C1-C4) showed the greatest potential for reduction of N_{pl} across all of the BMP scenarios.

7. Those field groups with more nitrogen BMPs in use within the Base case (C and D field groups) realized a lower relative reduction in estimated N_{pl} than those field groups with fewer BMPs in use within the Base case (A, B and E field groups).

8. Economic costs of the BMP scenarios generally ranged between $18/acre/year ($45/ha/yr) and $52/acre/year ($129/ha/yr), with a subset of BMP scenarios generating a benefit (net reduction in costs) and others a much higher cost. The BMP scenarios that focused on removal of manure and improved management decisions based on results from a soil N test generated net benefits. The BMP scenario that focused on removing manure and corn from the crop rotation tended to generate the highest costs.

9. There were sharp differences in BMP costs across individual fields. This related to initial management conditions.

10. The effectiveness of BMPs from an economic perspective did not match the environmental effectiveness. This is illustrated in the table below. The table presents the ranking of scenarios based on environmental criteria and economic criteria. The first set of columns provides environmental rankings for the capture zone as a whole; the next set of columns provide environmental rankings based on the subset of fields considered in the economic analysis. The far right set of columns presents rankings of scenarios based on economic criteria for the subset of fields. Comparing the subset, under environmental and economic criteria, the BMP in which manure was not applied in the study fields (BMP 24) was ranked the most effective. Conversely, BMP25 (drop manure/corn) was ranked second by environmental criteria but last on economic criteria. Using economic criteria, BMP21 (soil N test) was ranked second, but was ranked last using environmental criteria. The orderings of BMP22 (N balance) and BMP23 (max N balance) were reversed using the two criteria.

Environmental and Economic Rankings of BMP Scenarios

Environmental Ranking[1]						Economic Ranking		
All fields in capture zone analysis			Subset of fields in economic analysis			Subset of fields in economic analysis		
N_{pl} Reduction (%)	Rank	BMP scenario	N_{pl} Reduction (%)	Rank	BMP scenario	N_{pl} Cost of 1% reduction ($)	Rank	BMP scenario
57	1	BMP24 (drop manure) or BMP25 (drop manure/corn)	60	1	BMP24 (drop manure)	-	1	BMP24 (drop manure)
48	2	BMP23 (max N balance)	52	2	BMP25 (drop manure/corn)	-	2	BMP21 (soil N test)
34	3	BMP22 (N balance)	37[2]	3[2]	BMP23 (max N balance)	18	3	BMP22 (N balance)
14	4	BMP21 (soil N test)	35[2]	4[2]	BMP22 (N balance)	33	4	BMP23 (max N balance)
			20	5	BMP21 (soil N test)	52	5	BMP25 (drop manure/corn)

[1] Environmental rank based on relative decrease in estimated long-term potentially leachable N (N_{pl}) compared to the Base case (Table 18)

[2] These BMP scenarios were substantially equivalent (difference in N_{pl} reduction was <10%)

Key Conclusions

1. The results of this study suggest that from an agronomic and environmental perspective the BMP scenarios represent effective strategies for ensuring groundwater obtained at the production well in the future will meet the Ontario Drinking Water Standard (ODWS) for nitrogen (10 mg/L).

2. The results suggest that, at relatively nominal cost, agronomic BMPs could be used to protect groundwater resources. Under the agronomic and market conditions considered, the most environmentally and economically efficacious BMPs remove manure application, but do not disrupt crop rotations - in particular, do not remove corn.

Key Recommendations

1. Nitrogen BMPs in agricultural landscapes should be referenced in public planning for protection of groundwater resources. The agronomic and environmental efficiency is relevant in understanding how these BMP scenarios could impact long-term potentially leachable nitrogen that may enter groundwater system, and the economic efficiency is relevant in understanding how producers are impacted upon implementation of these BMP scenarios.

2. The most effective BMP scenario from an environmental and economic perspective removes manure application as an agronomic practice. In this study, this nitrogen management strategy provided a clear win for both producers and the public relative to protecting groundwater resources. It should be pursued as first among BMP options when considering environmental impacts and producer costs, provided producer costs associated with finding alternate locations to apply or dispose of manure are very low or zero. Future study could include an examination of alternative options for manure use and the associated costs if the application of manure was restricted in some portion of the capture zone.

TABLE OF CONTENTS

List of Tables

List of Figures

1 INTRODUCTION

The Clean Water Act received Royal Assent on October 19th, 2006. The purpose of the Act is to ensure that communities are able to protect their municipal drinking water supplies through developing collaborative, locally driven, science-based source protection plans (MOE, 2006). Source water protection (SWP) is intended to be the first barrier in a multi-barrier system, to prevent contamination of groundwater supplies at the source.

Some municipalities are proposing to manage agricultural risks to municipal drinking water by using beneficial management practices (BMPs). The Region of Waterloo (Region) is taking a proactive approach to evaluating the benefits of agricultural BMPs within the capture zone for a production well in its jurisdiction.

This study evaluates agricultural BMPs that could reduce the amount of potentially leachable nitrogen (N_{pl}) that could leach into groundwater. It provides producers, the public, municipalities and government information on the costs and benefits of BMPs that protect source water from nitrogen contamination.

1.1 PURPOSE AND OBJECTIVES

The purpose of this study was to examine the agronomic and environmental effectiveness, and the economic efficiency of BMPs used to protect groundwater resources by reducing the amount of nitrogen potentially available to leach into groundwater, based on the 1980-2008 time step.

The objectives of the project were:

- To collect historical data on nutrient loading by agricultural operations in the study area to be used as input data in the nitrogen mass balance model (MBM) developed by Stantec Consulting Ltd. to evaluate the impact of the BMPs on groundwater nitrate concentrations at the production well;
- To estimate and compare the ongoing costs of using agricultural BMPs in the capture zone; and
- To provide a summary of results, lessons learned and policy implications.

2 LITERATURE REVIEW

2.1 SOURCE WATER PROTECTION IN AGRICULTURAL LANDSCAPES

Nitrogen is an essential nutrient required by all crops. Increasing amounts of nitrogen are being added to crops in the form of fertilizer and manure to optimize yields and to meet the growing demand for food and fibre (AAFC, 2005). However, some nitrogen may eventually move from treated agricultural areas into the environment, particularly into water resources. Nitrogen losses to the environment occur because not all of the applied nitrogen is used by the crop and, therefore, residual nitrogen remains in the soil. Risk of water contamination may arise when unduly large surpluses of nitrogen are present in the soil under humid conditions (AAFC, 2005).

In order to protect drinking water, it is best to adopt an approach that uses multiple barriers to prevent contamination. Known as the 'multi-barrier approach', this includes measures to prevent contamination of sources of water together with adequate water treatment and distribution systems, water testing and training of water managers (Conservation Ontario, 2005).

"The first barrier to the contamination of drinking water involves protecting the sources of drinking water."[1] Source water protection (SWP) involves protecting both the quality and quantity of source water[2] including surface water and groundwater. Surface water is water that is in contact with the atmosphere; it comprises lakes, rivers, streams, creeks and oceans. Approximately 74% of Canadians get their drinking water from surface water sources (Blundell *et al.*, 2004). Groundwater is water found beneath the earth's surface between the cracks and spaces in soil, sand and rock. Approximately 26% of Canadians use groundwater to meet their daily water needs (Blundell *et al.*, 2004).

On the farm, producers can use different beneficial or best management practices (BMPs) to protect water sources and "ensure a supply of good quality water" for agricultural purposes (AAFC, 2004) as well as non-agricultural use. BMPs can act as the first barrier (of the multi-barrier approach) on agricultural landscapes to prevent or decrease the contamination of source water by nutrients, pesticides, micro-organisms, and soil and suspended sediment.

2.2 BMPS FOR NITROGEN IN AGRICULTURE

In agricultural landscapes it is difficult to effectively manage nitrogen when the objective is maximizing the amount of nitrate-nitrogen in the root zone that is available to produce

[1] Source: Justice Dennis O'Connor, Walkerton Inquiry 2002 as cited in Conservation Ontario, 2005.
[2] Source water is untreated water from streams, lakes or underground aquifers that people use to supply private wells and public drinking water systems.

crop yield while minimizing the amount of nitrate-nitrogen in the soil that could to leach into groundwater. Striking the right balance can be difficult for the following reasons (Keeney, 1991):

- The inefficiency of plant nitrogen uptake;
- The lack of knowledge of the site-specific factors that may affect nitrogen transformations and availability;
- The failure to account for the available nitrogen in the soil profile at the beginning of the growing season;
- The imprecise nature of the understanding of nitrogen availability from soil organic matter, crop residues and wastes;
- The impossibility of predicting yearly weather patterns; and
- The necessity to maximize economic returns on the land.

Di and Cameron (2002) suggest that effectively managing nitrogen is a multi-faceted task and requires an integrated approach based on the development and adoption of BMPs. Many others have recognized that several crop and fertility management practices significantly improve the potential to maximize crop yield while minimizing the quantity of nitrate leaching into groundwater (Keeney, 1991; Ritter, 2001; McKague, 2005). Since 1993, agricultural producers in Ontario have adopted the strategy of developing Environmental Farm Plans (EFP) (OFEC, 2004). These plans represent an assessment of farm property that identifies environmental strengths and challenges, including issues related to source water protection and nitrogen management in agricultural landscapes.

A list of recommended BMPs deemed appropriate for managing nitrogen in a specific agricultural landscape requires information on land characteristics and use, and an understanding of where nitrogen enters and exits the system (Meisinger and Randall, 1991).

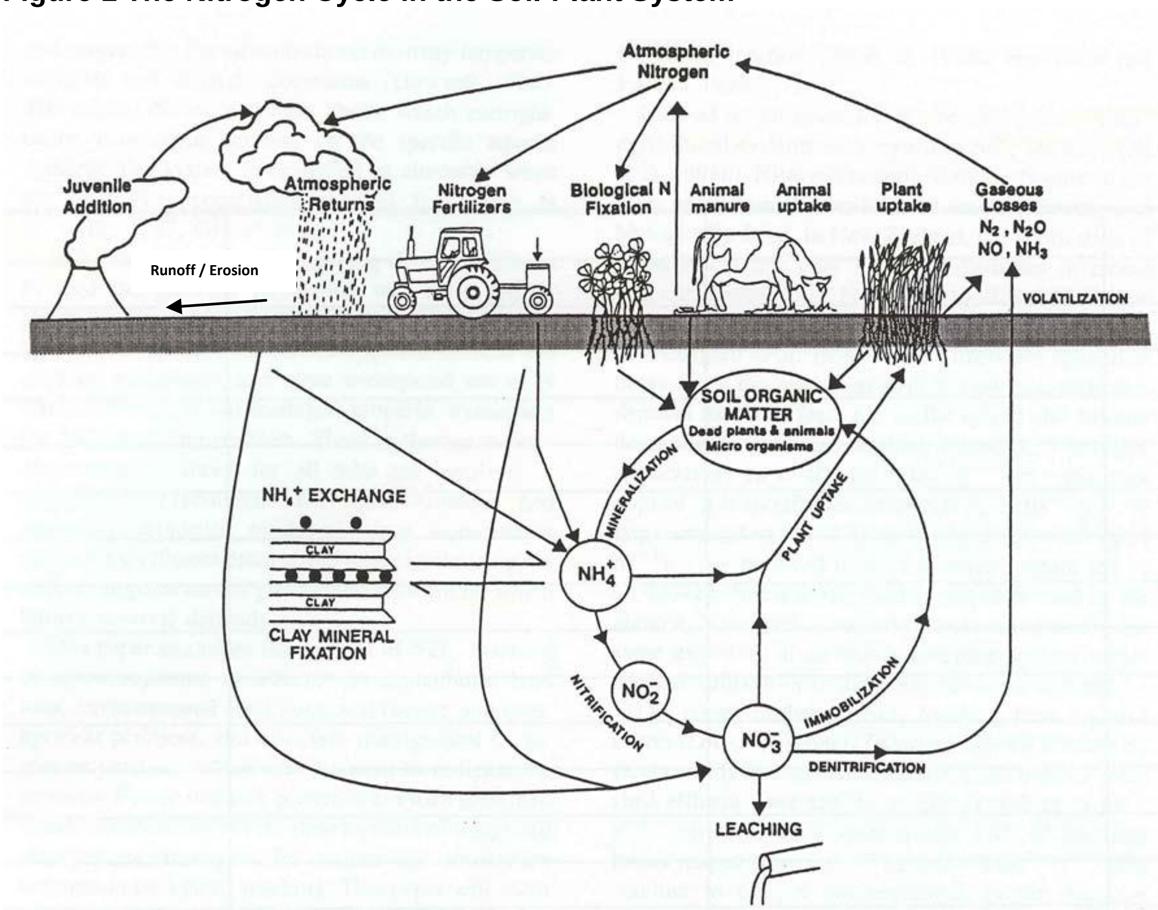
2.2.1 Nitrogen Sources and Sinks

Nitrogen enters and exits agricultural landscapes following a complex series of steps and processes typically described as the nitrogen cycle (Figure 1) (Di and Cameron, 2002).

Determining the relationships between the amount of nitrogen added to a system (i.e., sources or inputs), the amount of nitrogen leaving a system (i.e., sinks or outputs), and in particular, the amount of nitrate-nitrogen exiting a system by leaching into groundwater is difficult because: a) there are many possible sources of nitrate; b) point and non-point sources of nitrogen overlap, and c) many biogeochemical processes that alter nitrate and other chemical concentrations occur simultaneously (Kendall, 1998).

Nitrogen (N) budgets have been used to identify and estimate the magnitude of nitrogen inputs, outputs and potentially leachable nitrogen (as nitrate) in agricultural settings (Meisinger and Randall 1991; Cole, 2008).

Figure 1 The Nitrogen Cycle in the Soil-Plant System



(after McLaren and Cameron, 1990 in Di and Cameron, 2002)

Rising concentrations of nitrogen in surface water and groundwater, which are blamed on agricultural production systems, is a global issue (Di and Cameron, 2002; Ritter and Bergstrom, 2001). Effective control of leachable nitrogen is important for protecting source water originating from agricultural landscapes. Di and Cameron (2002) reviewed nitrogen leaching in temperate agroecosystems around the world and determined that the potential for nitrogen leaching in different land use systems was typically as follows:

forest< cut grassland < grazed pastures, arable cropping
< ploughing of pasture < market gardens.

While land use is of primary significance in determining the amount of potentially leachable nitrogen, the actual amount reaching groundwater is heavily influenced by several factors including: soil texture; water table depth; presence of natural or no till-related macropores; use of subsurface tile drainage; seasonal soil drainage patterns; amount of rainfall and irrigation especially following nitrogen fertilizer application; rate and timing of nitrogen fertilizer application; and use of cover crops (Di and Cameron, 2002).

2.2.2 Environmental Effectiveness of BMPs for Nitrogen

The information presented in this section focuses on the effectiveness of BMPs that address impairment of groundwater quality by leachable nitrogen as nitrate.

2.2.2.1 Farmstead and Single Dwelling Management Practices

Point sources of nitrate contamination of groundwater are found in agricultural landscapes and are generally located within the farmstead building complex. These may include: seepage from manure storage basins and lagoons; dead animal disposal pits; stockpiled manure; livestock feedlots; and livestock housing with dirt floors (Ritter and Bergstrom, 2001). The literature reviewed by Ritter and Bergstrom (2001) suggested that the lack of a containment barrier e.g., a liner, could result in higher concentrations of leachable nitrate in the soil under and around the structure. Failure of a containment barrier e.g., cracks, could result in a shock load of pollutants moving into groundwater.

Manure storage facilities were identified as contributing to an effective nutrient management program (Mostaghimi *et al.*, 2001). These facilities require professional services to ensure the design is appropriate. Failure of these types of structures can cause significant environmental damage, especially to surface water and groundwater.

In Ontario, the Environmental Farm Plan (EFP) program includes several questions aimed at identifying and assessing the potential risk of pollution from point sources on the farm. Containment of the pollutant and minimizing the potential for accidental spills of the pollutant are of primary importance. Facilities and activities that could result in a potential point source of nitrate leaching to groundwater include storage and handling of fertilizer; disposal of farm waste including dead animals; treatment of household wastewater; storage of livestock manure and prescribed materials (also called biosolids); livestock yards and outdoor confinement areas; silage storage; and milk centre wash water (OFEC, 2004). Since most agricultural landscapes in Ontario include single dwelling homes either within the farmstead or on severed parcels of land, the presence of septic systems (identified in the EFP under treatment of household wastewater) and compost (identified under disposal of farm waste) represent potential point sources of pollution.

2.2.2.2 In-Field Management Practices

Positive changes in groundwater quality associated with BMPs may take several decades to be realized in some watersheds and capture zones. In fact, there are few studies at the landscape or watershed scale that adequately document impacts of specific changes to agricultural management on groundwater quality (Tomer, 2003). However, in one such case, a groundwater study was conducted on a pair of very similar first-order watersheds (30 and 34 ha) in Iowa where corn was grown continuously. The evidence suggested that heavy nitrogen fertilization between 1969 and 1974 on one watershed continued to influence the concentration of nitrate in that watershed 30 years after the amount applied was decreased (Tomer, 2003).

Mostaghimi *et al. (*2001) summarized the effectiveness of BMPs that impact soluble pollutants e.g., nitrate: conservation tillage; filter strips; riparian buffers; cover crops; conservation crop rotation; nutrient management; precision farming; constructed wetlands; and fencing and use exclusion. For example, nutrient management is one of the most widely used BMPs to control nonpoint source pollution from agricultural land. The goal is to manage the amount, form, placement, and timing of plant nutrient applications to maximize yield while minimizing the loss of nutrients to surface water and groundwater. Development of an effective nutrient management plan is considered essential. Soil, crop tissue/residues and manure testing are/may be necessary to determine crop nitrogen needs. The goal is to determine the nutrient needs of each crop to meet yield goals. Split applications of nitrogen at planting and later in the growing season when the plant requires it are effective at helping to maximize yield while minimizing leachable nitrogen. Nitrification inhibitors in commercial fertilizers slow the bacterial conversion of ammonium to nitrate, although their incorporation into the soil is important to minimize other environmental concerns such as volatilization as ammonia. Coated fertilizer gradually releases nutrients in the soil and also may be useful in controlling potentially leachable nitrate. Organic sources of nutrients including green manure, livestock manure and municipal sludge were discussed. One cautionary comment indicated that manure application rates are often based on crop nitrogen needs; however, this can lead to an over-application of phosphorus because the nitrogen to phosphorus ratio of these materials is typically lower than what the crop requires. As a result, soils can become saturated with phosphorus (Mostaghimi *et al*., 2001).

Cole (2008) studied nitrogen and groundwater quality beneath a 54 ha hog farm in Ontario, Canada. Applied nitrogen was reduced by 46% in 1997. There was no corresponding reduction in corn yield during subsequent years, which suggested that historical applications of nitrogen exceeded the requirements of the crop. There was a corresponding reduction in nitrate concentrations of approximately 35% (observed in 2007) in the historically contaminated groundwater beneath the farm. Reductions in nitrates were observed regardless of type of source of nitrogen i.e., commercial fertilizer nitrogen vs. manure nitrogen. The findings suggested that a reduction in the rate of applied nitrogen as a BMP was effective in improving groundwater quality relative to nitrate contamination (Cole, 2008).

A study was conducted on 73 ha of farmland near a municipal well field in Oxford County, Ontario (Bekeris, 2008). The rate of applied nitrogen was reduced by 20 to 50% relative to historical rates as a BMP aimed at slowing the increase in groundwater nitrate concentrations in the municipal supply wells. While the outcome of the study suggested more rather than less nitrate was present in the shallow subsurface i.e., two to three metre depths, Bekeris (2008) suggested a lack of nitrate concentration data from the deep unsaturated zone and excess rainfall (>30% of normal) contributed to the unexpected finding. Bekeris (2008) observed that nitrate in the unsaturated zone assumed to be affected by the BMPs ranged from 3.4 to 13.2 g/yr/m^2, which indicated that some areas of the study site were more critical than others in terms of their contribution to groundwater nitrate (Bekeris, 2008).

Beginning in 1990, the Management Systems Evaluation Area (MSEA) evaluated existing and new nitrogen management technologies to reduce the potential for adverse impacts of agricultural practices on surface water and groundwater quality (Power, 2000). Research occurred across nine Midwestern states in the United States. Soil nitrate sampling and testing were done pre-plant and pre-side dress to determine the most appropriate nitrogen fertilizer rates for the actual field conditions. Also, banding ammoniated nitrogen fertilizers helped to slow nitrification rates and nitrate leaching, especially if the soil was packed over the band. The program showed that variable rate fertilization could be an effective tool when used in combination with an assessment of 'crop greenness' to determine localized areas of nitrogen deficiencies (Power, 2000).

Shipitalo and Edwards (2000) summarized the effects of conservation tillage on water movement and quality. They found that conservation tillage had a greater effect on how water moved through the soil than on how much water moved through the soil to groundwater. Conservation tillage can increase the number of macropores[3] in the soil, which transmit water to lower soil depths, and potentially the water table. This often contributes to a reduction in surface runoff water. If soil macropores are present and an intense rainfall occurs after application, a significant proportion i.e., up to a few per cent, of the applied chemical will move through these preferential flow paths regardless of the affinity of the chemical for soil. Time or prior light rains, however, can reduce the impact of the first intense rainfall event. When conservation tillage is used rather than conventional tillage, chemicals that are strongly adsorbed to soil, e.g., some pesticides and phosphorus, will tend not to move after the first or second intense rainfall. However, nitrate, which is a non-adsorbed solute, will continue to leach as rainfall continues to occur. These workers concluded that leaching of non-adsorbed solutes, e.g., some pesticides and nitrates, would continue regardless of the tillage system used (Shipitalo and Edwards, 2000).

Ritter (2001) reviewed several studies that compared tillage system and nitrate in subsurface tile runoff and groundwater. Although the findings were variable, in many cases, it appeared that increased infiltration in conservation tillage systems did not necessarily mean increased loss of nitrate into groundwater (Ritter and Bergstrom, 2001). Other factors such as the presence of macropores, cropping system and rainfall may be more influential in determining the amount of nitrate leaching to subsurface tile drainage systems and groundwater.

2.2.2.3 Off-Field Management Practices

At least three reviews of the impacts of agricultural drainage have been published (Skaggs *et al*., 1994; Fraser and Fleming, 2001; Rudy, 2004). Rudy (2004) reviewed the environmental impacts of agricultural drains. Since drainage systems have the potential to transfer contaminants such as nitrate, Rudy (2004) identified several BMPs from the literature that provide effective mitigation of pollution in drainage of water from agricultural lands (Rudy, 2004):

- drainage system design;
- buffer strips and riparian zones along drains;
- controlled drainage/sub-irrigation systems;
- constructed wetlands;
- bioreactors;
- drainage systems in response to the needs of climate change; and
- contingency planning.

Researchers in the Management Systems Evaluation Area (MSEA) found that 95% of the nitrate leaching through tiled soils was intercepted and discharged into surface

[3] Macropores are defined by the US Environmental Protection Agency as secondary soil features such as root holes or desiccation cracks that can create significant conduits for movement of non-aqueous phase liquid (NAPL) and dissolved contaminants, or vapour-phase contaminants. Source: http://www.epa.gov/ocepaterms/mterms.html.

waters. Further computer modeling efforts suggested that routing the tiled water through wetlands would significantly reduce the amount of nitrate discharged into watercourses. Controlled water tables using drainage tile lines for sub-irrigation were also proven effective in reducing nitrate losses (Power *et al.,* 2000).

There is a large body of North American and European research related to buffer strips (Borin *et al.,* 2004; Dosskey, 2001; Hickey and Doran, 2004; Viaud *et al*., 2004; Vought *et al*., 1995). For the purposes of this review the terms buffer strips, vegetative buffer strips and riparian buffers were considered synonymous (Hickey and Doran, 2004). Pictures of many types of buffers are found in the NRCS-USDA publication *Conservation Buffers to Reduce Pesticide Losses* (NRCS-USDA, 2000). Related practices with buffering attributes include: constructed wetland; channel vegetation; terrace; water and sediment containment basin; grade stabilization structure; and farm ponds / in stream wetlands (Lowrance *et al.,* 2001).

The effectiveness of buffers in mitigating problems associated with nitrogen and groundwater infiltration is driven by the functions performed by buffers. These functions are explained in greater detail by Dosskey (2001 and 2002) (Table 1).

Table 1 Factors Affecting Groundwater-Related Functions of Buffers

Function	**Impact-Governing Variables**	
	Field and Buffer Site Conditions	**Buffer Design and Management**
Surface runoff reduction	• Pollutant type and load • Sediment particle sizes • Surface runoff depth • Slope of buffer • Soil permeability of buffer • Flow-concentration pattern	• Distance between contour strips • Width of buffer strip • Vegetation type and density • Vegetation harvest • Sediment removal
Groundwater filtration	• Pollutant type and load • Groundwater depth - Tile bypass flow - Groundwater flow velocity - Soil organic matter content - Flow concentration pattern	• Width of buffer strip • Vegetation type • Vegetation harvest • Groundwater depth control • Tile bypass flow control

(Adapted from Dosskey, 2002)

Hickey and Doran (2004) noted that subsurface tile drainage, which is common in Ontario, allows runoff water to exit agricultural fields without contacting soil containing micro-organisms that could break down nutrients or the roots of plants that could take up nutrients - two processes that contribute to the effectiveness of buffers as a filter for the pollutants. The authors concluded that buffer strips may be most effective in preventing the deterioration of water quality in areas where the natural drainage patterns are intact (Hickey and Doran, 2004).

There is a large degree of variation in the findings related to the effectiveness of buffer strips. This was attributed to the wide range of conditions under which the studies were conducted (Hickey and Doran, 2004). These authors concluded from the literature that buffer strips can reduce non-point source pollution to streams but due to the variability in findings it is very difficult to make predictions about the effectiveness of a buffer under site-specific conditions. They also concluded that buffers 30 to 100 m in width are most effective but there is not enough information available regarding the effectiveness of buffers in the 1 to 10 m width range. They suggest that from a practical perspective landowners are more likely to ‘give up’ productive land to buffer strips in this latter width range (Hickey and Doran, 2004).

Several authors have compiled tables indicating the effectiveness of buffer strips in removing soil, sediment, nutrients, pesticides and pathogens from field runoff that enters the buffer strip as influent and leaves the buffer strip as effluent (Dosskey, 2001), (Hickey, 2004) (NRCS-USDA, 2000).

After extensive review of the literature on the pollution reduction functions of agricultural buffers, Dosskey (2002) cautioned: *there is a greater risk of overestimating buffer impact than underestimating it*. In an earlier paper, he also concluded that: *A great deal of professional judgement is still required to extrapolate current knowledge of buffer functions into broadly accurate estimates of water pollution abatement in response to buffer installation on crop land* (Dosskey, 2001). The author compared the probable level of impact of each buffer function by pollution type and uncertainty associated with the estimate of impact as indicated in Table 2.

Table 2 Probable Impact of Buffer Function by Pollution Type and Associated Uncertainty

Comparison of the probable level of impact that each individual buffer function can contribute to NPS pollution reduction nationwide (level of importance) by pollutant type, and the relative degree of uncertainty associated with that estimate[a]

Function	Level of importance, degree of uncertainty				Constraints on benefits	Major sources of uncertainty
	Sediment	P	N	Pesticides		
Surface runoff reduction	H	H	M	M-H	Extensive cultivation	Flow-concentration of runoff
	l	l	m	m	Flow–concentration of runoff	Limited data on dissolved pollutants
					Limits on enhanced infiltration	
					Sediment buildup	
					Site nutrient saturation	
Surface runoff filtration	H	H	M	M-H	Flow–concentration of runoff	Comparison to unbuffered condition
	h	h	h	h	Limits on enhanced infiltration	Flow–concentration of runoff
					Sediment buildup	Pollutant accumulation
					Site nutrient saturation	Long term impacts
Groundwater filtration	O	L	M	L	Deep groundwater and tile bypass flow	Comparison to unbuffered condition
	l	h	h	h	Aerobic conditions in buffer soil	Extent of applicable sites
					Short residence time of groundwater in buffer	Site nutrient saturation
					Site nutrient saturation	Comparison of vegetation types
Stream bank erosion reduction	M	L	L	O	Channel incision	Identify excessive bank instability
	h	h	h	h	Excessive bank instability	Limited data
						Extent of applicable sites
Stream water filtration	L	L	L	L	Noncropland sources of pollutants	Comparison to unbuffered condition
	m	m	m	m	Course of bed sediments	Limited longer-term data
					Existing sources of organic matter	Intermittent and ephemeral channels
					P saturation of sediments	
					Scour by large storm flows	
					Access to floodplain	

[a]H, M, L, and O refer to high, medium, low, and negligible impact, and h, m, and l refer to high, medium, and low uncertainty, respectively. For each function, some major constraints on the upper limit of impact and major sources of uncertainty are listed. P = phosphorus; N = nitrogen.

(Dosskey, 2002)

The effectiveness of constructed wetlands in removing nitrates from groundwater was demonstrated in a study by Larson *et al.* (2000). These researchers observed inflow and outflow from two constructed wetlands in 1997. They found that the amount of nitrates exiting wetlands in seepage water was estimated to be 61 and 25 kg N for each of two watersheds. This represented 10% and 4% of the total inlet of nitrate load. They concluded that seepage connected the wetland with the riparian buffer strip and moved the leachable N to denitrifying micro-organisms deeper in the soil profile and beyond the perimeter of the wetlands. They suggested that the overall removal of nitrates was enhanced (Larson *et al*., 2000).

2.2.3 Recommended BMPs for Nitrogen

Di and Cameron (2002) identified several BMPs in the literature that could be used effectively to manage nitrogen and minimize potentially leachable nitrogen:

- reduction of nitrogen application rates;
- synchronizing nitrogen supply to plant demand;
- use of cover crops;
- better timing of ploughing pasture;
- improved stock management;
- precision farming;
- regulatory measures; and
- computerized models as decision support systems.

In Ontario, the Ministry of Agriculture, Food and Rural Affairs (OMAFRA) has summarized the environmental impacts of nitrogen and recommended several ways to minimize the amount of nitrogen that could leach into groundwater (McKague, 2005):

- reduce total nitrogen loading e.g., match rations to livestock production needs to avoid excess loss of nitrogen in manure;
- prevent runoff from manure or other nutrient materials;
- manage fields to avoid excess nitrate that could leach to groundwater e.g., use a nutrient management plan, match nitrogen application/sources to crop production needs, use a crop rotation; and
- manage nutrient application to avoid ammonium losses to surface water, e.g., on tile-drained land, keep application rates of liquid manure below 40 m^3/ha (3,600 gal/ac) or pre-till the field before applying it; incorporate manure; use buffer strips and erosion control structures.

A study by the George Morris Centre provided an economic evaluation of BMPs for crop nutrients in Canadian agriculture (Brethour *et al*., 2007). The study presented a number of BMPs (with definitions) that are applicable to crop nutrients including nitrogen management.

1. Nutrient management planning – "involves careful attention to meeting crop nutrient needs, using cost-effective and environmentally responsible management practices" (Lane, 1998). It includes accounting for nutrients from other sources like manure and previous crops and utilizing crop response data to determine economically efficient application rates to maintain a balance between nutrient applications and removals (Bruulsema, 2004).

2. Soil testing – "used to estimate the fertility of the soil. In soil testing, chemicals that remove nutrients from the soil are used to estimate the nutrients that plants will be able to take up. The soil test is an index of the likelihood of crop response to applied nutrients" (Lane, 1998; Morris, 1994).
3. Foliage testing/plant tissue analysis – Foliage testing/plant tissue analysis helps producers determine the adequacy of fertilization practices. It provides the producer with information regarding the nutrient content of a crop that can be used during the growing season or from year-to-year. In combination with soil test information, fertilization practices can be adjusted to specific soil characteristics and plant needs (Flynn *et al.,* 1999).
4. Yield goal analysis – analyzing various yield scenarios to help make appropriate nutrient decisions (Bruulsema, 2004).
5. Application timing – "the timing of nutrient application involves applying what the crop needs when it needs it. This reduces the cost and loss of nutrients, while promoting plant growth" (Lane, 1998). According to McRae *et al.,* (2000), applying fertilizers after planting causes the least harm to the environment, whereas applying fertilizers at planting or before planting are more harmful. The greatest potential for fertilizers to cause harm to the environment occurs when fertilizers are applied before planting. Split nitrogen applications also ensure efficient fertilizer use and reduce nutrient losses.
6. Application method – of the many methods available to producers, McRae *et al.,* (2000) indicate that injecting and banding are the most environmentally sustainable fertilizer application methods, with injecting being the preferred application method with respect to environmental sustainability. On the other hand, broadcasting is identified as the least environmentally sustainable.
7. Variable-rate (VR) fertilization – part of a site-specific or precision farming system. Fertilizer rates are automatically controlled by an on board computer with an electronic prescription map and relies on global positioning system (GPS) technology to help guide applications of fertilizers (AAFRDa; Goddard, 1997).
8. Enhanced efficiency fertilizers include fertilizers with inhibitors or controlled release fertilizers that reduce nutrient losses and improve nutrient efficiency (CFI, 2005).
9. Vegetated buffers strips – "areas of land, adjacent to a water course or water body, kept in permanent vegetation. Vegetated buffers strips protect water quality by slowing the flow of water, thus facilitating the trapping of sediment, organic matter, nutrients and pesticides" (AAFRDb).
10. Cover crops – "grown to protect the soil when a crop is not normally growing. They help maintain soil structure, add organic matter, tie up excess nutrients and control pests" (Lane, 1997).
11. Crop rotation – "as a BMP, crop rotation involves alternating forage or cereal crops with row crops such as corn or potatoes. The forage and cereal crops have root systems that improve the soil structure and add organic matter to the soil. Some also over winter and protect the soil from erosion" (Lane, 1997).
12. Reduced tillage practices
    a. Minimum/Conservation tillage – "reduces the number of tillage passes, works the land across the slope and leaves crop residues on the soil surface to control erosion" (Gasser *et al.,* 1993).

b. No-till/Zero-till – "the practice of planting/seeding crops with no primary or secondary tillage separate from planting/seeding operations" (Lane, 1997).

13. Fertilizer storage – "as a BMP, it involves storing only the amount of fertilizer needed for immediate use. This reduces the risk of a major spill or other accident. Stored fertilizer should be secured in a strong, stable, dry structure with a good roof and a cement floor, where moisture, rain and surface water cannot enter" (AAFRDc).

Additional practices advocated by the Crop Nutrients Council and the Canadian Fertilizer Institute include ensuring that application equipment is maintained and calibrated properly, crop scouting for visual symptoms of nutrient deficiencies, keeping records of nutrients applied to and available in fields, and mapping and managing soil variability within fields (CFI, 2005).

Beneficial management practices are also promoted under the concept of "right rate, right time and right place (Bruulsema, 2004)." "Right rate" deals with choosing appropriate nutrient application rates. The principle of "right time" suggests that when nutrients are applied should be considered to make nutrients available according to crop needs and minimize losses to the environment. Lastly, the notion of 'right place' implies that nutrients be applied where they are needed and where crops are able to use them. The identified crop nutrient BMPs according to the concept of "right rate, right time and right place" are listed in Table 3. The table also identifies the resource protected when these BMPs are used.

Table 3 Resources Protected Through BMP Adoption

BMPs according to Performance Area	Resource Protected			
	Air	Water	Soil	Habitat
Right Rate: Match Supply and Demand for Crop Nutrients				
Application calibration & upkeep	x	x	X	x
Crop removal balance	x	x	X	x
Crop scouting/ assessment			X	
Nutrient management plans	x	x	X	x
Plant tissue analysis			X	
Record keeping			X	
Soil testing	x	x	X	x
Variable rate fertilization	x	x	X	x
Yield goal analysis			X	
Right Time: On Time Delivery of Crop Nutrients				
Application timing	x	x	X	x
Enhanced efficiency fertilizers	x	x		x
Inhibitors	x	x		x
Right Place: Appropriate Nutrient Placement				
Application method	x	x	X	x
Buffer strips		x		x
Reduced tillage	x	x	X	x
Cover cropping		x	X	x
Incorporation of fertilizer	x	x		x
On-farm fertilizer storage	x	x		

(CFI, 2005)

2.3 ECONOMIC COSTS AND BENEFITS

The purpose of this section is to review economic and environmental studies that have evaluated costs and benefits of BMPs both from a private (i.e., individual farm) and public (i.e., societal) perspective.

2.3.1 Nutrient Management Planning

A nutrient management plan (NMP) is a strategy to manage the amount, placement, timing, and application of nutrients (commercial fertilizer, manure, biosolids, etc.) for maximum economic benefit and minimum environmental risk. Nutrient management requires planning and recognizes that every farm has its own set of circumstances that affect efficiency of nutrient use. A NMP is tailored to the farming operation and the needs of the person implementing the plan (Brethour *et al.,* 2007).

Pease *et al.* (1998) investigated the effects of NMP and the associated practices (e.g., proper timing of application, improved manure storage, etc.) on farm profit and farm-level nitrogen losses for four Virginia livestock farms (a southwest dairy, a Shenandoah Valley dairy, a southeast crop/swine farm, and a Piedmont poultry farm). The results of the research indicated that positive changes in annualized net returns attributable to the farm's NMP included US$395, US$4,593, US$3,014 and US$2,297 for each of the four farms, respectively. The increases in income were primarily a result of reductions in commercial fertilizer purchases. The exception was the Piedmont poultry farm, where increased income was a result of additional sales of poultry litter due to decreased litter application rates (Pease *et al.,* 1998). NMP is a cost-effective process to reduce nitrogen losses on livestock farms. Adoption of nutrient management practices resulted in significant reductions in potential nutrient losses on the four farms examined in the research. Average annual nitrogen losses decreased by 23-45%, while phosphorus losses decreased by 0-66% (Pease, 1998).

Brethour *et al.* (2007) used a national survey of producers to estimate the economic costs and benefits of participation in BMPs. Farm profitability or net farm income, as indicated by expected net revenue (ENR), was simulated with and without implementation of the BMP on a per-acre and whole farm basis using representative farm models.[4] The BMPs selected for evaluation included soil testing, variable rate fertilization, buffer strips, no-till, minimum till and nutrient management planning. Table 4 shows the results by province and soil zone of the national survey and farm models related to the adoption of a NMP. Overall, the survey respondents indicated that NMP increased yields, creating an increase in ENR which outweighed additional operating costs and the costs to develop a NMP. As such, a positive change in ENR was experienced in all soil zones and provinces on the model farms given the adoption of a NMP (as shown in the last column of Table 4). Brethour *et al.* (2007) concluded that, based on producer perceptions and the assumptions used in the analysis, the results of the study indicated that nutrient management planning improved profitability for the representative farms.

[4] Representative farm models were developed based on provincial enterprise budgets and specific crop rotations.

Table 4 Change in Expected Net Revenue with the Adoption of a Nutrient Management Plan

	Range of Increase in Yields*	Change in Operating Costs	Cost to Develop a NMP[5]	% Change in ENR due to NMP[6]
	(bu/acre)	($/BMP acre)	($/BMP acre)	
Alberta – Black Soil Zone	3.8-7.7	6.5	0.7	78%
Alberta – Brown Soil Zone	3.9-5.9	2.6	0.7	33%
Sask – Black Soil Zone	3.8-6.7	4.8	0.7	38%
Sask – Brown Soil Zone	4.3-7.4	11.5	0.7	30%
Manitoba	3.8-5.1	4.3	0.6	20%
Ontario	1.4-3.0	-3.6	1.1	41%
Quebec	1.2-2.0	-4.9	1.3	13%

* Depending on the crops in rotation

(Brethour *et al.*, 2007)

2.3.2 Willingness to Pay for Reductions in Chemical Contamination

Crutchfield *et al.* (1995) compiled a list of contingent valuation studies that quantified willingness to pay for the protection of groundwater from chemical contamination, for example, protection from nitrates, pesticides, etc. These values ranged from US$40 per household per year to over US$1,000 per household per year (Crutchfield *et al.,* 1995).

As well, Crutchfield *et al.*(1995) used benefit transfer to estimate the benefits of protecting rural drinking water from agricultural chemical residual contamination in four geographical areas (policy sites): Central Nebraska, the White River Basin in Indiana, the Mid-Columbia Basin in the Pacific Northwest and the Lower Susquehanna Basin in Pennsylvania and Maryland. The research question was: "What is the extent of the possible willingness to pay to prevent groundwater contamination from farm chemicals in these regions?" (Crutchfield *et al*., 1995).

Of the eight studies Crutchfield *et al.*(1995) identified as possible benefit transfer data sources, the authors chose the three most easily applicable to their research: Shultz and Lindsay (1990); Jordan and Elnagheeb (1992); and Sun *et al.* (1992). Crutchfield *et al.* (1995) then conducted a direct benefits transfer, applying variables derived from policy site data to the original equations of the three studies selected.

Crutchfield *et al.* (1995) found that the willingness to pay (for all three sites) for the protection of groundwater from chemical contamination ranged from US$197 million per year to US$730 million per year. Household willingness to pay values were found to be US$128 per household per year, using the Shultz and Lindsay equation, US$233 per household per year, using the Jordan and Elnagheeb equation, and US$639 per household per year, using the Sun *et al.* equation.

[5]Note that cost of nutrient management plan (NMP) was annualized over 5 years.
[6]Note that the table and% change in ENR do not take into account available financial assistance. For information on the results of the research with financial assistance, refer to Brethour *et al*., 2007.

2.3.3 Costs and Benefits of Agricultural Water Quality Improvement Programs

The purpose of this section is to review the administration costs associated with cost-share programs that provide funding for BMPs in Ontario. These administration costs are deemed relevant because society's tax dollars pay for the programs. To aid in the identification of administration costs associated with BMPs, the following section also reviewed the costs and benefits of BMP programs in the United States.

According to Lynch and Tjaden (2000), based on a USDA study, the Conservation Reserve Program (CRP), that included the retirement of 40 to 50 million acres of cropland, had $3.5 to $4.5 billion per year of water quality benefits. These benefits included reduced erosion, increased recreational fishing, and improvements in ease of navigation, water storage and treatment, and flood control. The Conservation Reserve Program cost $1 billion per year, and therefore, had a net benefit of $2.5 to $3.5 billion annually (Lynch, 2000).

In terms of nutrient removal costs, Lynch and Tjaden (2000) also referenced the Chesapeake Bay's Riparian Forest Buffer Panel Technical Team who estimated that riparian forest buffers have the ability to remove 21 pounds of nitrogen per acre at US$0.30 per pound per year and about 4 pounds of phosphorous per acre at US$1.65 per pound per year. Lynch and Tjaden (2000) also reported, based on the Interstate Commission for the Potomac River Basin, that BMPs removed 20% of nutrient runoff at a cost of US$200 per acre, for a total of US$643,172,600 for the Bay basin. They stated that the reduction of runoff from highly erodible agricultural land was US$130 per acre.

The panel estimated, according to Lynch and Tjaden (2000), that, at the time of the nutrient runoff reduction proposal, "establishing forest buffers in Maryland could cost US$617,000 per year in order to achieve the 40% reduction of nutrients by the year 2000; comparable structural engineered approaches cost US$3.7 million per year." It is unclear whether these costs would accrue to the individual landowners or would be footed by the public via program funding.

Yadav and Wall (1998) studied the potential benefits of reducing groundwater nitrate concentrations and took their analysis further by asking the question: *"Does it pay for society to reduce groundwater nitrate concentrations by investing in programs that result in increased adoption of BMPs?"* Yadav and Wall (1998) used the Garvin Brook watershed in Minnesota as their test site. There were serious concerns regarding Garvin Brook and nitrate contamination of groundwater and this watershed was part of the Rural Clean Water Program[7] (RCWP). The analysis estimated that a BMP package capable of reducing nitrogen loading throughout the entire project would cost US$842,000. The benefit of a fertilizer management BMP was estimated to be about US$102,600 per year for the entire project area.

Overall, the analysis found that, under the current level of contamination, it would have taken about six years for the avoidance cost to equal the BMP program cost. However, if it is assumed that nitrate conditions worsen without the implementation of BMPs, the

[7]The RCWP provides financial and technical assistance to landowners and operators who own agricultural lands designated as critical areas or sources of nonpoint source pollution. The RCWP paid up to 75% of the cost to implement BMPs with a $50,000 maximum cost share allowed per landowner.

implementation costs of BMPs could be expected to equal avoidance costs (plus the benefits from fertilizer BMPs) in a 4-5 year period, which is shorter than the expected life of a BMP. This study concluded that it was more cost-effective in the long-run for society to invest in a BMP program to reduce nitrate in groundwater than to continually seek alternative sources of safe water supplies.

One study that is relevant due to its agricultural focus was conducted by Hite *et al.* in 2002. The study used contingent valuation methodology to assess public willingness to pay for reductions in agricultural non-point source pollution that would allow the water to meet quality standards in Mississippi. In particular, a survey was conducted to measure willingness to subsidize the adoption of variable rate technology to mitigate agricultural pollution. Variable rate technology matches nutrient and chemical application to local crop needs in order to reduce runoff and non-point pollution. The cost to implement the subsidization program ranged from US$59 million to US$119 million, depending on the price of the technology. Research findings suggested that public support existed for the promotion of variable rate technology. Of the 828 total respondents, 62.4% voted in favour of the program to promote the technology while 24.3% voted against the program. As such, estimated tax revenues for the program ranged from US$52 million to US$122 million. Tax revenues would, therefore, be sufficient to cover a substantial portion of the program's cost (Hite *et al*., 2002).

2.4 LINKS BETWEEN SOURCE WATER PROTECTION BMPS, ECOSYSTEM SERVICES AND THE IMPLICATIONS FOR HUMAN HEALTH

Boyd and Banzhaf (2006), in their inventory of ecological services, define ecosystem services as end-products of nature and natural resources that can be used to produce well-being. They define well-being as "aesthetic enjoyment, various forms of recreation, maintenance of human health, physical damage avoidance, and subsistence or foraged consumption of food and fiber." In their ecosystem service inventory, they include the provision of drinking water, stating that "for drinking water, water of a particular quality is a service directly relevant to a consumption decision." They also characterize wetlands as ecosystem services, in their ability to provide flood damage avoidance (Boyd and Banzhaf, 2006).

Surface water, near surface water and groundwater, which are all considered to be source water for downstream uses, can be affected by agricultural land management practices. Linking landscape land use with downstream activities is an important component in the overall assessment of ecosystem health and ecosystem services. The bases for improvements in ecosystem health and the supply of ecosystem services need to be identified and verified. Finding the appropriate indicators to make this linkage was the focus of a study conducted by Meador and Goldstein (2003). They found that when assessing the health of downstream fish communities, the most appropriate indicator was water physico-chemistry and riparian condition rather than land use itself (i.e., rangeland, agriculture, forest, urban). The presence of degraded fish communities is linked most readily to the presence of increased nutrients, suspended sediment and total solids (Meador, 2003). These are common pollutants attributed to drainage water from agricultural watersheds (Rudy, 2004).

Many source water protection BMPs, such as wetland enhancement, grazing management, alternative watering systems, nutrient management, improved storage of agricultural products (e.g., pesticides, fuel, fertilizer), and farmyard runoff control may result in a reduction in the amount of fertilizer, a common agricultural pollutant, leaching into waterways. The reduction in fertilizer contamination may produce healthier watersheds, which, in turn, can provide cleaner drinking water. High quality groundwater, which is a component of healthy watershed, can be classified, according to Boyd and Banzhaf (2006), as an ecosystem service. Several studies have examined health benefits associated with drinking water quality.

Krantzberg and de Boer (2006), in a study of the economic values of the Great Lakes, quantified social/lifetime health costs due to water quality problems in the Great Lakes. They found reduced productivity and increased social costs due to mercury exposure to children in the womb to be $93 to $250 million in Ontario. They found increased mortality rates due to pollution carried in the Great Lakes region, measured using death rates and increased sickness and hospital days, to be more than $5 million in Ontario (Krantzberg, 2006).

Krantzberg and de Boer (2006) also identified the value of wetlands and biodiversity attributes of the Great Lakes, including the health benefits that humans derive from air and water filtration, biotic enjoyment and useful medicines. They quantified this value at $70 billion. However, the value encompasses all wetland and biodiversity benefits from the Great Lakes, including wildlife habitat benefits and wildlife viewing benefits.

Hanley (1991) conducted a study on willingness to pay to reduce nitrates in drinking water supply, as excess nitrate levels have been associated with human health problems as well as having an adverse impact on aquatic life. Hanley (1991) used contingent valuation (open ended) as the valuation method. The study area was Anglia water supply region in Eastern England, which had a population of approximately 835,000 households. A sample of 400 households in the area were sent a survey by mail and asked to report their maximum willingness to pay to ensure that nitrate levels in their drinking water remained within European Union and World Health Organization guidelines. The guidelines specify an upper limit of 50 mg/L. Hanley (1991) reported that 35% of the households returned the survey. Hanley (1991) estimated the mean willingness-to-pay to be ₤12.97 per household/year. Hanley (1991) also aggregated the result to the study population and estimated benefits to be ₤10,832,707 per year (Hanley, 1991).

Giraldez and Fox (1995) conducted a study on costs and benefits of groundwater contamination caused by agricultural nitrate emissions in the village of Hensall, Ontario. The focus of the study was to investigate the value of a reduction in nitrogen contamination, so that the levels did not exceed 10 mg/L, the Ontario Drinking Water Standard (ODWS) for nitrogen. The village of Hensall has had nitrate levels higher than 10 mg/L. Giraldez and Fox (1995) considered three approaches to estimation of the cost of human health risks from exposure to nitrate in drinking water. The first approach used the value of a human life as the present value of lifetime average earnings. The second approach used income differentials among occupations considered to involve different levels of mortality risk. The wage premium observed for more risky occupations was used to calculate the value that workers placed on incremental changes in mortality risk. This wage premium was extrapolated to an estimate of the value of life. It derived values from actual rather than proposed expected behaviour and was therefore a market based approach. The third approach was contingent valuation. Giraldez and Fox (1995) also used other studies to derive the actual value of health costs of groundwater contamination in the village of Hensall (Giraldez, 1995).

Giraldez and Fox (1995) estimated that costs of nitrate contamination of groundwater obtained using the lifetime earnings approach ranged from $693 to $6,289 per year. Using the wage risk studies, Giraldez and Fox (1995) estimated the health costs of nitrate water pollution above 10 mg/L in the Village of Hensall to be $11,360 per year. Giraldez and Fox (1995) used Hanley's (1991) value of 12.97 pounds (C$25.92) per person per year. For the 1,155 individuals in the Village of Hensall, that would approximate C$29,938 per year. The authors concluded that the value of a reduction in nitrate concentrations to meet provincial drinking water standards would amount to $2,508 to $11,380 per year in the Hensall situation.

Sun, Bergstrom and Dorfman (1992) estimated the benefits of groundwater contamination control using a willingness-to-pay measure. The study area was Dougherty Country in Southwest Georgia, United States. The authors conducted a survey to question respondents about their willingness to pay to support a program that would keep pollution of groundwater by agricultural pesticides and fertilizers below the Environmental Protection Agency's health advisory levels for drinking and cooking. A formal survey was conducted during October and November, 1989. Out of 1440 randomly selected households, the authors were able to obtain 603 valid responses. The valuation techniques used by the authors were dichotomous choice contingent valuation and open ended contingent valuation. The results of the survey estimated a mean willingness to pay for groundwater pollution program to be US$641 (1989 dollars) with 95% confidence interval of US$493 to US$890 (1989 dollars) (Sun, 1992).

Hurley *et al*. (1999) examined the willingness to pay of rural Iowa residents to delay nitrate contamination in their water supply. The research involved a contingent valuation survey conducted in two small watersheds in predominantly agricultural areas of southern Iowa. Both areas were concerned with agricultural pollutants. Respondents were asked their reaction to the potential siting of a large-scale hog facility in their area, and a series of three questions designed to determine their willingness to pay (WTP) to delay nitrate contamination in their water. The estimated annual mean WTP was US$50, US$64, and US$82 for delays of 10, 15, and 20 years respectively. The WTP estimates were aggregated to the county level to estimate the total value that residents were willing to pay for water quality protection. Adams County, with an adult population of 3,677 in 1990, could expect revenue amounts of US$186,461 to US$301,073 per year. Clarke County, with 6,119 adults, could expect revenues of US$310,294 to US$501,024 per year (Hurley, 1999).

Collins and Steinback (1993) used averting expenditures to estimate willingness to pay of rural households in West Virginia, United States for an improvement in water quality from a level that does not meet state water quality guidelines to a level meeting state guidelines. Collins and Steinback (1993) considered the following pollutants: bacteria, minerals, organic chemicals and associated odour. The authors conducted a mail survey of 878 households with water contamination in the fall of 1990. The response rate was 43% (Collins and Steinback, 1993).

Collins and Steinback (1993) calculated rural household willingness to pay for reduced water contamination by multiplying the percentage of actions in each averting expenditure category (boiling water, delivered bottled water, hauling water, installing a treatment system, purchasing bottled water, correcting the source of the contamination, establishing a new water source, and cleaning or repairing the water system) by the average annual cost of each type of action. In addition, the authors calculated the average annualized costs for water treatment systems that were effective in meeting state water quality standards. Annual household willingness to pay for a reduction in water contamination ranged from US$309 to US$1,090, depending on the contaminant and the averting behaviour. Table 5 specifies the annual costs incurred by households in averting water contamination in 1990 US dollars and Table 6 specifies annual household willingness to pay for a reduction in water contamination in 1990 US dollars.

Table 5 Annual Costs Incurred by Households Averting Water Contamination (1990 US Dollars*)

	All Contaminants	Bacteria	Minerals	Organic
All Household Actions	$433	$384	$437	$992
Boiling	$573	$550	$562	$1,128
Delivered Bottled Water	$560	$400	$880	N/A
Hauling of Water	$529	$507	$607	$470
Install Treatment System	$307	$238	$315	$640
Purchase Bottled Water	$223	$220	$186	$329
Corrected Source of Contamination	$185	$276	$3	N/A
New Water Source	$153	$166	$133	$156
Clean/Repair Water System	$28	$29	$14	$7

Notes: *Values are assumed to be 1990 dollars since the survey was administered in 1990.

(Environment Valuation Reference Inventory. EVRI Number: 97357-13364. Originally cited in Collins and Steinback (1993))

Table 6 Annual Household Willingness to Pay (WTP) for a Reduction in Water Contamination (1990 US Dollars*)

	Bacteria	Minerals	Organic	Odor
Household Labor**	$165	$106	$459	--
Monetary	$155	$251	$631	--
Total (Household Labor plus Monetary)	$320	$357	$1,090	--
Effective Water Treatment	$309	$340	--	$203

Notes:
*Values are assumed to be 1990 dollars since the survey was administered in 1990.
**Household labor costs were calculated using survey responses on the duration and frequency of each averting behavior, valuing adult labor at the after-tax wage rate computed from the survey questions on household income, and valuing child labor at the after-tax minimum wage.

(Environment Valuation Reference Inventory. EVRI Number: 97357-13364. Originally cited in Collins and Steinback (1993))

A similar study was previously conducted in the municipality of Strathroy-Caradoc (Brethour *et al*, 2009). The purpose of this study was to understand the costs and benefits of using beneficial management practices in source water protection and to compare these with an alternative means of providing safe drinking water. In this case, an actual case study was considered, where a pipeline from Lake Huron was built to alleviate high nitrate levels in municipal drinking water. It was a retrospective analysis in which the realized costs of the pipeline were compared against the latent costs of the BMPs, had they been implemented well in advance of the pipeline.

This study was significant and largely unique in its linking of existing crop-nitrogen management practices, nitrogen-water modeling of alternative BMPs, and economic analysis of the BMP and existing drinking water management. The results of this analysis suggested that BMPs can be an effective and low-cost means of protecting groundwater and drinking water in regions that anticipate nitrogen contamination problems, provided they are implemented with adequate lead time.

The Base Case best represented actual field conditions from 1994 to 2007. The Rate Case represented a change in the rate of nitrogen applied to the corn crop by producers, which required no additional investment in equipment or change to their preferred crop rotation. The Rotation Case required producers to invest moderately in additional equipment and change their preferred crop rotation. However, farm practices were still considered to be within a ‘normal practice’ framework for Ontario agriculture. The relative estimate of mean annual nitrogen load decreased as the intensity of nitrogen management using BMPs increased. BMPs were effective in reducing nitrogen load in groundwater by 34 to 44% in the Rate Case and by 45 to 55% in the Rotation Case. These relative estimates of nitrogen load reductions at the farm field level translated into relative estimates of total nitrate reductions at the well field level of 24 to 36% in the Rate Case and 30 to 48% in the Rotation Case.

The results of the economic analysis showed that the two BMP alternatives resulted in nominal costs compared with existing cropping practices that were identified from producer consultations. Had either of these BMP alternatives been implemented with sufficient lead time, in effect they would have constituted a lower cost solution to the nitrogen management situation in the town’s drinking water compared with the pipeline scenario.

While the Rotation Case decreased nitrate concentration and nitrate loads to a greater extent than the Rate Case, the cost of implementing the Rate Case was the lower of the two options. Since either approach would have satisfied nitrogen standards in drinking water, it was concluded that the Rate Case was preferred to the Rotation case, based on economics. The implementation of the BMPs in lieu of the pipeline would have marginally increased the net benefits of securing the nitrogen status of drinking water from the study wells, compared with the pipeline. The measured net benefits of the well upgrades relative to the pipeline were very similar in magnitude, and somewhat sensitive to the discount rate applied. It was also noted that the nitrogen contamination was not the only issue of consideration in the decision to access water via the pipeline. In particular, there were issues related to iron and manganese in the well field that resulted in an exceptionally high maintenance well system that needed extensive treatment. Without the costs of eliminating manganese and iron, both BMP solutions would have provided an even lower cost solution to the pipeline implementation.

2.5 SUMMARY OF THE ECONOMIC AND ENVIRONMENTAL LITERATURE

Many source water protection BMPs, such as conservation tillage, nutrient management, improved storage of agricultural products (e.g., pesticides, fuel, fertilizer), buffers, wetland enhancement, grazing management, alternative watering systems, and farmyard runoff control may result in a reduction in the amount of agricultural pollutants leaching into both surface water and groundwater. The reduction in agricultural contaminants may produce healthier watersheds, which, in turn, can provide cleaner drinking water. High quality groundwater, which is a component of a healthy watershed, is classified, according to Boyd and Banzhaf (2006), as an ecosystem service.

The literature illustrated there are both costs and benefits to establishing and maintaining BMPs at the farm level for the protection of surface water and groundwater. In addition to these costs and benefits, the literature also illustrated there are costs and benefits to society from these associated practices. Although the literature did not evaluate the societal benefits of specific BMP practices, it illustrated the value of a more general result that could be derived from BMPs, for example, a reduction in chemical or nutrient contamination or improvements from wetland enhancement or restoration.

Understanding the public and private value of ecosystem services such as those provided by agricultural BMPs is necessary to understand the true value of on-farm environmental improvements for source water protection.

3 STUDY AREA

3.1 SELECTION OF THE STUDY AREA

A study area within the Waterloo Region was one of several identified during initial discussions in the selection process conducted in an earlier, complementary study (Brethour *et al.*, 2009). Details of the selection process are provided in the final report entitled *Cost Benefit Analysis of Source Water Protection Beneficial Management Practices Final Report - AESI 156* (Brethour *et al.*, 2009), which includes the results of the complementary case study of a well field located near Strathroy, Ontario.

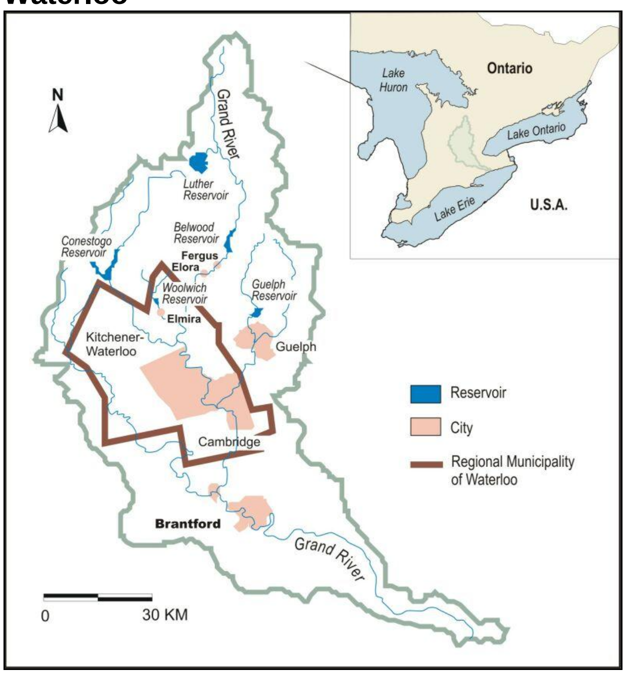
Discussions with the Region resulted in the identification of a production well where an economic analysis of alternative BMP scenarios would help to guide the Region in its efforts to prioritize and budget for agricultural BMPs that could be used to improve water quality at the production well.

3.2 DESCRIPTION OF THE STUDY AREA

3.2.1 Region of Waterloo

The Region of Waterloo is located in southern Ontario in the centre of the triangle formed by three Great Lakes (Ontario, Erie and Huron) (Figure 2). The Region includes three urban municipalities (Cambridge, Kitchener and Waterloo) and four rural townships (North Dumfries, Wellesley, Wilmot and Woolwich). The Region has a population of over 450,000 people and is one of the fastest growing areas in Ontario (Region of Waterloo, 2007).

Figure 2 Region of Waterloo



(Retrieved from: http://www.uoguelph.ca/gwmg/wcp_home/Maps/G_mapc.jpg)

The geology and hydrogeology of the Region has been studied extensively. Various reports are available for viewing in the Water Services Department, Region of Waterloo Administration Building, Kitchener, ON.

The Wisconsinan Glacial Episode was the last glacial event to alter the Region. The intersection of glacial lobes left terminal moraine behind, the largest of which is known today as the Waterloo Moraine (Figure 3). The Waterloo Moraine covers approximately 400 km^2 and consists of glacio-fluvial deposited sands and gravels with interfingering till units (Radcliffe, 2000).

A cross-section of the Waterloo Moraine shows the complex distribution of sand and gravel deposits (aquifers) which store groundwater. The groundwater in the aquifers is accessed by the Region through a well system and used to supply drinking water to local residents (Figure 4).

Figure 3 The Waterloo Moraine

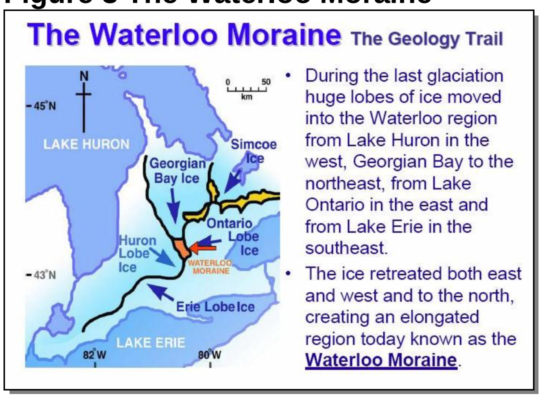
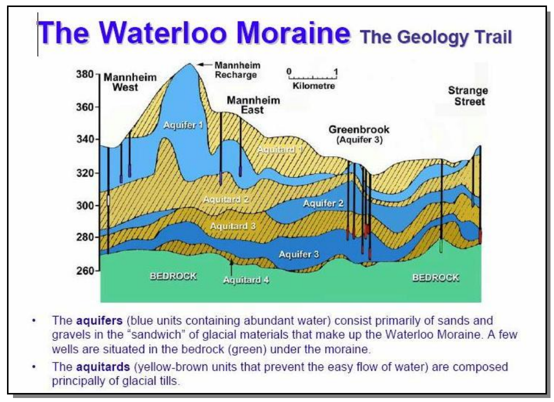


Figure 4 Cross-section of the Waterloo Moraine



(Morgan, 2008)

The Region draws 20% of its water supply from the Grand River and 80% from groundwater resources (Region of Waterloo, 2007). A network of over 100 supply wells pump water from subsurface aquifers.[8] These aquifers also supply most rural residents with their water. Constraints on the ability to supply water from these wells include water quantity and quality issues within well fields; declining efficiencies of wells; and operational constraints. Implementation of a comprehensive strategy to protect the Region's local groundwater resources has been ongoing since 1992.

The study area is located near the City of Kitchener. Identification of the specific location of the capture zone of the production well in this study is not necessary for the purpose of this study. If details regarding the specific location are required the reader is advised to contact Water Services, Region of Waterloo.

[8]Geologic units where water is stored between sand or gravel grains or between rock fractures.

3.2.1 Agricultural Land Uses

The study area consists mainly of Waterloo fine sandy loam (Wa) and Brant loam (Ba) soil types. Also, Bennington loam (Bn), Fox sandy loam (Fo), Berrien sandy loam (Be), Bookton sandy loam (Bo), Wauseon sandy loam (Wu), Lisbon sandy loam (Li), Brady sandy loam (By) soil types are found in the area. Slopes range from level (A) to nearly level (B) to very gently sloping (C) (Ecologistics Limited, 1996).

Agricultural croplands where all or part of a field is inside the 100-yr surface to well advective travel time (SWAT)[9] of the capture zone of the production well and where detailed N management information was available, were grouped as follows for the purpose of this study: A1-A5 (35.4 ha), B1-B7 (32.0 ha), B9-B12 (21.0 ha), B8&B13 (9.7 ha), C1-C4 (74.5 ha), D1-D3 (46.3 ha), and E1-E2 (46.4 ha). Sub groups of fields were identified (e.g., A5 (0.52 ha adjacent to wellhead), B8&B13 (9.7 ha predominately alfalfa/pasture), B9/B10/B12 (14.0 ha representative of a livestock-based rotation)) when warranted. The total field area was 265 ha, which represented 44% of all agricultural land within the 738 ha bounded by the 100-yr SWAT capture zone of the production well.

General information is available from the literature and personal communications regarding crop types and acreage (not shown here), crop rotation and fertilizer application rates. The lands within the 100-yr SWAT of the capture zone of the production well (738 ha) are mainly agricultural (i.e., approximately 70%) and typically used to grow corn, soybeans, forage and cereal grains (winter wheat, barley, oats) (OMAFRA, 2007). Typical crop yields in Waterloo County from 1971 to 2007 ranged from: 3.7-8.7 t/ha (59-139 bu/ac) for corn; 1.1-3.0 t/ha (17-44 bu/ac) for soybeans; 2.6-5.6 t/ha (39-83 bu/ac) for winter wheat; 2.3-4.5 t/ha (43-83 bu/ac) for barley and 5.7-12.0 t/ha (2.1-4.4 tons/ac) for hay (OMAFRA, 2007).

A review of available information and discussions with industry specialists yielded information on typical rates of nitrogen applied to different crops grown in Ontario and the Region (Table 7).

Table 7 Suggested Rate of Fertilizer Nitrogen in Ontario

Crop	Source of Information and suggested rate of fertilizer nitrogen			
	Ipsos Reid/CFI Jan 2007 Survey (ON)	IPNI by Tom Bruulsema (ON)*	OMAFRA by Keith Reid (Waterloo Region**)	OMAFRA Recommendations***
	kg/ha (lbs/ac)	kg/ha	kg/ha	kg/ha
Grain Corn		97	125	
Soybeans	123 (110)	15		0

9 Surface to Well Advection Time (SWAT): The average time required by a water particle to travel from a point at the ground surface to the well, including both vertical and horizontal movement. Retrieved from: http://www.sourcewaterinfo.on.ca/content/spProject/glossary.php

Crop	Source of Information and suggested rate of fertilizer nitrogen			
	Ipsos Reid/CFI Jan 2007 Survey (ON)	IPNI by Tom Bruulsema (ON)*	OMAFRA by Keith Reid (Waterloo Region**)	OMAFRA Recommendations***
	kg/ha (lbs/ac)	kg/ha	kg/ha	kg/ha
Winter Wheat	158 (141)	80		90
Barley		41		70
Hay	77 (69)	12		15

* Estimated average application rates of fertilizer nitrogen (N) to Ontario crops, based on surveys of producers, crop advisers, and experts, and adjusting to match total provincial fertilizer sales data for 2002

** Waterloo Region ≤ 2800 crop heat units (CHU)

*** Retrieved from: http://www.omafra.gov.on.ca/english/crops/facts/fert-rec-tables-3.htm

A discussion with C. Brown, Nutrient Management Field Crops Program Lead, Ontario Ministry Agriculture, Food and Rural Affairs provided several insights into agriculture in the Region. For example, rotations differ depending on whether the crops are used for livestock or cash crop production. Current cash crop production includes a corn/soybean/wheat rotation generally in a three year rotation. Depending on commodity prices the ratio may change, for example, there has been an increase in wheat production in recent years. Since the 1970s, soybean and wheat production have increased at the expense of oat, barley and forage production, which were used for livestock. Soybean production increased in the 1980s due to increases in the number of varieties available in a range of crop heat units (Brown, pers. comm., 2008).

The number of livestock farms in the Region has declined since the 1970s; however, those that remain are larger. Livestock rotations for hog production include corn/soybean/wheat with emphasis on corn. Crop rotations for dairy production tend to include 3 yr alfalfa/ 2 yr corn/ 1 yr soybean. Dairy farms tend to have 30-50% of acreage in forages. Corn could be either silage corn then grain corn or corn/soybean then spring grains (barley or oats) underseeded with alfalfa. If soybeans are in the rotation the field would probably be planted back to alfalfa (Brown, pers. comm., 2008).

In the Region there is a significant Mennonite population, which varies from the very traditional to the more progressive. These producers have increased the amount of soybeans in their rotations; however, the livestock base often has not changed very much (Brown, pers. comm., 2008).

3.2.2 Non Agricultural Land Uses

Land classifications within the 100-yr SWAT capture zone of the production well included agricultural (approximately 70%), natural (13%), quarry/pit (7%) and other, including residential property, (9%) lands. Examination of aerial photography of the study area showed one large woodlot (>50 ac) and two small woodlots, along with approximately 10 farmsteads or single dwellings within the 10-yr SWAT. Enquiries indicated the large woodlot was mainly deciduous trees.

3.2.3 Analyte of Concern: Nitrogen as Nitrate (NO_3^-)

In 2007, nitrate concentrations in groundwater at the production well ranged from 6.4 to 8.5 mg/L (n=52) (Region of Waterloo, 2008), which approaches but still meets the Ontario Drinking Water Standard (ODWS) of 10 mg/L (Ontario Ministry of the Environment, 2001). When the production well was established in 1969, nitrate concentrations in groundwater were approximately 2.5 mg/L. However, over the past several decades, water obtained from the well has contained increasing concentrations of nitrate, which is an environmental and human health concern.

4 ESTIMATES OF THE EFFECTIVENESS OF NITROGEN BENEFICIAL MANAGEMENT PRACTICES

4.1 OVERVIEW OF PREREQUISITE STEPS TO THE ECONOMIC ANALYSIS

Development of a representative economic analysis of existing SWP BMP for managing nitrogen in an agricultural landscape relied on the following prerequisite steps:

1. Determination of historical and existing agricultural management practices representative of the Base case within the capture zone;
2. Determination of appropriate nitrogen BMP scenarios;
3. An environmental analysis involving development of representative estimates of the effectiveness of BMPs in managing nitrogen within agricultural landscapes using nitrogen (N) budgets to estimate long-term potentially leachable nitrogen (N_{pl}), i.e., nitrogen below the plant root zone that could escape into groundwater; and
4. The results from the nitrogen mass balance model (MBM) used to estimate the change in nitrogen concentrations in groundwater obtained at the production well.

4.2 METHODS

4.2.1 <u>Development of Base Case and BMP Scenarios</u>

4.2.1.1 Importance and Scope of Producer Knowledge

Producer knowledge about crop production and nitrogen (N) management practices within the capture zone was very important because it increased the accuracy and relevancy of the N budgets used to represent the Base case in the capture zone. Producers within the 10-yr SWAT for the production well were asked if they were interested in providing information regarding their agricultural practices. Between the fall of 2008 and spring of 2009 interested producers were interviewed by an agronomist to gather current and historical data. The amount of detail obtained was dependent on the producer's recollection and the availability of records. For some fields detailed records were provided whereas for other fields verbal estimates of current and historical practices were provided. With all producers interviewed, the further back in time the more general the recount of agricultural practices. The information received from the producers generally included details related to crop rotations and yields; manure type, rate, timing and method of application; nitrogen fertilizer type, rate, timing and method of application; and tillage practices.

4.2.1.2 Development of the Base Case and BMP Scenarios

The information obtained from the producers and other relevant data sources provided the developmental basis for the Base case within the capture zone i.e., the specific nature of agricultural production in the study area, including which N BMPs were in use or not in use within the capture zone from 1960-2008. Five BMP scenarios were developed based on the details identified in the Base case, applicable N BMPs, and the range of types and levels of external influence that could be implemented within the capture zone. The comparison of the N BMP scenarios with the Base case was based on knowledge of historical field conditions, since there was more certainty related to what had occurred in the past than related to what might occur in the future. The N BMP scenarios assumed implementation occurred in 1980 because, prior to this time, producer estimates of agricultural practices were less accurate and, in general, there was less awareness of the environmental impacts of nutrients, including nitrogen, from agricultural sources.

The range of nutrient BMPs considered during the development of the N BMP scenarios is listed in Table 8. The basic description of each N BMP scenario is provided in Table 9; however, more detailed descriptions are provided in the economic section of this report and in a related study by Stantec for the Region.

4.2.2 Estimation of Long-Term Potentially Leachable Nitrogen in the Capture Zone

4.2.2.1 Leachable Nitrogen and Nitrogen Budgets

While land use is of primary significance in determining the amount of N_{pl}, the amount of N that actually reaches groundwater is heavily influenced by several factors including: soil texture; depth to groundwater level; presence of natural or no till-related macropores; use of subsurface tile drainage; seasonal soil drainage patterns; amount of rainfall and irrigation especially following N fertilizer application; rate and timing of N fertilizer application; and use of cover crops (Di and Cameron, 2002).

Nitrogen budgets have been used to identify and estimate the magnitude of N inputs, outputs and N_{pl} (as nitrate) in agricultural settings (Meisinger and Randall 1991; Cole, 2008). Meisinger and Randall (1991) is regarded as a seminal reference related to the development of N budgets and, as such, is regularly referenced in this report.

N budgets are based on the following formula:

$$N_{pl} = N_{inputs} - N_{outputs} - \Delta N_{storage}$$

where long-term potentially leachable nitrogen (N_{pl}) is the sum of the sources of nitrogen (N_{inputs}) minus the sum of the sinks of nitrogen ($N_{outputs}$) minus the change in long-term storage of nitrogen in the soil ($\Delta N_{storage}$) (Meisinger and Randall, 1991; Cole, 2008).

The goal in this study was to develop “approximate N budgets to evaluate ‘what if’ scenarios where alternative N management practices may be compared over a long period to estimate their risk of nitrate loss” (Meisinger and Randall, 1991). **Note** that numeric values generated by N budgets provide a scientific basis for comparing and prioritizing field activities; site-specific field sampling is required to confirm actual N loss (as nitrate (NO_3^-)) into groundwater.

Table 8 Nutrient Beneficial Management Practices

BMP Type	BMP No.	Nutrient BMPs	Notes
R		**Right Rate:**	**Match Supply and Demand for Crop Nutrients**
			Choosing appropriate nutrient application rates
R	1	Application calibration and upkeep	- Maintaining equipment
R	2	Crop removal balance	- Calculating how much nitrogen is needed
		(combined with R4)	- Computerized models can help e.g., NMAN
R	3	Crop scouting / assessment	- Crop scouting for visual symptoms of nitrogen deficiencies
R	4	Nutrient management plans	- Accounting for nitrogen from other sources
		(includes R2 Crop removal balance)	- Using crop response data to determine economically efficient application rates
R	5	Plant tissue analysis	- Testing plant tissue to confirm nitrogen content and adequacy of nitrogen program e.g., corn leaf and/or stalk test
			- Using information to fine-tune nitrogen management
R	6	Record keeping	- Documenting nitrogen applied and available per field
			- Mapping and managing soil variability per field
R	7	Soil testing	- Testing soil to confirm nutrient content and adequacy of nutrient program e.g., soil nitrate test for corn
R	8	Variable rate fertilization	- Using electronic equipment to automatically control fertilizer applications
R	9	Yield goal analysis	- Analyzing various yield scenarios to help make appropriate nutrient decisions e.g., Ontario N calculator
T		**Right Time:**	**On Time Delivery of Crop Nutrients**
			Making nutrients available when crops need them
			Limiting environmental loss of nutrients
T	1	Application timing	- Applying what the crop needs when it needs it e.g., split applications in corn
			- Reducing cost and loss of nutrients

BMP		Nutrient BMPs	Notes
Type	**No.**		
T	2	Enhanced efficiency fertilizers	- Using fertilizers with inhibitors or controlled release formulas
P		**Right Place:**	**Appropriate Nutrient Placement**
			Placing nutrients where plants can use them best
			Minimizing environmental losses
P	1	Application method	- Banding and injecting are the most environmentally sustainable fertilizer application methods
		(includes P6 Incorporation of fertilizer)	- Placing nutrients in the plant root zone
P	2	Crop rotation	- Alternating forage and/or cereal crops with row crops
P	3	Buffer strips	- Protecting water quality with vegetation that slows water flow and traps sediment, organic matter, nutrients, and pesticides
P	4	Reduced tillage	- Reducing tillage passes, working across the slope, and leaving crop residues on the soil surface to control erosion
P	5	Cover crops	- Growing a crop during the off season to help maintain soil structure, add organic matter, tie up excess nutrients, and control pests
P	6	Incorporation of fertilizer (combined with P1)	- Placing nutrients in the plant root zone
P	7	Storage	- Containing nutrients until use
A		**Right Advice:**	**Appropriate Professional Advice and Analytical Information**
			Making informed decisions as field conditions change
A	1	Advice from a professional agricultural consultant	- Using information from specialists to maximize nutrient management results e.g., Certified Crop Advisor (CCA)
A	2	Results from a certified analytical laboratory	- Using analyses from certified laboratories to maximize nutrient management results e.g., soil fertility for Ontario conditions

(Adapted from Canadian Fertilizer Institute, 2005)

Table 9 Nitrogen BMP Scenarios, 1980-2008, Region of Waterloo, ON

N Management Scenario		Description	Main N Components Affected			
Study ID	**Study Short Name**		**Information / Advice**	**Inorganic Fertilizer[1]**	**Organic Fertilizer[2]**	**Crop Type**
BASE	**Base case**	- Represents no external influence on N management - Actual N management plus extrapolated values 1960-2008				
BMP21	**Soil N test**	- Represents minimum external influence on N management - Provides soil N test results and how to use them 1980-2008	x	x		
BMP22	**N balance**	- Represents moderate external influence on N management - Optimize N management based on producer's existing system 1980-2008	x	x	x	
BMP23	**Max N balance**	- Represents maximum external influence on N management - Optimize N management based on current BMP knowledge 1980-2008	x	x	x	x[3]
BMP24	**Drop manure**	- Represents targeted external influence on one main component of N management - Optimize N management based on existing system BUT drop manure/biosolids use 1980-2008		x	Drop manure / biosolids	
BMP25	**Drop manure/ corn**	- Represents targeted external influence on two main components of N management - Optimize N management based on existing system BUT drop manure/biosolids use AND drop corn from rotation 1980-2008		x	Drop manure / biosolids	Drop corn

[1] Commercial nitrogen sources

[2] Manure, biosolids, cover crops, crop residues

[3] Add wheat with red clover plough down cover crop

The relative value of N_{pl} (estimated as kg N/ha/yr available to leach below the plant root zone; also called nitrate load) arising from comparative N budgets can be used to:

- Predict the long-term impact of N on groundwater quality when combined with hydrogeologic data and field level studies;
- Predict changes in the long-term impact of N on groundwater quality after the implementation of various BMP scenarios within the capture zone; and
- Prioritize those agricultural fields where the implementation of BMPs may lessen the long-term impact of N on groundwater quality.

Since nitrogen loading to the aquifer in the vicinity of the production well in this study is largely due to agricultural activities, N budgets representing existing and historical N management practices were created for agricultural fields where all or part of the field was inside the 100-yr SWAT capture zone of the production well, and where detailed N management information was available. N budgets were developed for croplands since these were considered a major source of N in the capture zone. N budgets were not created for agricultural fields where detailed N management information was not available or for septic systems, woodlots and natural areas, as the latter were considered minor sources of N (Rudolph, pers. comm., 2008; Di and Cameron, 2002).

The resulting estimates of long-term N_{pl} from 1960 to 2008 for each agricultural field where all or part of the field was inside the capture zone of the production well represented the Base case in the Mass Balance Model (MBM). These estimates, along with actual field measurements of nitrate loads, were used subsequently to validate N loading rates in the model and to assess the potential impact of various agricultural N management strategies on the concentration of nitrate in groundwater at the production well. Also, the resulting estimates of N_{pl} were used in the economic analysis as a basis for comparing the financial cost and environmental benefit of the nitrogen BMP scenarios.

4.2.2.2 N Budget Items and Data Sources

Meisinger and Randall (1991) provided a detailed methodology for developing N budgets, which also promoted the use of on-site data and locally-based assumptions when possible. Recall the following N budget formula: $N_{pl} = N_{inputs} - N_{outputs} - \Delta N_{storage}$. The N budget framework used in this study was adapted from the literature (Brethour *et al.*, 2009; Cole, 2008; Havlin, 2004; Barry *et al.*, 1993; Meisinger and Randall, 1991). Table 10 lists the budget items used in this study to develop estimates of N_{inputs}, $N_{outputs}$ and $\Delta N_{storage}$. N budget values were determined using data obtained from producer interviews, historical surveys of land management practices, published provincial information and scientific literature. Author knowledge and experience were used to make assumptions and to develop extrapolations when a published source was not available, or when the published information required modification to reflect site-specific conditions.

The most accurate information was generally available for the 2000-2008 time period. Extrapolation back across the time step to 1980 for the BMP scenarios and to 1960 for the Base case was required. The results of the N budgets were assumed to apply to the remainder of the agricultural land within the capture zone where N management data was not available.

Table 10 Nitrogen (N) Budget Framework For Cropland, 1980-2008, Region of Waterloo, ON

N Budget Item (kg N/ha)	Item Description and Data Sources
Time Step	**1980-2008**
Crop Type	Crop grown in field in current year Based on producer knowledge, provincial data, extrapolation, and/or author experience
Crop Yield	Crop commodity harvested from the field in current year Based on producer knowledge, provincial average, extrapolation, and/or author experience
Manure	Nitrogen in manure/biosolids applied in fall or spring prior to current crop Based on producer knowledge, provincial average, extrapolation, and/or author experience
Fertilizer	Nitrogen in fertilizer applied before, during or after planting of current crop Based on producer knowledge, OMAFRA Pub 811 2009, NMAN2, extrapolation, and/or author experience
Seed	Nitrogen content of the seed that was planted to grow the current crop Based on OMAFRA Pub 611 2006 for N content of seed harvested, Pub 811 2009 for seeding rate
Atmospheric Deposition	Nitrogen accumulated in the soil from the atmosphere by wet (i.e., in precipitation) or dry deposition Based on Barry *et al.*, 1993
Symbiotic N_2 Fixation	Nitrogen accumulated in the crop by symbiotic microorganisms that fix nitrogen from the air Based on OMAFRA Pub 611 2006
Non-Symbiotic N_2 Fixation	Nitrogen accumulated in the soil by non-symbiotic microorganisms that fix nitrogen from the air Based on Barry *et al.*, 1993; Havlin, 2004
Mineralization: Manure	Nitrogen released or mineralized from the breakdown of residues from previously-applied manure/biosolids Based on OMAFRA Pub 811 2009
Mineralization: Crop Residue	Nitrogen released or mineralized from the breakdown of residues from the previous crop including cover crop Based on OMAFRA Pub 811 2009 and yield
N Input	**TOTAL nitrogen entering or available in the soil-crop system**
Crop Uptake	Nitrogen removed or harvested from the field Based on OMAFRA Pub 611 2006
Gaseous Losses: Manure Volatilization	Nitrogen lost or volatilized as a gas from applied manure/biosolids Based on OMAFRA Pub 811 2009 and yield
Gaseous Losses: Fertilizer Volatilization	Nitrogen lost or volatilized as a gas from applied fertilizer Based on OMAFRA Pub 611 2006 and Peoples et al., 1995
Gaseous Losses: Plant Senescence	Nitrogen lost or volatilized as a gas from natural plant senescence (die-off) and miscellaneous sources Based on Meisinger and Randall, 1991

N Budget Item (kg N/ha)	Item Description and Data Sources
Immobilization: Crop Residue/Cover crops	Nitrogen tied up or immobilized in residues from the previous crop including cover crop (Note: N immobilized in manure/biosolids is accounted for in $\Delta N_{storage}$) Based on OMAFRA Pub 611 2006 and Pub 811 2009
Denitrificaton	Nitrogen lost from low oxygen/poorly aerated soils (i.e., water saturated soils) after conversion by denitrification to a gas Based on Meisinger and Randall, 1991
Erosion / Runoff	Nitrogen lost in soil eroded from the soil surface or in water running off the soil surface Based on Meisinger and Randall, 1991
N Output (Kg/Ha)	**TOTAL nitrogen leaving or not available in the soil-crop system**
Change In Storage ($\Delta N_{storage}$)	**Overall change in nitrogen stored within the soil-crop system (ΔN_{st})** from beginning to end of the study time step (includes change in soil inorganic nitrogen (ΔN_{si}), which is essentially nitrate-N, and change in soil organic nitrogen (ΔN_{so}(OM)), which is essentially organic matter-N) i.e., N_{st} = total N in the soil-crop system at end of time step (e.g., 2008) less total N at beginning of time step (e.g., 1960); N_{st} components include inorganic and organic N forms. N_{st} is often assumed to be at steady state i.e., no change overall unless a 'soil building' management strategy is introduced (e.g., manure or a red clover plough down cover crop) Based on OMAFRA Pub 611 2006 and Pub 811 2009
Potentially Leachable N (N_{pl})	**Nitrogen potentially available below the plant root zone to leach into groundwater over the long-term (called long-term potentially leachable nitrogen (LPLN or N_{pl}))** **Based on $N_{pl}=N_{inputs}-N_{outputs}-\Delta N_{storage}$**
Note: Nitrification occurs within the soil substrate and converts nitrogen to a form most readily taken up by plants. It is not included in the nitrogen budget since it does not directly affect nitrogen inputs or outputs to the soil-crop system.	

4.2.2.3 Calculation of Weighted Estimates of N_{pl} within the Capture Zone

Estimates of N_{pl} for each field and year within the applicable time step (Base case 1960 to 2008; BMP scenarios 1980-2008) were used to calculate a weighted estimate of N_{pl} (also referred to as annual nitrate load) within a field group or across the capture zone of the production well as follows:

$$\begin{aligned} \text{Mean Total } N_{pl} &= \Sigma(N_{pl}/\text{field x area/field}) / \Sigma(\text{area/field}) \\ &= \Sigma(\text{kg N/ha/yr x ha}) / \Sigma(\text{ha}) \\ &= \text{kg N/ha/yr} \end{aligned}$$

4.2.2.4 Establishment of N_{pl} Categories

Meisinger and Randall (1991) recommended using criteria based on local information to create N_{pl} categories that would help users interpret estimates of N_{pl}. In the absence of local data, they offered default categories (Table 11). Meisinger and Randall (1991) suggested that fields with estimated N_{pl} values in the high category should be sampled first to determine the actual amount of nitrogen available to leach into groundwater. If excessive nitrogen was confirmed then management strategies could be developed on a priority basis. In this study, Base case N_{pl} estimates at the upper and lower 1/3 percentile thresholds were used to determine N_{pl} categories per decade. The data were split by decade to reflect previously identified shifts in the magnitude of the estimates between decades and to highlight the most accurate information obtained from producers, which was associated with the 2000s (Table 11).

In agriculture, field management changes from year-to-year due to the use of crop rotation and manure/biosolids management strategies. It is important to include information associated with one or more crop rotation cycles when studying the potential environmental impacts of farming practices. In this study, the relative area of land associated with each N_{pl} category per decade was determined to assess the extent of the potential impact of each nitrogen management scenario on lands within the capture zone. First, annual estimates of N_{pl} per field per N management scenario were categorized depending on the decade as indicated in Table 11. Second, the area of land (ha) associated with each category per decade was calculated (i.e., the area of one field could be included multiple times within one category per decade). Finally, the relative area of land (%) associated with each category per decade was calculated.

Table 11 Categorization of Potentially Leachable Nitrogen (N_{pl}) per Decade, Base Case, 1980-2008, Region of Waterloo, ON

Categories of N_{pl}[1] (kg N/ha/yr)								
1980-1989			**1990-1999**			**2000-2008**		
low	**medium**	**high**	**low**	**medium**	**high**	**low**	**medium**	**high**
<24	24-61	>61	<36	36-67	>67	<18	18-61	>61
<28[2]	28-56[2]	>56[2]						

[1] Base case N_{pl} estimates at the upper and lower 1/3 percentiles were used to identify categories in this study

[2] default categories provided by Meisinger and Randall (1991); based on continuous corn production using 168 kg N/ha/yr

4.2.3 Estimation of Nitrate Concentrations in Groundwater at the Production Well

In a related study, a mass balance model (MBM) developed by Stantec for the Region was used to estimate the concentration of nitrate at a production well used to provide drinking water for the Region. The MBM included the annual estimates of long-term N_{pl} from N budgets reported in this study as input data, representing nitrate load from agriculture to groundwater in the capture zone of the production well.

The MBM integrates a database program and a GIS program through an easy to use model interface. The overlying assumption in the MBM is that the observed nitrate concentration in water from a well represents the mass of nitrate that infiltrates to the groundwater table and is diluted by the recharge available within the capture zone. Essentially, the MBM provides an advective transport model where dispersion and diffusion are not considered.

In the MBM, the nitrate concentrations at a production well are estimated by the integration of the nitrate mass from each surface to well advection time (SWAT). The

MBM was calibrated to the nitrate concentration measured at the production well. The predicted nitrate concentration at the production well is dependent on the following model parameters:

- SWATs;
- recharge;
- background nitrate concentration;
- nitrate loading function; and,
- denitrification rate.

Details of the model are available from Stantec or the Region.

The main objective of the related study for the Region was to determine if the BMP scenarios could be effective at reducing nitrate concentrations at the production well. The MBM was used to evaluate nitrate concentrations for the Base case and five BMP scenarios.

4.3 RESULTS AND DISCUSSION

4.3.1 Land Use Overview

Land classifications within the production well capture zone (i.e., all land bounded by the 100-yr SWAT, 738 ha) included agricultural (70%), natural (13%), quarry/pit (7%) and other, including rural residential, (9%) lands (Table 12). Detailed agricultural land management information was obtained for more than 90% of the agricultural lands within the capture zone bounded by the 15-yr SWAT and for approximately 44% of the agricultural lands within the total capture zone (i.e., all area bounded by, or within, the 100-yr SWAT) (Table 12).

The available land management data indicated the capture zone for the production well was farmed in a variety of livestock and cash crop-based rotations. The main crops included field corn, soybeans, wheat and alfalfa. Other crops included barley, oats, white beans, pumpkins, squash, cabbage, lettuce and pasture. In the Base case, a red clover cover crop was used occasionally in conjunction with wheat production. Livestock included beef, hog and poultry production. Dairy production was not evident within the capture zone. Solid and liquid manure, and biosolids were historically applied to these lands. Reduced tillage practices and the use of formal nutrient management plans (NMPs) were evident but not well documented in the available information.

Soil and tissue testing for nitrogen content were not used within the study area. Most respondents indicated that a split application of fertilizer during corn production was a standard practice; however, the nature of the split application varied from pre-plant broadcast application to late post-emergence side dressing. One of the producers interviewed indicated a crop consultant was used to assist with nutrient management.

Identification of agricultural point sources of long-term N_{pl} was not within the scope of this study. However, there was evidence of historical manure storage that may have been uncontained and, due to the rural nature of the area, the use of private septic systems throughout the capture zone was probable.

4.3.2 Proportion of Capture Zone with N Budgets and Estimates of N_{pl}

Nitrogen (N) budgets for the Base case and the BMP scenarios were completed for 44% of all agricultural land within the total capture zone (i.e., all land bounded by the 100-yr SWAT) for the time step 1980-2008. Base case N budgets were completed for field groups as follows: A1-A5 fields from 1969-2008; B1-B13 and C1-C4 fields from 1960-2008; D1-D4 fields from 1980-2008; and E1-E2 fields from 1978-2008. N budgets were completed for more than 90% of agricultural land within the 3, 5, 10, and 15-yr SWATs and for 30% to 77% of agricultural land in the remaining SWATS, except for the 30-yr and 100-yr SWATs where N budgets were completed for 20% and 24%, respectively, of agricultural land (i.e., each SWAT represents the additional area only) (Table 12). Overall, N budgets were completed for approximately 44% of the agricultural lands within the total capture zone (i.e., all area bounded by, or within, the 100-yr SWAT).

4.3.3 Example N Budgets for Base Case and BMP Scenario

In this study, approximately 4,300 annual N budgets were prepared using MS Excel® software, including each combination of field x year x N management, for the fields within the capture zone of the production well. Example N budgets, plus related notes and references for one field including two nitrogen management scenarios (Base and BMP23 (max N balance)) across one crop rotation time step, are presented in Table 13. The complete N budget database is on file with the Region.

4.3.4 Estimates of N_{pl} – Base Case

In this study the 29-year time step from 1980-2008 was of particular interest since it was used to develop comparisons between the Base case and five BMP scenarios, which were designed to reduce the amount of long-term N_{pl} in the capture zone. In the Base case, the estimated N_{pl} from 1980-2008 was 44 kg N/ha/yr, which represented 19% of the mean annual input of nitrogen (233 kg N/ha/yr) to the soil-plant system (Table 14). The estimated mean total N_{pl} per year for each 9 or 10 year time step (1980-89; 1990-99; 2000-08) within the study was 44, 49 and 39 kg N/ha/yr, respectively, which represented 20%, 20% and 17% of the mean annual input of N (221, 246 and 232 kg N/ha/yr, respectively) to the soil-plant system (Table 14). On an annual basis, estimated total N_{pl} ranged from a low of 30 kg N/ha in 1981 and 2008, to a high of 63 kg N/ha in 1991 (Table 14).

Estimates for the time step 2000-2008 were considered most reliable since they were based on the most accurate data obtained from producer knowledge and published sources. An examination of annual findings indicated a general decline in estimated N_{pl} from 51 kg N/ha in 2000 to 30 kg N/ha in 2008 and in the relative proportion of total N that was available to leach into groundwater on an annual basis (21% in 2000 to 14% in 2008) (Table 14).

Table 12 Land Use and Availability of Agricultural Land Management Data within the SWAT Areas of the Capture Zone, Region of Waterloo, ON

SWAT	SWAT Area[1]		Agricultural Land by Field Group Management Data Available						All Agricultural Land Management Data			Natural	Quarry Pit	Other
			A1-A5	B1-B7	B8-B13	C1-C4	D1-D3	E1-E2	Available		Not Available			
			Proportion of SWAT Area						Proportion of SWAT Area	Proportion of all agricultural land in SWAT Area	Proportion of SWAT Area	Proportion of SWAT Area		
(yr)	(m^2)	(ha)	(%)						(%)			(%)		
3	11414	1	0	0	70	0	0	0	70	100	0	30	0	0
5	1571	0	22	11	0	0	0	0	33	100	0	0	0	67
10	409712	41	20	38	1	2	0	0	61	98	1	26	0	12
15	626962	63	34	21	0	24	3	0	82	94	5	10	0	3
20	551518	55	2	5	4	44	10	0	65	77	20	8	0	7
25	683207	68	1	0	1	17	4	2	25	36	44	23	0	9
30	611104	61	1	0	0	4	4	6	15	20	58	17	4	7
40	1068762	107	0	0	8	6	3	5	23	34	44	14	8	12
50	884735	88	0	0	12	8	4	5	29	41	41	8	8	14
100	2527747	253	0	0	3	3	2	9	16	24	50	11	15	9
Total	7376731	738	4	4	4	10	3	5	31	44	39	13	7	9

Notes:
[1] each SWAT represents the additional area only; the Total represents all area bounded by, or within, the 100-yr SWAT
Natural: land observed to be forested or uncultivated
Quarry Pit: land observed to be excavated
Other: land occupied by houses or roadways
Agricultural: land observed or known to be cultivated
Remaining Agricultural Fields: land observed to be agricultural but detailed information on agricultural practices not available

Table 13 Example Nitrogen Budgets with Notes and References, 1980-2008, Region of Waterloo, ON

N Budget Item (Kg/Ha)	Example N Budgets for One Field Over 4 yr Crop Rotation								Example Notes and References			
	BASE				BMP23 Max N Balance				BMP23 Max N Balance			
Year	1997	1998	1999	2000	1997	1998	1999	2000	1997	1998	1999	2000
Crop Type	soybeans	wheat/rdclvr	corn	corn	soybeans	wheat/rdclvr	corn	corn	soybeans	wheat/rdclvr	corn	corn
Crop Yield **(Kg/Ha)**	2,822	2,762	8,047	4,265	2,822	2,762	8,047	4,265	Supplier	OMAFRA, provincial estimate	OMAFRA, provincial estimate	Supplier
	Estimated N (Kg/Ha)				Estimated N (Kg/Ha)							
Manure	0	0	269	0	0	0	164	0	producer estimate	producer estimate	BMP22	BMP22
Fertilizer	0	112	67	179	0	94	4	133	BMP22 NMAN2 pub811p113 N not normally required	BMP22 NMAN2 minus10% per decade	BMP23 NMAN2 yld goal 150 bu/ac; need 124 lbN/ac-43 lbN/ac [in10 ton/ac]manure-70lbN/ac rdclvr- 11 lb/ac frm wheat=4lb/a popup+0lbUAN[gives 4lboverage since fine tuned]	BMP22 NMAN2 yld goal 150 bu/ac; need 123 lbN/ac- 13 manure credit - 0manure-0frmcorn =4 lb/ac [5 gal/ac] popup+115 lb/ac [32 gal/ac]UAN pre w herbicide gives 8lboverage
Seed	7.1	2.3	0.2	0.2	7.1	2.3	0.2	0.2	Pub 611 for N content of seed harvested, Pub 811 for seeding rate	Pub 611 for N content of seed harvested, Pub 811 for seeding rate	Pub 611 for N content of seed harvested, Pub 811 for seeding rate	Pub 611 for N content of seed harvested, Pub 811 for seeding rate
Atmospheric Deposition	18	18	18	18	18	18	18	18	Barry et al., 1993	Barry et al., 1993	Barry et al., 1993	Barry et al., 1993
Symbiotic N_2 Fixation	203	108	0	0	207	160	0	0	OMAFRA, Pub 611, Table 6-9, crop uptake of soys minus N applied	Pub611p120 4 t/ha top growth =160 kgN/ha=143 lbN/ac ie 100% catch; corresponds to 70 lbN/ac credit to next crop (NB pub611 credits70 vs NMAN2 credits63 lbN/ac to rdclvr)		
Non-Symbiotic N_2 Fixation	5	5	5	5	5	5	5	5	Barry et al., 1993	Barry et al., 1993	Barry et al., 1993	Barry et al., 1993
Mineralization: Manure	12	5	0	23	7	3	0	14	OMAFRA, pub 811, 2009	OMAFRA, pub 811, 2009	OMAFRA, pub 811, 2009	OMAFRA, pub 811, 2009

N Budget Item (Kg/Ha)	**Example N Budgets for One Field Over 4 yr Crop Rotation**								**Example Notes and References**			
	BASE				**BMP23 Max N Balance**				**BMP23 Max N Balance**			
Mineralization: Crop Residue	0	31	59	0	0	35	85	0		bean credit (30 Kg/Ha), OMAFRA, pub 811, 2009 linked to average omafra estimate of yields for last three years (35.53 lb/bu)	wheat credit (11 lb/ac) pub 811, 2009 linked to ave omafra estimate of ylds for last 3 yrs (79.23 bu/acre) and pub611p119,120,122; red clover credit 70 lb N/ac	
N Input	**245**	**281**	**419**	**226**	**245**	**318**	**277**	**171**				
Crop Uptake	181	55	119	63	181	55	119	63	OMAFRA, pub 611, 2006, Tables 6-9, 6-10	OMAFRA, pub 611, 2006, Tables 6-9, 6-10	OMAFRA, pub 611, 2006, Tables 6-9, 6-10	OMAFRA, pub 611, 2006, Tables 6-9, 6-10
Gaseous Losses: Manure Volatilization	0	0	8	0	0	0	5	0	OMAFRA, pub 811, 2009, Table 9-12	OMAFRA, pub 811, 2009, Table 9-12	OMAFRA, pub 811, 2009, Table 9-12	OMAFRA, pub 811, 2009, Table 9-12
Gaseous Losses: Fertilizer Volatilization	0	6	3	9	0	5	0	7	OMAFRA, pub 611, 2006; Peoples, 1995; 5% of fertilizer N	OMAFRA, pub 611, 2006; Peoples, 1995; 5% of fertilizer N	OMAFRA, pub 611, 2006; Peoples, 1995; 5% of fertilizer N	OMAFRA, pub 611, 2006; Peoples, 1995; 5% of fertilizer N
Gaseous Losses: Plant Senescence	9	9	9	9	9	9	9	9	Meisinger & Randall, 1991	Meisinger & Randall, 1991	Meisinger & Randall, 1991	Meisinger & Randall, 1991
Immobilization: Crop Residue	31	59	0	0	35	85	0	0	bean credit (30 Kg/Ha), OMAFRA, pub 811, 2009 linked to average omafra estimate of yields for last three years (35.53 lb/bu)	wheat credit (11 lb/ac) pub 811, 2009 linked to ave omafra estimate of ylds for last 3 yrs (79.23 bu/acre) and pub611p119,120,122; red clover credit 70 lb N/ac		
Denitrificaton	2	10	32	12	2	9	21	9	6% inorganic, 12% organic, from Meisinger & Randall, 1991	6% inorganic, 12% organic, from Meisinger & Randall, 1991	6% inorganic, 12% organic, from Meisinger & Randall, 1991	6% inorganic, 12% organic, from Meisinger & Randall, 1991
Erosion / Runoff	3	3	3	3	3	3	3	3	Meisinger & Randall, 1991	Meisinger & Randall, 1991	Meisinger & Randall, 1991	Meisinger & Randall, 1991
N Output	**226**	**142**	**175**	**96**	**231**	**166**	**157**	**91**				
Change In Storage ($\Delta N_{storage}$)	**-12**	**51**	**170**	**-23**	**-7**	**79**	**104**	**-14**		JSR rdclvr soil bldg; Nfixn-Ncredit	total applied manure N - proportion available - volatilization	

N Budget Item (Kg/Ha)	Example N Budgets for One Field Over 4 yr Crop Rotation								Example Notes and References			
	BASE				BMP23 Max N Balance				BMP23 Max N Balance			
Long-term Potentially Leachable N (N_{pl})	**30**	**88**	**74**	**153**	**21**	**73**	**16**	**94**				

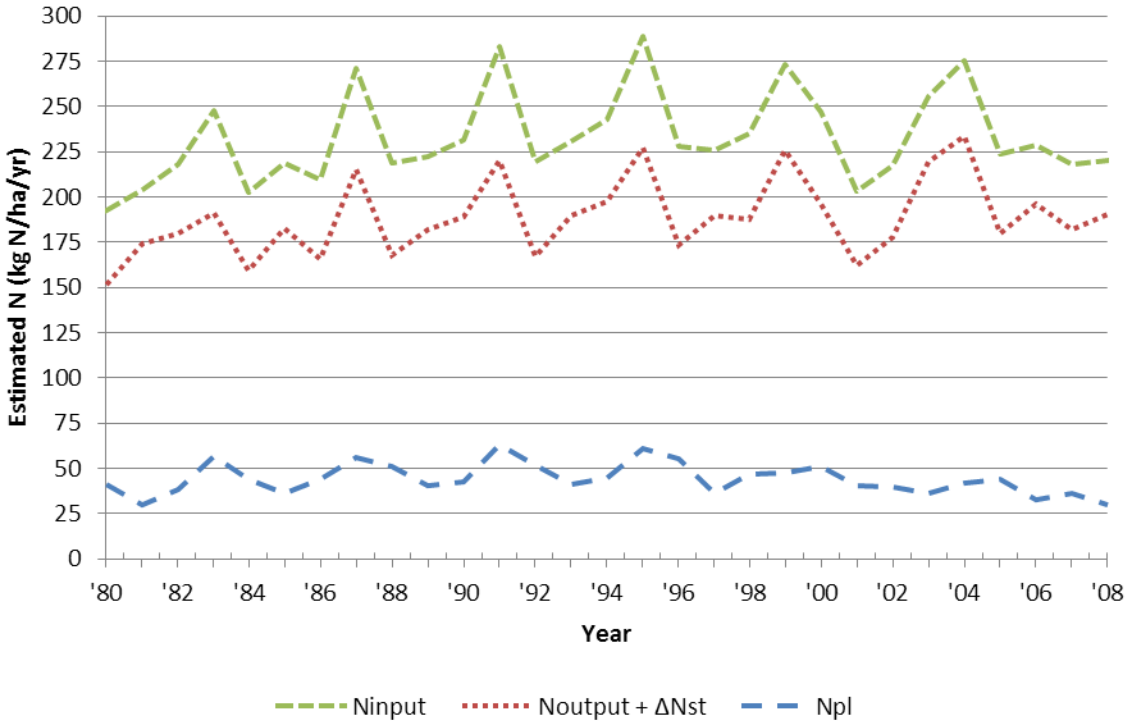
Table 14 Estimates of Mean Nitrogen Input, Output + Storage, and Load Potentially Available to Leach into Groundwater from Agricultural Fields in the Capture Zone, Base Case, 1980-2008, Region of Waterloo, ON

Time		Base Case			
Step	No. of Yrs	N_{input}	$N_{output} + \Delta N_{st}$	N_{pl} [1]	N_{pl} / N_{input} [2]
		(kg N/ha/yr)			(%)
1980 - 2008	29	233	189	44	19
1980 - 1989	10	221	177	44	20
1990 - 1999	10	246	197	49	20
2000 - 2008	9	232	193	39	17
1980	1	192	151	41	21
1981	1	204	174	30	15
1982	1	218	180	38	18
1983	1	248	191	57	23
1984	1	203	159	44	22
1985	1	219	183	36	16
1986	1	210	166	44	21
1987	1	271	215	56	21
1988	1	219	168	51	23
1989	1	223	182	41	18
1990	1	231	189	43	18
1991	1	283	220	63	22
1992	1	219	167	52	24
1993	1	231	189	41	18
1994	1	243	198	45	19
1995	1	289	227	61	21
1996	1	228	173	55	24
1997	1	226	190	36	16
1998	1	235	188	47	20
1999	1	273	226	47	17
2000	1	247	196	51	21
2001	1	203	162	41	20
2002	1	217	178	40	18
2003	1	256	220	36	14
2004	1	275	233	42	15
2005	1	224	180	44	20
2006	1	228	196	33	14
2007	1	218	182	36	17
2008	1	220	190	30	14

[1] Estimated mean amount of nitrogen that could leach into groundwater every year of the time step

[2] Estimated mean excess nitrogen in the soil-plant system available to leach below root zone

Figure 5 Estimates of Mean Annual Nitrogen Input, Output + Storage, and Load Potentially Available to Leach into Groundwater from Agricultural Fields in the Capture Zone, Base Case, 1980-2008, Region of Waterloo, ON



4.3.5 Estimates of N_{pl} – BMP Scenarios

The mean estimates of long-term N_{pl} for the BMP scenarios ranged from 19 to 38 kg N/ha/yr compared to the mean estimate of N_{pl} for the Base case (44 kg N/ha/yr) (1980-2008; n=29 yrs; Table 15). In percentage terms, the mean estimates of N_{pl} for the BMP scenarios were approximately 14 to 57% less than the mean estimate of N_{pl} for the Base case (Figure 6) as follows:

- 57% less N_{pl} under BMP24 (drop manure) and BMP25 (drop manure/corn);
- 48% less N_{pl} under BMP23 (max N balance);
- 34% less N_{pl} under BMP22 (N balance); and
- 14% less N_{pl} under BMP21 (soil N test).

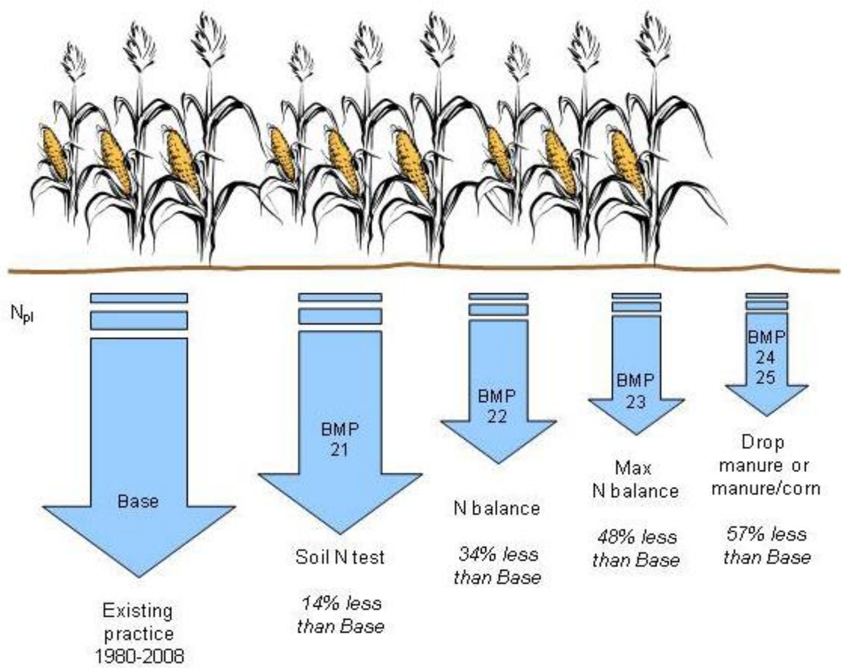
On an annual basis (n=1 yr), the ranges of estimates of N_{pl} per field per year per N management scenario from 1980 to 2008 were as follows: Base case 30-63 kg N/ha/yr; BMP21 (soil N test) 24-55 kg N/ha/yr; BMP22 (N balance) 18-40 kg N/ha/yr; BMP23 (max N balance) 13-33 kg N/ha/yr; BMP24 (drop manure) 11-26 kg N/ha/yr; and BMP25 (drop manure/corn) 11-35 kg N/ha/yr (Table 15). These estimates were comparable to values discussed by Meisinger and Randall (1991).

Table 15 Estimates of Mean Potentially Leachable Nitrogen from Nitrogen Management Scenarios, 1980-2008, Region of Waterloo, ON

Time		Estimates of Mean Long-term Potentially Leachable Nitrogen					
Step	No. of Yrs	Base	BMP21 Soil N test	BMP22 N balance	BMP23 Max N balance	BMP24 Drop manure	BMP25 Drop manure/ corn
		(kg N/ha/yr)					
1980 - 2008	29	44	38	29	23	19	19
1980 - 1989	10	44	37	28	22	17	22
1990 - 1999	10	49	43	32	26	21	20
2000 - 2008	9	39	34	25	20	20	14
1980	1	41	32	31	24	23	14
1981	1	30	24	19	15	11	23
1982	1	38	34	26	19	16	31
1983	1	57	47	29	23	16	23
1984	1	44	34	29	25	14	20
1985	1	36	31	25	19	14	17
1986	1	44	38	30	22	17	25
1987	1	56	46	31	24	18	27
1988	1	51	43	35	27	21	25
1989	1	41	37	28	21	16	20
1990	1	43	39	31	24	19	15
1991	1	63	55	33	26	21	23
1992	1	52	45	37	30	25	14
1993	1	41	37	31	25	20	23
1994	1	45	41	31	24	19	17
1995	1	61	54	32	24	21	18
1996	1	55	47	40	33	26	35
1997	1	36	32	25	24	14	21
1998	1	47	43	34	27	23	21
1999	1	47	40	26	21	20	16
2000	1	51	43	33	28	24	15
2001	1	41	38	26	21	19	11
2002	1	40	33	27	21	22	12
2003	1	36	33	26	19	19	12
2004	1	42	38	26	18	20	14
2005	1	44	38	27	23	22	20
2006	1	33	28	19	15	14	15
2007	1	36	33	23	19	20	17
2008	1	30	26	18	13	16	14

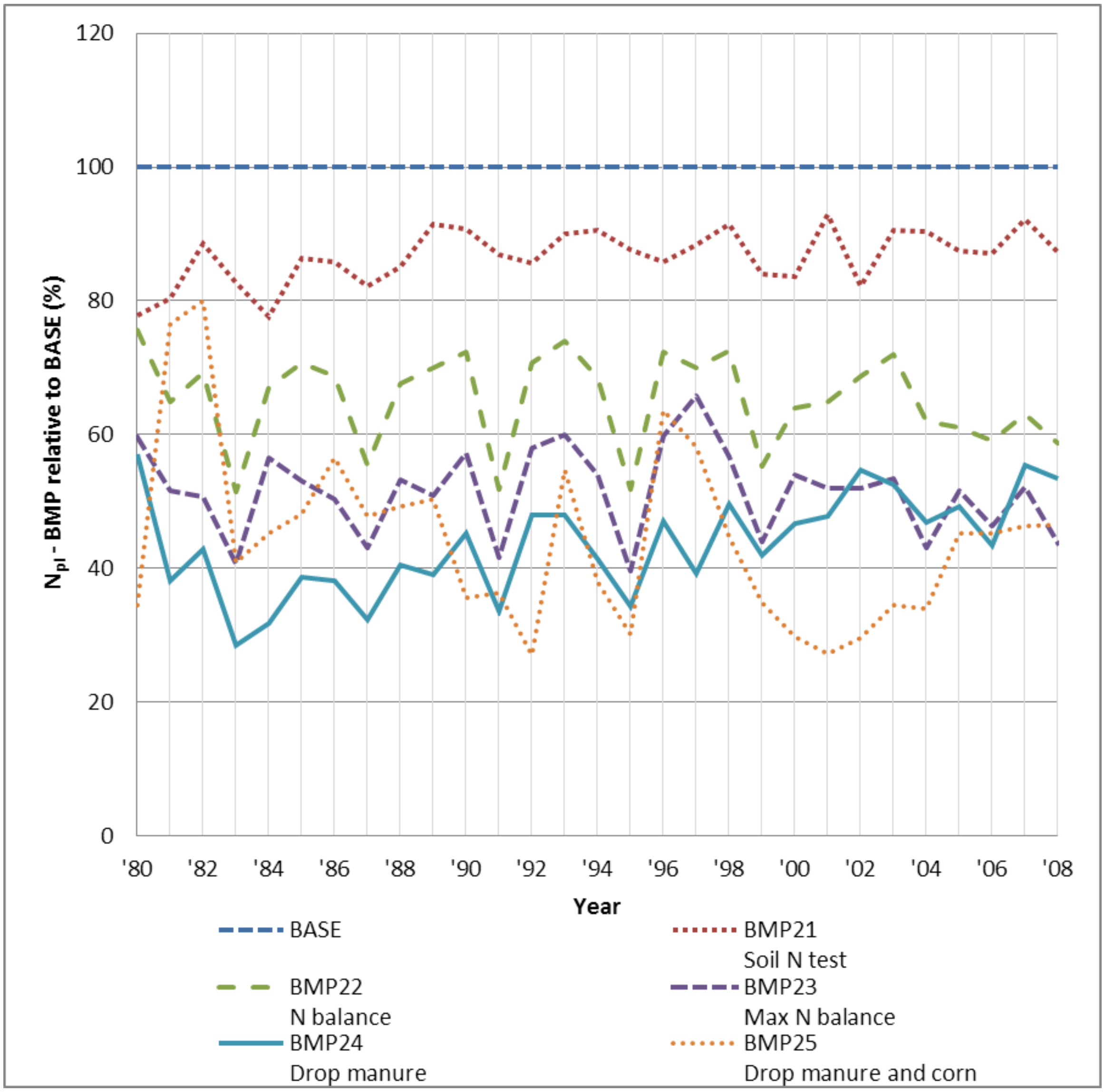
Note: see Figure 7 for annual % change or reduction in N_{pl} from BMPs compared to Base case

Figure 6 Relative Effect of Nitrogen Management Scenario on Estimated Mean Annual Long-Term Potentially Leachable Nitrogen (N_{pl}), 1980-2008, Region of Waterloo, ON



Mean annual estimates of long-term N_{pl} were compared on a relative basis with the Base case (Figure 7). The results show the year-to-year changes in the amount of N potentially available to leach below the plant root zone, which relates to annual changes in the mix of crops and associated production decisions and practices within the capture zone. During the 2000s, the time step for which data were most accurate, BMP23 (max N balance) and BMP24 (drop manure) scenarios had similar impacts on N_{pl} while the BMP25 (drop manure/corn) scenario had a greater impact during the first part of the decade and a similar impact during the latter part of the decade. The results suggest that, in future terms, any of the three scenarios may be the most effective N management strategy for reducing N_{pl} in groundwater within the capture zone.

Figure 7 Relative Estimates of Mean Annual Long-Term Potentially Leachable Nitrogen, 1980-2008, Waterloo, ON

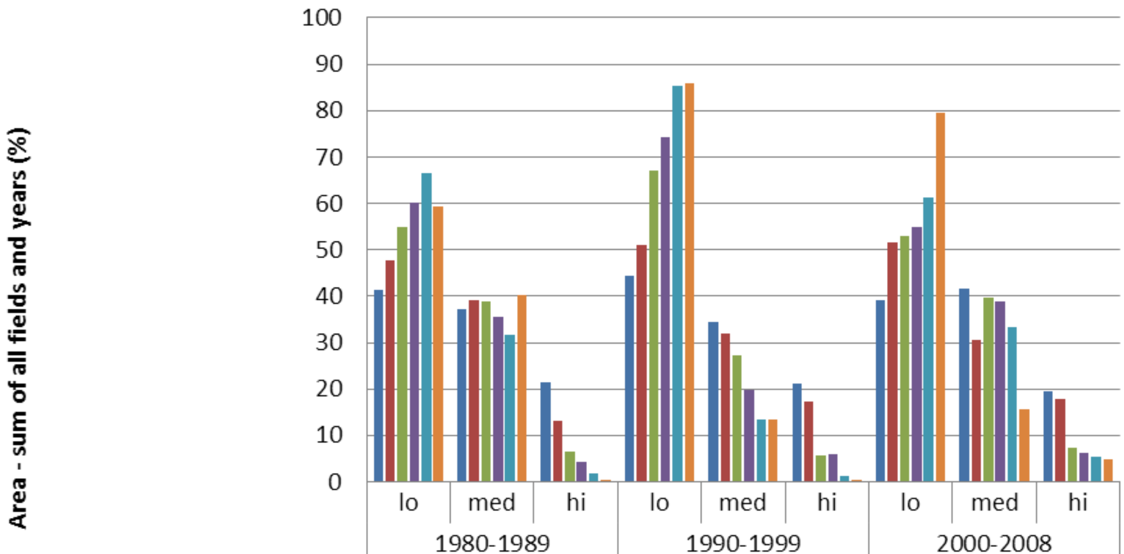


Recall that Meisinger and Randall (1991) recommended using criteria based on local information to create N_{pl} categories that would help users interpret estimates of N_{pl}. The categories established for this study are presented in Table 11. Meisinger and Randall (1991) suggested that fields with estimated N_{pl} values in the high category should be sampled first to determine the actual amount of N available to leach into groundwater. If excessive N was confirmed then management strategies could be developed on a priority basis. In this study, the relative area of land (%) associated with each N_{pl} category was calculated on a per decade basis. The following observations were made based on the results of this analysis (Figure 8):

- across all decades, all BMP scenarios had more land in the low N_{pl} category and less land in the high N_{pl} category than the Base case; results for the medium N_{pl} category were variable;

- across all decades, BMP22 (N balance), BMP23 (max N balance), BMP24 (drop manure) and BMP25 (drop manure/corn) scenarios resulted in 1-7% of lands in the high category; BMP21 (soil N test) resulted in 13-18% of lands in the high category; Base case resulted in 19-21% of lands in the high category;
- in the 1980s and 1990s, BMP24 (drop manure) and BMP25 (drop manure/corn) scenarios resulted in 1-2% of lands within the high category compared to BMP22 (N balance) and BMP23 (max N balance) scenarios, which resulted in 4-6% of lands within the high category. In the 2000s the difference was narrowed, BMP24 (drop manure) and BMP25 (drop manure/corn) scenarios resulted in 5% of lands within the high category compared to BMP22 (N balance) and BMP23 (max N balance) scenarios with 6-7% of lands within the high category; and
- in the 1990s, the decade with the highest estimates of N_{pl}, BMP22 (N balance), BMP23 (max N balance), BMP24 (drop manure) and BMP25 (drop manure/corn) scenarios resulted in proportionally more land in the low category i.e., 67-86% in the 1990s vs. 55-67% in the 1980s and 53-79% in the 2000s.

Figure 8 Relative Estimates of Total Area per Decade with Low, Medium and High Rates of Potentially Leachable Nitrogen, 1980-2008, Region of Waterloo, ON



	1980-1989 lo	1980-1989 med	1980-1989 hi	1990-1999 lo	1990-1999 med	1990-1999 hi	2000-2008 lo	2000-2008 med	2000-2008 hi
Base	41	37	21	44	35	21	39	42	19
BMP21 Soil N test	48	39	13	51	32	17	52	30	18
BMP22 N balance	55	39	6	67	27	6	53	40	7
BMP23 Max N balance	60	36	4	74	20	6	55	39	6
BMP24 Drop manure	67	32	2	85	13	1	61	33	5
BMP25 Drop manure and corn	59	40	1	86	14	1	79	16	5

4.3.6 Relative Reduction In Estimates of N_{pl} and the Economic Analysis

The economic analysis required a clear basis for economic comparison between the Base case and the five BMP scenarios evaluated in this study in order to determine:

- the financial costs of implementing the alternative BMP scenarios; and
- the environmental benefits per the cost-effectiveness ratios and the cost of 1% reduction in estimated N_{pl} per hectare per year to maintain groundwater quality at the production well within the Ontario Drinking Water Standard (ODWS) of 10 mg/L N.

Four representative fields, each with subfields (A1-A4; B9/B10/B12; C1-C4; D1-D3), within the capture zone, were included in the economic analysis. Although N BMPs were used to some degree by all producers in the Base cases for the selected fields, the Base cases for field groups B9/B10/B12 and D1-D3 were minimally impacted by existing BMPs. Therefore, for the purposes of this study, fields B9/B10/B12 and D1-D3 represented the best examples of livestock-based and cash crop-based rotations, respectively, when comparing the relative impacts of the BMP scenarios with the Base case.

The estimated N_{pl} (Table 16) and the relative reduction in estimated N_{pl} (Table 17) for each BMP scenario, compared to the Base case, were calculated for each representative group of fields (A1-A4; B9/B10/B12; C1-C4; D1-D3) within the capture zone from 1981 to 2008, the years for which published crop budget data were available (OMAFRA).

In the Base case, estimates of N_{pl} ranged from a low of 21 kg N/ha/yr for field group D1-D3 to a high of 75 kg N/ha/yr for field group B9/B10/B12. BMP21 (soil N test) resulted in a 12% (B9/B10/B12 at 65 kg N/ha/yr) to 28% (D1-D3 at 15 kg N/ha/yr) reduction in N_{pl} relative to the Base case across the field groups (Table 16 and Table 17). BMP22 (N balance) resulted in a 14% (C1-C4 at 26 kg N/ha/yr) to 73% (B9/B10/B12 at 20 kg N/ha/yr) relative reduction in N_{pl} across the field groups. BMP23 (max N balance) resulted in a 2% (D1-D3 at 21 kg N/ha/yr) to 70% (B9/B10/B12 at 22 kg N/ha/yr) relative reduction in N_{pl} across the field groups. BMP24 (drop manure) resulted in a 0% (D1-D3 at 21 kg N/ha/yr) to 80% (B9/B10/B12 at 15 kg N/ha/yr) relative reduction in N_{pl} across the field groups. BMP25 (drop manure/corn) resulted in a 23% (D1-D3 at 16 kg N/ha/yr) to 77% (B9/B10/B12 at 17 kg N/ha/yr) relative reduction in N_{pl} across the field groups.

Those field groups where manure/biosolids were used during crop production (A1-A4; B9/B10/B12; C1-C4) showed the greatest potential for reduction of N_{pl} across all of the BMP scenarios. BMP22 (N balance) and BMP23 (max N balance) reduced the estimated N_{pl} to ≤26 kg N/ha/yr across the livestock-based field groups (A1-A4; B9/B10/B12; C1-C4) while BMP24 (drop manure) and BMP25 (drop manure/corn) reduced the estimated N_{pl} to ≤17 kg N/ha/yr. For field group D1-D3, the cash crop-based field group, BMP21, BMP22 and BMP25 reduced the estimated N_{pl} to ≤16 kg N/ha/year. BMP23 and BMP24 had no net effect on N_{pl}.

Table 16 Estimated Potentially Leachable Nitrogen (N_{pl}) Per Field Group, Economic Analysis, 1981-2008, Region of Waterloo, ON

Field Group	Estimated Potentially Leachable Nitrogen (N_{pl})					
	Base	BMP21	BMP22	BMP23	BMP24	BMP25
		Soil N test	N balance	Max N balance	Drop manure	Drop manure and corn
	(kg N/ha/yr)					
A1-A4	46	39	23	17	11	17
B9/B10/B12[1]	75	65	20	22	15	17
C1-C4	30	23	26	25	10	17
D1-D3[2]	21	15	16	21	21	16
All Fields	35	28	22	22	14	17

[1]Field group B9/B10/B12 represents the best example of a livestock-based rotation when comparing the relative impacts of the BMP scenarios with the Base case.

[2]Field group D1-D3 represents the best example of a cash crop-based rotation when comparing the relative impacts of the BMP scenarios with the Base case.

Table 17 Relative Reduction in Estimated Potentially Leachable Nitrogen (N_{pl}) Per Field Group, Economic Analysis, 1981-2008, Region of Waterloo, ON

Field Group	Relative Reduction in N_{pl} [1]					
	Base	BMP21	BMP22	BMP23	BMP24	BMP25
		Soil N test	N balance	Max N balance	Drop manure	Drop manure and corn
	(% decrease in N_{pl})					
A1-A4	100	14	49	64	76	63
B9/B10/B12[2]	100	12	73	70	80	77
C1-C4	100	25	14	17	66	43
D1-D3[3]	100	28	22	2	0	23
All Fields	100	20	35	37	60	52

[1] Based on estimates of N_{pl} (kg N/ha/yr) in Table 16

[2] Field group B9/B10/B12 represents the best example of a livestock-based rotation when comparing the relative impacts of the BMP scenarios with the Base case.

[3] Field group D1-D3 represents the best example of a cash crop-based rotation when comparing the relative impacts of the BMP scenarios with the Base case.

4.3.7 Comparison of N_{pl} Results for All Fields in the Capture Zone versus the Subset of Fields in the Economic Analysis

In this study, estimates of N_{pl} were developed using all available data for field groups A, B, C, D and E in the capture zone. The economic analysis, however, required more consistency in the database to make it more representative of normal practice for livestock and cash crop-based operations using a corn/beans/wheat rotation. A subset of fields from field groups A, B, C and D was selected to meet this requirement and the corresponding N_{pl} values were tabulated (Table 16 and Table 17). The N_{pl} values for all data and the subset of data were compared (Table 18) to determine whether the results of the economic analysis could be extrapolated to the entire capture zone. The environmental analysis of all field groups included a time step of 29 yrs (1980-2008) and an area of 265 ha within the capture zone compared to the subset of fields used in the economic analysis, which included a time step of 28 yrs and an area of 170 ha within the capture zone (Table 18).

Two of the four field groups (C1-C4 and D1-D3) included one less year in the time step but the same areas within the capture zone. For the C and D field groups, there were no differences between the two analyses in relative reduction in estimated N_{pl} (Table 18).

Two of the four field groups (A1-A4 and B9/B10/B12) included one less year in the time step and smaller areas because fields were dropped (i.e., A5 and B11 with long-term alfalfa/pasture) from their respective field groups due to anomalies in field management practices that could bias the findings for a standard corn/beans/wheat rotation. There were minimal differences between the A field groups (≤2% difference) and small differences between the B field groups (≤6% difference) in relative reduction in estimated N_{pl} for the two analyses across all BMP scenarios (Table 18).

The results suggest the economic analysis was representative of livestock- and cash crop-based rotations that may be considered normal practice in Ontario. The economic analysis eliminated unique agricultural production factors within the capture zone in this study that could influence the results of the economic analysis and make them less applicable to other parts of Ontario. Whereas the capture zone analysis included all the normal and unique features associated with agricultural production in the area e.g., horticultural crop production on 5% of the land and fields in long-term alfalfa/pasture.

Care should be taken when extrapolating the N_{pl} results for each BMP scenario within the economic analysis to the capture zone as a whole, due to differences in the estimated mean annual N_{pl} values and related environmental rankings across all fields in the capture zone, compared to the subset of fields used in the economic analysis (Table 18 Differences in Relative Reduction in Estimated Potentially Leachable Nitrogen (Npl) for All Fields Analysis, 1980-2008 and Subset Fields in Economic Analysis, 1981-2008, Region of Waterloo, ON
). In the economic analysis, the estimated mean annual reduction in N_{pl} differed by +6%, 0, -11%, +3% and -5% for BMP21 (soil N test), BMP22 (N balance), BMP23 (max N balance), BMP24 (drop manure) and BMP25 (drop manure/corn), respectively, compared to the analysis for all fields within the capture zone.

**Although the environmental ranking for each BMP (which was based on the N_{pl} results) was the same or within one level for the subset of fields compared to all fields, the differences in percentage reduction in N_{pl} between the two analyses impact the calculated 'cost of 1% reduction in N_{pl}' in the economic analysis (see Section 5.0 Economic Analysis and
Table 25 Cost-Effectiveness Ratios). Consequently, the calculated 'cost of 1% reduction in N_{pl}' within the economic analysis is not readily extrapolated to the capture zone as a whole. For example, in BMP21 (soil N test) the 6% difference in N_{pl} (20% reduction for subset fields in the economic analysis vs 14% reduction for all fields in the capture zone analysis) results in a lower calculated 'cost of 1% reduction in N_{pl}' for the subset fields in the economic analysis (Table 18 and** Table 25).

Table 18 **Differences in Relative Reduction in Estimated Potentially Leachable Nitrogen (N_{pl}) for All Fields Analysis, 1980-2008 and Subset Fields in Economic Analysis, 1981-2008, Region of Waterloo, ON**

Field Group	Fields	No. of Yrs	Relative Reduction in N_{pl} [1]						
			Base	BMP21 Soil N test	BMP22 N balance	BMP23 Max N balance	BMP24 Drop manure	BMP25 Drop manure/corn	Difference Range
			(% decrease in N_{pl})						(%)
A - All	A1-A4 + A5	29	100	16	49	63	74	64	0-2
A – Subset (economic analysis)	A1-A4	28	100	14	49	64	76	63	
B - All of subgroup	B9/B10/B12 + B11[2]	29	100	14	68	65	74	76	1-6
B – Subset (economic analysis)	B9/B10/B12	28	100	12	73	70	80	77	
C - All	C1-C4	29	100	25	13	18	66	44	0-1
C – All (economic analysis)	C1-C4	28	100	25	14	17	66	43	
D - All	D1-D3	29	100	27	23	1	0	24	0-1
D – All (economic analysis)	D1-D3	28	100	28	22	2	0	23	
B - All of subgroup	B1-B7	29	100	15	54	52	63	74	-
B - All of subgroup	B8B13[3]	29	100	42	-46	-46	25	25	-
E - All	E1E2	29	100	0	24	69	52	52	-
Overall reduction in N_{pl} (% decrease in N_{pl})									
All Fields[4] (265 ha)		29	100	14	34	48	57	57	0-11
Subset Fields (economic analysis) (170 ha)		28	100	20	35[5]	37[5]	60	52	
Rank (1=greatest reduction in N_{pl})									
All Fields[4] (265 ha)		29		4	3	2	1	1	0-1 rank
Subset Fields (economic analysis) (170 ha)		28		5	4[5]	3[5]	1	2	

[1] For estimates of N_{pl} (kg N/ha/yr) see Table 15 and Table 16

[2] Field B11 included alfalfa and variations in manure applications

[3] Estimated N_{pl} increased from 6 kg N/ha/yr in Base case to 9 kg N/ha/yr in BMP23 and BMP24

[4] Also included fields A5, B1-B7, B11, B8B13, E1E2

[5] These BMP scenarios were substantially equivalent (difference in N_{pl} reduction ass <10%)

4.3.8 Reliability and Sensitivity of Estimates of the Effectiveness of Nitrogen Beneficial Management Practices

4.3.8.1 N Budgets as a Qualitative Tool for Comparing Nitrogen Management Practices and Estimates of N_{pl} per Field

The use of assumed values in each line item in the annual N budget created uncertainty in the resulting estimate of N_{pl}, especially as the time step expanded beyond the availability of detailed field information. Uncertainty in N budget terms is discussed in detail by Meisinger and Randall (1991). The N budget calculations were mainly sensitive to inputs of commercial fertilizer, manure/biosolids, and crop types and yields. When used to compare 'what if' scenarios; however, N budgets are a very useful method for predicting relative N_{pl} available to leach into groundwater from various farming systems (Cole, 2008; Barry *et al.*, 1993; Meisinger and Randall, 1991).

4.3.8.2 Comparison of N_{pl} Results for Field Measurements versus N Budgets

Site-specific field sampling and measurement are required to estimate the actual amount of N (also referred to as nitrate load) present below the plant root zone and potentially available to leach into groundwater (N_{pl}). However, obtaining this field data is costly. Estimates of N_{pl}, calculated using N budgets, provide a qualitative assessment of potential nitrate load. Although N budget estimates of N_{pl} are less costly to prepare, they also may be less representative of actual field conditions and are best used to compare 'what if' scenarios related to nitrogen management practices (Meisinger and Randall, 1991).

In this study, field and N budget estimates of N_{pl} were compared. The comparisons were not time-related as the field measurements were obtained for the 2009 crop year and the N budgets were calculated for the crop years up to 2008. The comparison of results showed that the estimates of N_{pl} calculated from actual field measurements were similar to the estimates of N_{pl} calculated using N budgets (Table 19).

Shallow soil coring location BH2-08 was located in the southern portion of field A4, which was in continuous corn production since 2005. The amount of nitrogen available to leach into groundwater (N_{pl}) was calculated to be 15 kg N/ha based on field measurements and assumed root zone bottoms of 0.6 m and 0.9 m. N budget estimates of N_{pl} from 2005 to 2008 ranged from 15 kg N/ha to 0 kg N/ha, respectively, depending on previous crop.

Shallow soil coring location BH7-08 was located at the northwest corner of field B8. Field B8 typically included 7 yrs of alfalfa hay plus 1 yr of corn in the crop rotation. The first year of alfalfa hay was grown in 2009 after underseeding in 2008. The amount of nitrogen available to leach into groundwater (N_{pl}) was calculated to be 10 kg N/ha and 8 kg N/ha based on field measurements and assumed root zone bottoms of 0.6 m and 0.9 m, respectively. N budget estimates of N_{pl} for 2001 and 1994 were 20 kg N/ha and 0 kg N/ha, respectively.

Table 19 **Comparison of Estimates of Potential Leachable Nitrogen, Field Measurements versus N Budgets, Region of Waterloo, ON**

<table>
<tr><th colspan="5">Field Measurement</th><th colspan="5">N Budget - Estimate of Base Case</th></tr>
<tr><th rowspan="2">Field Location[1]</th><th rowspan="2">Time[2]</th><th rowspan="2">Crop</th><th>Soil Depth[3]</th><th>Estimated Nitrogen Load (N_{pl})</th><th rowspan="2">Field Location</th><th rowspan="2">Time</th><th rowspan="2">Crop[4]</th><th>Soil Depth</th><th>Estimated Nitrogen Load (N_{pl})</th></tr>
<tr><th>(m BGS)</th><th>(kg N/ha/yr)</th><th></th><th>(kg N/ha/yr)</th></tr>
<tr><td rowspan="4">A4; south</td><td rowspan="4">Mar 2009-Apr 2010</td><td rowspan="4">corn after corn</td><td rowspan="2">0.6-4.0</td><td rowspan="2">15</td><td rowspan="4">A4</td><td>2008</td><td rowspan="3">corn after corn</td><td rowspan="4">below the root zone</td><td rowspan="3">0</td></tr>
<tr><td>2007</td></tr>
<tr><td rowspan="2">0.9-4.0</td><td rowspan="2">15</td><td>2006</td></tr>
<tr><td>2005</td><td>corn after soybeans</td><td>15</td></tr>
<tr><td rowspan="2">B8; northwest</td><td rowspan="2">Mar 2009-Apr 2010</td><td rowspan="2">alfalfa; first year after underseed to barley</td><td>0.6-2.3</td><td>10</td><td rowspan="2">B8</td><td>2001</td><td rowspan="2">alfalfa; first year after underseed to barley</td><td rowspan="2">below the root zone</td><td>20</td></tr>
<tr><td>0.9-2.3</td><td>8</td><td>1994</td><td>0</td></tr>
<tr><td rowspan="2">B11; east</td><td rowspan="2">Mar 2009-Apr 2010</td><td rowspan="2">white beans after corn</td><td>0.6-3.1</td><td>68</td><td rowspan="2">B11</td><td>2005</td><td rowspan="2">white beans after corn</td><td rowspan="2">below the root zone</td><td>33</td></tr>
<tr><td>0.9-3.1</td><td>39</td><td>1993</td><td>10</td></tr>
</table>

BGS = below ground surface

N_{pl} = potentially leachable nitrogen; i.e., nitrogen present below the plant root zone

[1] sampling locations: field A4 at BH2-08; field B11 at BH5-08; field B8 at BH7-08

[2] bromide tracer applied on Mar 4, 2009 at BH2-08 and BH5-08 and on Mar 27, 2009 at BH7-08

[3] upper value represents assumed bottom of root zone;
lower value represents 1 year terminal depth of bromide tracer

[4] crop type; includes crop and manure rotation histories most similar to 2009 field samples; A4 no manure since 1999; B8 manure in 2007 and 1999 only; B11 manure applied every year or every other year

Nitrogen budgets for hay fields are difficult to estimate. Unlike a standard crop such as corn, wheat or beans, hay fields are harvested multiple times in a year. With each harvest, nitrogen is removed with the hay. Therefore, the amount of nitrogen removed through harvest can vary greatly depending on the number of times the field is harvested in a given year. In addition, hay is comprised of alfalfa and grass. Alfalfa is a legume that fixes nitrogen from the atmosphere and has relatively high nitrogen content. As each year passes, the ratio of alfalfa to grass changes, with alfalfa generally dying out over the initial three to five years. As a result, the nitrogen content of the hay mixture varies with time. This causes the estimates of N_{pl} associated with hay to be more variable than for other crops. The field measurements and N budget N_{pl} estimates suggest that nitrate load from hay fields is low and, given the acreage involved in the capture zone, not a significant contributing factor to nitrate loading within the aquifer.

Shallow soil coring location BH5-08 was located along the eastern portion of field B11. In 2009, white beans were grown in the field. The amount of nitrogen available to leach into groundwater (N_{pl}) was calculated to be 68 kg N/ha and 39 kg N/ha based on field measurements and assumed root zone bottoms of 0.6 m and 0.9 m, respectively. N budget estimates of N_{pl} for 2005 and 1993 were 33 kg N/ha and 10 kg N/ha, respectively. Historically, manure was applied to this field every year or every other year. Inconsistencies in application rates and methods plus environmental conditions have a substantial impact on the actual amount of nitrogen in the soil, making it difficult to match field measurements with N budget estimates of N_{pl}.

4.3.9 Estimates of Nitrate Concentrations in Groundwater at the Production Well

The results from the MBM, which estimated the concentration of nitrate in groundwater at the production well, are provided in a separate report submitted to the Region by Stantec.

The relative reductions in estimates of N_{pl} at the farm field level translated into relative reductions in the concentration of N in groundwater at the production well when simulated using the mass balance model (MBM) to the year 2100. The results of this study suggest that implementation of N BMP scenarios designed to enhance existing nitrogen management practices (BMP21 (soil N test), BMP22 (N balance) and BMP23 (max N balance)) or remove key sources of nitrogen (BMP24 (drop manure) and BMP25 (drop manure/corn)) in agricultural fields represent effective environmental strategies for ensuring groundwater obtained at the production well in the future will meet the Ontario Drinking Water Standard (ODWS) for nitrogen (10 mg/L). However, the results for BMP21 (soil N test) approached the ODWS in 2075 (i.e., 9.76 mg/L), which suggested it was the least effective from an environmental perspective of the five nitrogen BMP scenarios evaluated in this study.

4.4 OBSERVATIONS

The following observations were made during the development and evaluation of the estimates of the effectiveness of nitrogen beneficial management practices:

1. The capture zone was considered representative of a rural landscape with approximately 70% of the land used for agricultural production.

2. The type and range of agricultural production practices observed within the capture zone of the production well were typical of southern Ontario. The use of biosolids and the production of cabbage, squash, pumpkins and lettuce (5% of capture zone area) were noted as these practices are less widely used in southern Ontario.

3. The reliability and extent of available information and data related to actual agricultural land management practices was considered good to excellent (representative of >90% of agricultural land within the 15-yr SWAT and ~44% of the overall capture zone), which provided a sound basis for data extrapolation when needed.

4. The level and accuracy of detailed information across farm operations was inconsistent for various reasons including: loss of operational memory due to a change in farm manager/owner during the study time step (i.e., up to 49 yrs); lack of available or access to written records for some or all of the study time step; open-ended interviews provided less consistent information than may have been obtained using a survey instrument.

5. In the Base case the use of N BMPs on fields within the capture zone increased during the 2000-2008 time step. The reasons for these changes were not identified within the scope of this study.

6. All producers interviewed in this study indicated they were using at least one or more N BMPs in their normal farm practice (i.e., within the Base case). Therefore, the implementation of the BMP scenarios included in this study represented a 'staggered start line' where individual BMPs from each scenario were added to the field management strategy in the N budget to support the achievement of the desired N balance and thus limit the potential for N leaching into groundwater.

7. The N budget process used a consistent, repeatable, science-based approach that yielded scientifically defensible results. The framework for the N budgets was developed using two key papers by Meisinger and Randall (1991) and Barry *et al.* (1993). Regional relevancy of the N budgets was achieved by using Ontario-based references (e.g., *Soil Fertility Handbook* Pub. 611; *Agronomy Guide for Field Crops* Pub. 811; *NMAN2* software), which were used to support assumptions related to N budget line items. The opinion of an experienced agrologist was used to fine tune the assumptions when published sources provided a range of values.

8. In future studies, the N budget frameworks from this study and its complementary study (Brethour *et al.*, 2009) should be considered to determine which framework is best suited to the needs of the study.

9. In the Base case there was a general decline in the use of manure/biosolids within the capture zone during the study time step (1960-2008); however, this decline was not consistent for all fields within the capture zone.

10. Those field groups where manure/biosolids were used during crop production (A1-A4; B9/B10/B12; C1-C4) showed the greatest potential for reduction of N_{pl} across all of the BMP scenarios.

11. During the 2000s, the time step for which data were most accurate, the BMP23 (max N balance) and BMP24 (drop manure) scenarios had similar impacts on N_{pl} while the BMP25 (drop manure/corn) scenario had a greater impact during the first part of the decade and a similar impact during the latter part of the decade. The results suggest that, in future terms, any of the three scenarios may be the most effective N management strategy for reducing N_{pl} to groundwater within the capture zone.

12. In the analysis, key characteristics such as soil type, crop rotation, and existing N management practices were not uniform across the study area. This made the nitrogen budgeting process complex. The N budget approach provided a useful framework for conducting a detailed and consistent assessment of N inputs and outputs within the capture zone of the production well.

13. Meisinger and Randall (1991) recommended using criteria based on local information to create N_{pl} categories (e.g., high, medium, low) that would help users interpret estimates of N_{pl} obtained from N budgets. Fields with estimated N_{pl} values in the high category could be sampled first to determine the actual amount of nitrogen available to leach into groundwater. In this study, the estimates of N_{pl} from actual field measurements compared well with the estimates of N_{pl} from the N budgets (Table 19) which, in turn, compared well with N budget values discussed by Meisinger and Randall (1991). This suggests the N budgets were a useful method for: i) prioritizing where field samples should be obtained within the capture zone to confirm the need for enhanced N management strategies and/or ii) identifying what and where enhanced N management strategies should be most effective within the capture zone.

14. The relative estimate of mean annual N_{pl} generally decreased as the intensity of N management increased i.e., from the BMP21 (soil N test) scenario to the BMP22 (N balance) scenario to the BMP23 (max N balance) scenario (Figure 7). The relative estimate of mean annual N_{pl} was generally lower for the remaining two BMP scenarios, which represented significant targeted external influences on producer N use i.e., BMP24 (drop manure) and BMP25 (drop manure/corn) (except for BMP24, which was similar to BMP23 toward the end of the study time step) (Figure 7).

15. The relative decline in estimated N_{pl} varied for individual field groups across the BMP scenarios depending on the number of BMPs in use within the Base case. Those field groups with more N BMPs in use within the Base case (C and D field groups) realized a lower relative reduction in estimated N_{pl} than those field groups with fewer BMPs in use within the Base case (A, B and E field groups) (Table 18).

16. Field group B9/B10/B12 represented the best example of a livestock-based rotation with very few or no BMPs in place within the Base case during the 1981-2008 time step evaluated in the economic analysis. In comparative terms, the estimates of N_{pl} were 75, 65, 20, 22, 15, 17 kg N/ha/yr for the Base case and BMP21, BMP22, BMP23, BMP24, and BMP25 scenarios, respectively (Table 16). This corresponded to a 70 to 80% reduction in N_{pl} across BMP22 (N balance), BMP23 (max N balance), BMP24 (drop manure), and BMP25 (drop manure/corn) scenarios. A 12% reduction in estimated N_{pl} occurred under BMP21 (soil N test) when the commercial nitrogen inputs for corn were reduced by up to 22.4 kg/ha (i.e., 20 lb/ac) (Table 17) based on the assumption that real time information about soil N content could lead to improved N management decisions.

17. Field group D1-D3 represented the best example of a cash crop-based rotation with few BMPs in place within the Base case during the 1981-2008 time step evaluated in the economic analysis. In comparative terms, the estimates of N_{pl} were 21, 15, 16, 21, 21, 16 kg N/ha/yr for the Base case and BMP21 (soil N test), BMP22 (N balance), BMP23 (max N balance), BMP24 (drop manure), and BMP25 (drop manure/corn) scenarios, respectively (Table 16). This corresponded to a 0 to 23% reduction in N_{pl} across BMP22 (N balance), BMP23 (max N balance), BMP24 (drop manure), and BMP25 (drop manure/corn) scenarios. A 28% reduction in estimated N_{pl} occurred under BMP21 (soil N test) when the commercial nitrogen inputs for corn were reduced by up to 22.4 kg/ha (i.e., 20 lb/ac) (Table 17) based on the assumption that real time information about soil N content could lead to improved N management decisions. Since BMP21 resulted in a greater decline in N_{pl} relative to the other more intensive BMP scenarios, the result for BMP21 may overestimate the potential reduction achievable for the D field group.

18. The relative reductions in estimates of N_{pl} at the farm field level translated into relative reductions in the concentration of nitrogen in groundwater at the production well when simulated using a mass balance model (MBM) to the year 2100. The results of this study suggest that implementation of N BMP scenarios designed to enhance existing N management practices (BMP21 (soil N test), BMP22 (N balance) and BMP23 (max N balance)) or remove key sources of nitrogen (BMP24 (drop manure) and BMP25 (drop manure/corn)) in agricultural fields represent effective agronomic and environmental strategies for ensuring groundwater obtained at the production well in the future will meet the Ontario Drinking Water Standard (ODWS) for nitrogen (10 mg N/L). However, the results for BMP21 (soil N test) approached the ODWS in 2075 (i.e., 9.76 mg/L), which suggested it was the least effective of the five nitrogen BMP scenarios evaluated in this study.

19. The mean estimates of long-term N_{pl} for the BMP scenarios ranged from 19 to 38 kg N/ha/yr compared to the mean estimate of N_{pl} for the Base case (44 kg N/ha/yr) (1980-2008; n=29 yrs; Table 15). In percentage terms, the mean estimates of N_{pl} for the BMP scenarios were approximately 14 to 57% less than the mean estimate of N_{pl} for the Base (Figure 6) i.e.,
    - 57% less N_{pl} under BMP24 (drop manure) and BMP25 (drop manure/corn);
    - 48% less N_{pl} under BMP23 (max N balance);
    - 34% less N_{pl} under BMP22 (N balance); and
    - 14% less N_{pl} under BMP21 (soil N test).

5 ECONOMIC ANALYSIS

This section provides an overview of the approach and results from the economic analysis of the nitrogen BMP scenarios. The purpose of this analysis was to determine the costs of implementing the alternative BMP scenarios. The analysis is conducted in retrospective: the timeframe for the economic analysis ranges from 1981 to 2008 (28 years). The costs of BMP implementation are assessed by taking the difference in profits on a field by field basis between the Base case and the respective BMP scenarios, adjusting for the timing of costs using the present value method.

5.1 APPROACH

Figure 9 provides an overview of the economic analysis. For all scenarios, the revenue is calculated by the given yield times the prices in the respective years. The historical prices for the crops were obtained from OMAFRA. Data for the basic crop budgets were taken from OMAFRA's annually published crop budgets from 1981 to 2008 to establish the Base case, represented by the actual (including BMPs already implemented by the producer) and extrapolated N management practices used on the agricultural fields within the capture zone. The crop yields and fertilizer application rates were used as inputs from the previously described model, where the costs for commercial fertilizer are based on OMAFRA crop budgets for the respective years.

In each case, the present value of profits were simulated for the Base case and BMP scenarios, in 2008 terms, using a 5% discount rate. The difference in present values between each of the BMP scenarios versus the Base case allowed the BMP cost to be evaluated. For easier interpretation, the present value difference results for the BMP were converted to an annual value per acre (per hectare) over the 1981-2008 period.

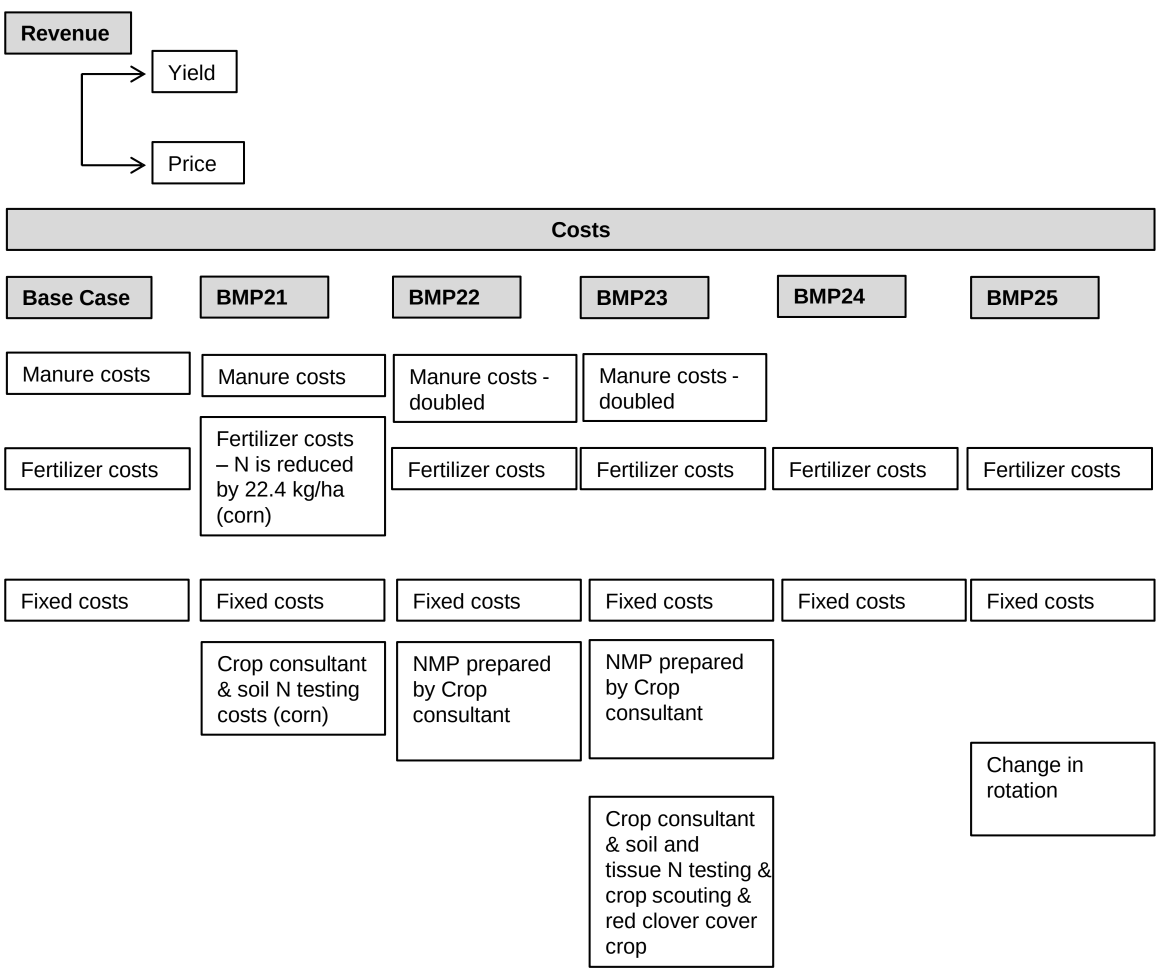
The following costs are additional or different according to the various BMP scenarios compared with the Base case: manure application costs, commercial fertilizer and application costs, soil and tissue N testing, red clover seed and crop advisor costs, which are described in the BMP scenario overview below.

The application of manure represents a cost to the producer that was variable across the Base case and the BMP scenarios. OMAFRA conducts a custom farm work rates survey every three years. Survey results were reported for different regions across Ontario. Where possible, results for Region 3 (which includes Waterloo) were applied. The average of the survey rates was incorporated; where there were gaps in survey data the two years in between were estimated using the average of the two years where survey results were available. The appendix lists the costs for manure application that were used in the analysis.

In some cases, fields were converted into pasture. To account for the establishment of pasture, the establishment costs for alfalfa were taken into account for the initial year (based on OMFRA crop budgets). For the years the pasture was in use, pasture rental rates were established. These pasture rental rates were based on a current survey in Bruce County. It was assumed that the pasture was rented to graze beef cows and calves. The daily rental rate for 150 days was $0.72 per head and an entry fee of $10 per head applies. The stocking rate was 1.38 acres/head. These values were deflated with the farm input price index. The assumed pasture rental rates are presented in the appendix (**Error! Reference source not found.**).

The BMP scenarios described below include five suites of BMPs that vary the level of N management for crop production while reducing the amount of nitrogen potentially available to leach into groundwater. In each case, except one (BMP25 (drop manure/corn)), the BMPs enhanced management practices, but maintained the same crop yield as in the Base case. In BMP25 (drop manure/corn), a soybean-wheat crop rotation was assumed. Crop yields were extrapolated based on OMAFRA yield data and weighted according to each producer's normal historical yield results. The following section describes the cost assumptions for each BMP scenario.

Figure 9 Economic Analysis - Method Overview



In most cases, fixed costs, manure application costs and fertilizer costs were deducted from revenue, except in the BMP24 (drop manure) and BMP25 (drop manure/corn) scenarios, where no manure was applied. The Base case was calculated by deducting manure application, fertilizer and fixed costs from the revenue.

BMP21 – Soil Nitrogen Test and Fertilizer N Reduction

This BMP scenario was applied only to fields were corn was planted. For BMP21 (soil N test), manure was still applied to the field, but the commercial fertilizer rate was reduced by 20 lb/acre (22.4 kg/ha) (actual N). It was assumed that a crop consultant visited each producer in years that corn was grown to discuss findings and management options. According to a crop consultant (personal communication, Steve Redmond, PAg, CCA), the crop consultant would take 2 soil samples, where the analysis would cost approximately $50 and the time for the crop consultant $60, at present time.

These costs would not have been incurred in the 1980's and were thus not available. The current crop consultant and soil nitrogen testing costs were deflated with the Statistics Canada Farm Input Price Index. As an example, in 1981 the cost for soil N sampling and consultant time were assumed to be $28 and $34, respectively. The costs for crop consultant services and soil N sampling were added in the years in which corn was planted. As a result, less N was applied, which was reflected in the lower commercial fertilizer costs.

BMP22 – Nitrogen Balance

Under this BMP scenario, producers' existing agricultural practices were adjusted to balance the amount of N needed by the crops and to minimize the amount of N_{pl}. A crop consultant prepared a nutrient management plan for the producer. After consultation with a crop consultant, the cost for the time of the crop consultant was assumed to be $5 per acre ($12/ha), which was deflated with the farm input price index (see appendix **Error! Reference source not found.**). In BMP22 (N balance), for the purposes of the economic analysis, all manure application rates were halved and the manure applied over double the area compared with the Base case, under the assumption that additional land outside of the study fields was available for manure disposal. Thus, the costs of manure application costs were doubled. (For the purposes of the capture zone analysis, the manure application rates in the N budgets were determined using NMAN2 software and the rates were not necessarily halved in all situations.)

BMP23 – Maximum Nitrogen Balance

Under this BMP scenario, producers' agricultural practices were adjusted and/or changed to maximize N management opportunities to balance the amount of N needed by the crops and to further minimize the amount of N_{pl}. This BMP scenario included all of the practices and related assumptions used for BMP22. In addition, a red clover cover crop was established during wheat production and the crop consultant assists in conducting soil and tissue N testing, and crop scouting. These costs are listed as well in **Error! Reference source not found.** and **Error! Reference source not found.** in the appendix.

BMP24 – Drop Manure

In this BMP scenario it was assumed that no manure was applied on the fields. The assumption was that if manure had previously been applied on study area fields that it could be redirected and applied to nearby fields at essentially no additional cost[10]. The same crop rotation as in the Base case was assumed. No consultant costs were assumed in this scenario.

BMP25 – Drop Manure and Corn

In the final BMP scenario, manure was not applied to the fields and, in addition, corn was removed from the crop rotation within the capture zone. No consultant costs were assumed. The crop rotation and yields were changed to account for the removal of corn; a soybean-wheat rotation was assumed.

5.2 DATA

Table 20 represents a summary of data used in this assessment and the respective sources.

Table 20 Data Sources for Field Crops

Data	Source
Crop yields, nitrogen sources and rates	Input from N budgets used in N MBM – Cordner Science and Stantec
Farm operating expenses and fixed costs	OMAFRA crop budgets
Prices for field crops	OMAFRA Field crop statistics http://www.omafra.gov.on.ca/english/stats/crops/index.html
Machinery costs – manure and fertilizer application	OMAFRA, Customer services survey, received from John Molenhuis, Business Analysis and Cost of Production Program Lead at OMAFRA
Fertilizer prices	Historical OMAFRA crop budgets
Prices for soil and tissue nitrogen testing	Consultation with crop consultant – Steve Redmond PAg CCA

The assessment of the BMP scenarios focused on the ongoing use of BMPs by producers; it did not address costs transferred elsewhere e.g., to the municipality, due to restrictions imposed on normal farm practice (in the case of manure) or the cost of purchasing new equipment when adopting new practices. For example, the costs of disposing / using manure that could not be applied by the producer due to restrictions in the capture zone per BMP24 (drop manure) or BMP25 (drop manure/corn) were not assessed. Furthermore, there may be additional management skills or time required when more tasks must be considered within critical time periods in the growing season per BMP21 (soil N test), BMP22 (N balance) or BMP23 (max N balance), and these factors were not considered within the scope of the study.

[10] Site specific conditions would determine the extent to which manure can be easily redirected and applied elsewhere. However, in the broader mixed crop-livestock area surrounding the study fields, it is reasonable to expect that manure could be easily redirected; indeed, there could be a revenue stream from manure transfers although this was not considered in this study.

5.3 RESULTS

In order to calculate the profit differences, the present value of profits in the respective BMP scenarios was deducted from the present value under the Base case. The results were presented on a per field and acre (hectare) basis. Revenue and costs were accounted for in nominal terms. The annual profit differences over the time period were compounded from 1981 to 2008, using a 5% discount rate.

Field A

Field A was divided into 4 subfields, totalling 86 acres (34.80 ha). Fields A1-A4 were under a soybean/corn rotation. Commercial fertilizer and manure were only applied on corn. In years when chicken manure was not applied, inorganic N in the form of UAN (28% nitrogen) was applied. Establishment costs for pasture were assumed to be similar to alfalfa establishment costs. Once the pasture was established no further maintenance costs were assumed. For soybeans, all costs were accounted for as per OMAFRA crop budgets. Although the N budget used to estimate potentially leachable nitrogen (N_{pl}) in this study does not include the application of additional N during soybean production, the costs for monoammonium phosphate (MAP) are included in the economic budget based on the OMAFRA crop budget. For corn fertilizer, the fertilizer costs for MAP were accounted for and the remainder of the N needed was accounted for by calculating the costs of urea or anhydrous ammonia for the required amount of N from the N budget.

Table 21 shows the differences in profits between the Base case and BMP scenarios. The first row shows the profit differences per BMP scenario on a per field basis, the second row shows the differences on an average per acre basis and the third row shows the average costs per acre per year on an annual basis, the fourth and fifth rows show these costs calculated on a per hectare basis.

As explained earlier, the BMP21 (soil N test) scenario involved the services of a crop consultant in years where corn was planted, which resulted in a reduction of fertilizer costs, as less fertilizer was applied. In this case, the reduced costs for fertilizer applied made up for the costs assumed for the consulting services. Hence, the results showed a net profit. For BMP21 (soil N test), the present value of adoption was $1,356 in increased profits over the time frame of 28 years (1981 to 2008) in the A fields. On a per acre basis, this amounted to $16 ($40/ha), or approximately $1 per acre/year ($2/ha/year) .

The present value of BMP22's (N balance) implementation cost (decreased profits) was $1,061 per acre ($2622/ha), or $38 dollars per acre per year ($94/ha/year). The costs were higher in this case than in the BMP21 (soil N test) scenario because the manure application costs were doubled. Furthermore, the costs for the preparation of a nutrient management plan were included as well. The crop consultant costs in the BMP21 scenario only incurred to corn fields. However, in this case, the costs for the preparation of the nutrient management plan by the consultant were distributed over all fields.

The second most costly option was scenario BMP23 (max N balance) as it included an entire suite of N best management practices, as explained earlier. The annual costs for scenario BMP23 (max N balance) amounted to $1646 per acre ($4067/ha) and $59 per acre ($146/ha) on an annual basis.

The most costly option was BMP25 (drop manure/corn) at $127/acre/year ($314/ha/year). The significant differences in profit occurred here because the rotation changed to include wheat and soybeans where corn was the more profitable crop. Hence, the adoption of BMP25 (drop manure/corn) incurred the highest profit loss.

The most beneficial scenario was BMP24 (drop manure) as the costs of manure application were not incurred. This generated a net benefit through the BMP implementation, and accrued to $31 per acre per year ($77/ha/year).

Table 21 Results - A Fields

	BMP21	BMP22	BMP23	BMP24	BMP25
Field	$ (1,356)	$ 91,273	$ 141,516	$ (75,533)	$ 306,426
Per acre	$ (16)	$ 1,061	$ 1,646	$ (878)	$ 3,563
Per acre/yr	$ (1)	$ 38	$ 59	$ (31)	$ 127
Per ha	$ (40)	$ 2622	$ 4067	$ (2170)	$ 8805
Per ha/yr	$ (2)	$ 94	$ 146	$ (77)	$ 314

Field B (example of a normal livestock-based rotation - corn/beans/wheat)

Field B was divided into 13 subfields, totalling 150 acres (60.70 ha). In the Base case, fields B1-B7 and B9-B12 were generally under a corn/soybean/wheat rotation, which also included white beans, red clover plough down and/or alfalfa in different fields at different times in the rotation during the 29-year time step for this study. Fields B8 and B13 were under continuous alfalfa with 1 yr corn as a break crop in the rotation.

For the illustration of a livestock-based rotation, subfields B9, B10 and B12, totalling 35.8 acres (14.50 ha) were selected. For soybeans, all costs were accounted for as per OMAFRA crop budgets. Although the N budget used to estimate N_{pl} in this study did not include the application of additional N during soybean production, the costs for MAP were included in the economic budget based on the OMAFRA crop budget. For corn fertilizer, the fertilizer costs for MAP were accounted for and the remainder of the N was accounted for by calculating the costs of urea or anhydrous ammonia for the required amount of N from the N budget. The same approach was taken with wheat. In the BMPs where wheat was underseeded with red clover, the additional costs for red clover seed were included in the budget[11]. The additional costs are listed in the appendix in **Error! Reference source not found.**.

Table 22 shows the differences in profits between the Base case and BMP scenarios. The first row shows the profit differences per BMP scenario on a per field basis, the second row shows the differences on an average per acre basis and the third row shows the average costs per acre per year on an annual basis, the fourth and fifth rows show these costs calculated on a per hectare basis.

In BMP21 (soil N test) the fertilizer costs were reduced by 20 lbs/acre (22.4 kg/ha) and a crop consultant was hired for soil N testing, which only applied to the corn fields. For

[11] Manitoba Agriculture, Food and Rural Initiatives, Retrieved from: http://www.gov.mb.ca/agriculture/soilwater/nutrient/fnm02s02.html

this BMP, a present value of a benefit of $9 per acre per year ($22.24/ha/year) was incurred by the producer.

For the B Fields, BMP22 (N balance) included the application of manure in fewer years than the Base case. That is, manure was not applied on white beans and only for corn. Again, in the economic analysis, since manure application rates were generally decreased thus requiring more time and area to apply all of the manure, the manure application costs were doubled in the years where manure was applied. The costs for a crop consultant were accounted for in the preparation of a nutrient management plan. This generated a cost of $6 per acre per year ($15/ha/year).

Scenario BMP23 (max N balance) included the costs of a crop consultant associated with N testing of soil and plant tissue. The present value of costs per acre per year was $42 ($104/ha/year).

BMP24 (drop manure) generated a net benefit of $58 per acre per year ($143/ha/year), based on similar reasons as explained in the Field A scenario.

A new crop rotation was implemented in BMP25 (drop manure/corn) where, instead of the corn-soybean-wheat rotation, a soybean-wheat rotation was implemented with manure application removed. BMP25 generated a present value of net benefit of $39 per acre per year ($96/ha/year).

Table 22 Results - B Fields (Livestock-Based Rotation)

	BMP21	BMP22	BMP23	BMP24	BMP25
Field	$ (8,583)	$ 5,892	$ 42,061	$ (57,994)	$ (38,831)
Per acre	$ (240)	$ 165	$ 1,175	$ (1,620)	$ (1,085)
Per acre/yr	$ (9)	$ 6	$ 42	$ (58)	$ (39)
Per ha	$ (593)	$ 408	$ 2904	$ (4003)	$ (2681)
Per ha/yr	$ (22)	$ 15	$ 104	$ (143)	$ (96)

Field C

Field C was divided into five subfields, totalling 184 acres (74.5 ha). The Base case was a corn/soybean/wheat rotation. In some subfields alfalfa or pasture were grown.

The results in Table 23 show that, under a 5 percent discount rate, it would have resulted in a benefit for the producer of $ 74,096 to implement scenario BMP21 (soil N test) over the timeframe of 28 years in the C fields. This would have amounted to $ 403/acre ($996/ha) or $14 per acre per year ($35/ha/year), when considering the time frame of over 28 years. This BMP results in the highest benefit for the producer.

Scenario BMP24 (drop manure) resulted in the second highest net benefit, with a benefit of $33 per acre ($82/ha) and a $1 benefit per acre per year ($2/ha/yr).

With scenario BMP22 (N balance), the manure application costs were doubled and a crop consultant was engaged to implement a nutrient management plan. The implementation costs amounted to $669 per acre ($1653/ha) over the timeframe of 28 years, or $24 per acre per year ($59/ha/year).

The BMP23 (max N balance) scenario was again the second most costly as it included a whole suite of BMPs. The implementation costs amounted to $1,075 per acre ($2656/ha), or $38 per acre per year ($94/ha/year).

In the case of BMP25 (drop manure/corn) the present value of the implementation cost was $290,465, largely because corn was taken out of the rotation.

Table 23 Results - C Fields

	BMP21	BMP22	BMP23	BMP24	BMP25
Field	$ (74,096)	$ 123,176	$ 197,825	$ (6,089)	$ (290,465)
Per acre	$ (403)	$ 669	$ 1,075	$ (33)	$ (1,579)
Per acre/yr	$ (14)	$ 24	$ 38	$ (1)	$ (56)
Per ha	$ (996)	$ 1653	$ 2656	$ (81)	$ (3902)
Per ha/yr	$ (35)	$ 59	$ 94	$ (2)	$ (138)

Field D (example of a normal cash crop-based rotation - corn/beans/wheat)

Field D was divided into three subfields totalling 114 acres (58.27 ha). The cropping rotation in the Base case was corn/soybean/wheat. Fertilizer was applied to winter wheat and corn, but no manure was applied in the Base case. No manure was applied on these fields in the BMP scenarios either. Table 24 presents the differences in profits between the Base case and the BMP scenarios.

The results showed that, under a 5 percent discount rate, the present value of benefits of implementing BMP21 (soil N test) was $9,377 or $82/acre ($203/ha) and $3 per acre per year ($7/ha/year), when considering the time frame of over 28 years. This benefit occurred because of the reduction in fertilizer costs.

With BMP22 (N balance), a benefit of $26 per acre ($64/ha) incurred. When stretched over the time frame the benefits per acre/year were $1 ($2/ha/year). This benefit accrued because slightly less fertilizer was applied in this scenario. These costs balanced out the consultancy costs.

For BMP23 (max N balance) a cost of $89 per acre ($220/ha) was incurred and over the timeframe of 28 years the costs were $3 per acre per year ($7/ha/year). It was the second most costly scenario as it includes the entire range of BMPs.

BMP24 (drop manure) was the same as the Base case. Hence, no net costs were incurred.

The highest costs were incurred with BMP25 (drop manure/corn), which involved a change in crop rotation, where corn was taken out of the rotation. That resulted in a cost per acre of $461 ($1139/ha) and a cost of $16 per acre per year ($40/ha/year).

Table 24 Results - D Fields (Cash Crop-Based Rotation)

	BMP21	BMP22	BMP23	BMP24	BMP25
Field	$ (9,377)	$ (2,925)	$ 10,107	$ -	$ 52,581
Per acre	$ (82)	$ (26)	$ 89	$ -	$ 461
Per acre/yr	$ (3)	$ (1)	$ 3	$ -	$ 16
Per ha	$ (203)	$ (64)	$ 220	$ -	$ 1139
Per ha/yr	$ (7)	$ (2)	$ 7	$ -	$ 40

5.4 OBSERVATIONS

Table 25 shows the results of the economic assessment and the estimated reductions in N_{pl} due to implementation of the BMP scenarios. The table depicts the cost-effectiveness ratio (cost of implementation/percentage reduction of amount of leachable nitrogen). The table is separated into sections, depicting a summary for each field's results as well as a weighted average summary of fields. The first line of the table shows the reduction of leachable nitrogen in percent. For each field, the costs per acre per year are presented in the second line, costs per hectare in the third line, and the cost of each percentage reduction in leachable nitrogen (cost-effectiveness ratio) in the forth line. As this is a cost-effectiveness analysis only the costs are presented; the benefits were implicit and unmeasured, understanding that all of the BMPs satisfied the drinking water standard. An overall ranking based on the cost effectiveness measure is presented in the last line of the table.

Table 25 Cost-Effectiveness Ratios

	BMP21	BMP22	BMP23	BMP24	BMP25
	A fields (subset A1-A4)				
Estimated reduction in potentially leachable nitrogen (N_{pl}) (%)	14	49	64	76	63
Costs/acre/year	($1)	$38	$59	($31)	$127
Costs/hectare/year	($2)	$94	$146	($77)	$314
Cost of 1% reduction in nitrogen (per acre/year)	-	$0.77	$0.93	-	$2.01
Ranking	2	3	4	1	5
	B fields (subset B9/B10/B12)				
Estimated reduction in potentially leachable nitrogen (N_{pl}) (%)	12	73	70	80	77
Costs/acre/year	($8.56)	$5.88	$41.96	($57.85)	$38.74
Costs/hectare/year	($21.15)	$14.53	$103.69	($142.95)	$93.26
Cost of 1% reduction in nitrogen(per acre/year)	-	$0.08	$0.60	-	$0.50
Ranking	2	4	5	1	3
	C fields				
Estimated reduction in potentially leachable nitrogen (N_{pl}) (%)	25	14	17	66	43
Costs/acre/year	($14.38)	$23.91	$38.40	($1.18)	$56.38
Costs/hectare/year	($35.53)	$59.08	$94.89	($2.92)	139.32
Cost of 1% reduction in nitrogen (per acre/year)	-	$1.76	$2.23	-	$1.30

	BMP21	**BMP22**	**BMP23**	**BMP24**	**BMP25**
Ranking	1	4	5	2	3
	D fields				
Estimated reduction in potentially leachable nitrogen (N_{pl}) (%)	28	22	2	0	23
Costs/acre/year	($3)	($1)	$3	-	$82
Costs/hectare/year	($7)	($2)	$7	-	$203
Cost of 1% reduction in nitrogen (per acre/year)	-	-	$1.96	-	$3.58
Ranking	1	2	3	-	4
	All Fields				
Estimated reduction in potentially leachable nitrogen (N_{pl}) (%)	20	35	37	60	52
Costs/acre/year	($8)	$18	$33	($12)	$52
Costs/hectare/year	($20)	$45	$82	($30)	$129
Cost of 1% reduction in nitrogen (per acre/year)	-	$ .51	$ .89	-	$1.00
Ranking	2	3	4	1	5

As an illustration, for the A fields, it would cost on average $0.77 per acre per year ($1.90/ha) (over a 28-year time frame, taking a discount rate of 5% into account) to reduce one percent of leachable nitrogen for BMP22 (N balance). For BMP23 (max N balance) it would cost $0.93 ($2.30/ha), and for BMP25 (drop manure/corn) it would cost $2.01 ($4.97/ha). For BMP21 (soil N test) and BMP24 (drop manure) no cost-effectiveness ratio resulted as benefits accrued that were larger than costs. In the case of BMP24 (drop manure) and BMP25 (drop manure/corn) it should be noted that it was assumed that manure was applied elsewhere, so the costs of manure disposal were not attributed to the case fields. Hence, BMP24 (drop manure) is the most beneficial BMP scenario, followed by BMP21 (soil N test), as they resulted in a benefit for the producers.

BMP21 (soil N test) and BMP24 (drop manure) rank very high across fields. Given past N practices, BMP24 (drop manure) was clearly an economically effective BMP as it reduced total N applied and avoided manure application costs. What is implicit is that in the past, producers applied manure and mineral fertilizer in excess of total nitrogen requirements - so removing manure induced balance in nitrogen applications that had not occurred historically.

In general, removing corn from crop rotations under BMP25 (drop manure/corn), where corn was included in the Base case, was quite costly. Scenario BMP23 (max N balance), although it has a high efficacy, was very costly as it included a wide range of BMPs. Scenario BMP21 (soil N test) results in a benefit to producers across fields, however, it has a lower efficacy in comparison to all other BMP scenarios. Significantly, in all scenarios the drinking water standard was achieved in the MBM simulation of nitrate concentration in groundwater at the production well to the year 2100. A sensitivity analysis is presented in the appendix (**Error! Reference source not found.** and **Error! Reference source not found.**). The results show that the analysis was robust to different discounting factors of 3 and 8 percent.

6 CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study was to examine the agronomic and environmental effectiveness, and the economic efficiency of beneficial management practices (BMPs) used to protect groundwater resources by reducing the amount of nitrogen potentially available to leach into groundwater, based on the 1980-2008 time step. To do so, a nitrogen mass balance model (MBM) was developed and the results from nitrogen (N) budgets developed from actual cropping practices within the capture zone of a production well in Waterloo Region were used to estimate long-term potentially leachable nitrogen (N_{pl}). Five BMP scenarios were compared to determine: i) their potential effectiveness in reducing the amount of nitrogen available to leach from agricultural fields into groundwater and ii) their relative potential for ensuring groundwater obtained in the future at a production well in Waterloo Region will meet the Ontario Drinking Water Standard (ODWS) for nitrogen (10 mg/L). Finally, the economic costs associated with the alternative BMPs were assessed.

6.1 SUMMARY OF MAIN OBERSERVATIONS

The results of the study showed the following:

1. The implementation of N BMP scenarios designed to enhance existing N management practices (BMP21 (soil N test), BMP22 (N balance) and BMP23 (max N balance)) or remove key sources of nitrogen (BMP24 (drop manure) and BMP25 (drop manure/corn)) in agricultural fields represent effective agronomic and environmental strategies for ensuring groundwater obtained at the production well in the future will meet the ODWS for nitrogen.

2. The mean estimates of long-term N_{pl} for the BMP scenarios ranged from 19 to 38 kg N/ha/yr compared to the mean estimate of N_{pl} for the Base case (44 kg N/ha/yr) (1980-2008; n=29 yrs; Table 15). In percentage terms, the mean estimates of N_{pl} for the BMP scenarios were approximately 14 to 57% less than the mean estimate of N_{pl} for the Base case (Figure 6) i.e.,
   - 57% less N_{pl} under BMP24 (drop manure) and BMP25 (drop manure/corn);
   - 48% less N_{pl} under BMP23 (max N balance);
   - 34% less N_{pl} under BMP22 (N balance); and
   - 14% less N_{pl} under BMP21 (soil N test).

3. The relative estimate of mean annual N_{pl} generally decreased across the capture zone as the intensity of N management using BMPs increased from BMP21 (soil N test) to BMP22 (N balance) to BMP23 (max N balance) (Figure 7). The relative estimate of mean annual N_{pl} was generally lower for the remaining two BMP scenarios, which represented significant targeted external influences on producer N use i.e., BMP24 (drop manure) and BMP25 (drop manure/corn) (except for BMP24, which was similar to BMP23 toward the end of the study time step) (Figure 7).

4. In the example set of fields representing a livestock-based rotation (B9/B10/B12) there was a 70 to 80% reduction in estimated N_{pl} across the BMP22 (N balance), BMP23 (max N balance), BMP24 (drop manure), and BMP25 (drop manure and corn) scenarios. A 12% reduction in estimated N_{pl} occurred under BMP21 (soil N test) (Table 17).

5. In the example set of fields representing a cash crop-based rotation (D1-D4) there was a 0 to 23% reduction in N_{pl} across the BMP22 (N balance), BMP23 (max N balance), BMP24 (drop manure), and BMP25 (drop manure/corn) scenarios. A 28% reduction in estimated N_{pl} occurred under BMP21 (soil N test) although this value may overestimate the potential reduction achievable for this field group since the analysis resulted in a greater decline in N_{pl} relative to the other more intensive BMP scenarios (Table 16).

6. Those field groups where manure/biosolids were used during crop production (A1-A4; B9/B10/B12; C1-C4) showed the greatest potential for reduction of N_{pl} across all of the BMP scenarios.

7. Those field groups with more nitrogen BMPs in use within the Base case (C and D field groups) realized a lower relative reduction in estimated N_{pl} than those field groups with fewer BMPs in use within the Base case (A, B and E field groups).

8. Economic costs of the BMP scenarios generally ranged between $18/acre/year ($45/ha/year) and $52/acre/year ($129/ha/year), with a subset of BMP scenarios generating a benefit (net reduction in costs) and others a much higher cost. The BMP scenarios that focused on removal of manure and improved management decisions based on results from a soil N test generated net benefits. The BMP scenario that focused on removing manure and corn from the crop rotation tended to generate the highest costs.

9. There were sharp differences in BMP costs across individual fields. This related to initial management conditions.

10. The effectiveness of BMPs from an economic perspective did not match the environmental effectiveness. This is illustrated in Table 26. The table presents the ranking of scenarios based on environmental criteria and economic criteria. The first set of columns provide environmental rankings for the capture zone as a whole; the next set of columns provide environmental rankings based on the subset of fields considered in the economic analysis. The far right set of columns presents rankings of scenarios based on economic criteria for the subset of fields. Comparing the first two sets of columns, the table shows that the subset of fields in the economic analysis were representative of all fields in the capture zone, based on environmental criteria - the only difference was that BMP 24 was slightly superior to BMP 25 in the subset, but could not be differentiated at the level of the capture zone. Under environmental and economic criteria, the BMP in which manure was not applied in the study fields (BMP 24) was ranked the most effective. Conversely, BMP25 (drop manure and corn) was ranked highly on environmental criteria but last on economic criteria. Using economic criteria, BMP21 (soil N test) was ranked second, but was ranked last using environmental criteria. The orderings of BMP22 (N balance) and BMP23 (max N balance) were reversed using the two criteria.

Table 26 Environmental and Economic Rankings of BMP Scenarios

Environmental Ranking[1]						Economic Ranking		
All fields in capture zone analysis			Subset of fields in economic analysis			Subset of fields in economic analysis		
N_{pl} Reduction (%)	Rank	BMP scenario	N_{pl} Reduction (%)	Rank	BMP scenario	N_{pl} Cost of 1% reduction ($)	Rank	BMP scenario
57	1	BMP24 (drop manure) or BMP25 (drop manure/corn)	60	1	BMP24 (drop manure)	-	1	BMP24 (drop manure)
48	2	BMP23 (max N balance)	52	2	BMP25 (drop manure/corn)	-	2	BMP21 (soil N test)
34	3	BMP22 (N balance)	37[2]	3[2]	BMP23 (max N balance)	18	3	BMP22 (N balance)
14	4	BMP21 (soil N test)	35[2]	4[2]	BMP22 (N balance)	33	4	BMP23 (max N balance)
			20	5	BMP21 (soil N test)	52	5	BMP25 (drop manure/corn)

[1] Environmental rank based on relative decrease in estimated long term potentially leachable N (N_{pl}) compared to the Base case (Table 18)

[2] These BMP scenarios were substantially equivalent (difference in N_{pl} reduction was <10%)

6.2 CONCLUSIONS

The results of this study suggest that from an agronomic and environmental perspective the BMP scenarios represent effective strategies for ensuring groundwater obtained at the production well in the future will meet the ODWS. These results were consistent with a previous study by Brethour *et al.* (2009). Unlike the previous work, this study involved significant diversity in crop production practices within the capture zone of the production well, which increased the complexity of estimating long-term potentially leachable nitrogen (N_{pl}) and modeling impacts on groundwater quality at the production well. Similar to Brethour *et al*. (2009), however, this study demonstrated that the nitrogen (N) budget approach provided a useful framework for conducting a detailed and consistent assessment of N inputs and outputs related to agricultural fields within the capture zone of the production well.

The estimates of potentially leachable nitrogen (N_{pl}) from actual field measurements within the capture zone compared well with the estimates of long-term N_{pl} from the N budgets, which, in turn, compared well with N budget values discussed by Meisinger and Randall (1991). This suggests the N budgets were a useful method for: i) prioritizing where field samples should be obtained within the capture zone to confirm the need for enhanced N management strategies and/or ii) identifying what and where enhanced N management strategies should be most effective within the capture zone.

The mean estimates of long-term N_{pl} for the BMP scenarios were approximately 14 to 57% less than the mean estimate of N_{pl} for the Base case (1980-2008). The results of this study suggest that implementation of N BMP scenarios designed to enhance existing N management practices or remove key sources of N in agricultural fields represent effective environmental strategies for ensuring groundwater obtained at the production well in the future will meet the ODWS.

The results suggest that, at relatively nominal cost, agronomic BMPs could be used to protect groundwater resources. Under the agronomic and market conditions considered, the most environmentally and economically efficacious BMPs remove manure application, but do not disrupt crop rotations - in particular, do not remove corn.

These results also present interesting questions. First, is manure a fertilizer resource asset or a waste disposal liability? This study implicitly assumes the former which is consistent with current conditions in which manure is viewed as a valuable substitute for chemical fertilizer, but this contradicts a past in which manure was structurally over-applied (and thus assessed little value). Secondly, if restrictions are placed on manure application on specific fields, the costs associated with accessing additional acreage to apply manure are inherently site-specific. In this study, where the capture zone included relatively intensive mixed livestock/cash crop production, it was reasonable to assume the costs of redirecting manure are quite low or zero; in other cases of more extensive land use or greater density of livestock, there may be material costs of restrictions on manure application, ranging from longer distance transport to fields where manure will be applied to the need for additional manure storage.

6.3 RECOMMENDATIONS

1. Nitrogen BMPs in agricultural landscapes should be referenced in public planning for protection of groundwater resources. The agronomic and environmental efficiency is relevant in understanding how these BMP scenarios could impact long-term N_{pl} that may enter groundwater, and the economic efficiency is relevant in understanding how producers are impacted upon implementation of these BMP scenarios.

2. The most effective BMP scenario from an environmental and economic perspective removes manure application as an agronomic practice. In this study, this nitrogen management strategy provided a clear win for both producers and the public relative to protecting groundwater resources. It should be pursued as first among BMP options when considering environmental impacts and producer costs, provided producer costs associated with finding alternate locations to apply or dispose of manure are very low or zero. Future study could include an examination of alternative options for manure use and the associated costs if the application of manure was restricted in some portion of the capture zone.

3. To ensure the N budget process yields scientifically defensible results and therefore legitimate comparisons amongst N management strategies, a consistent, repeatable, science-based approach must be followed. It is essential that N budget assumptions are: i) based on published values and recommendations whenever possible and ii) consistently applied across all fields and N BMP scenarios. If a previously established N budget assumption is changed or modified, the rationale for the variance should be science-based and supported by published values and recommendations. The opinion of an experienced agrologist should be used to: i) fine tune assumptions when published sources provide a range of values or ii) provide an estimate based on experience when a literature search fails to yield the required information. In future studies, the N budget frameworks from this study and its complementary study (Brethour *et al.*, 2009) should be considered to determine which framework is best suited to the needs of the study.

4. For additional details related to the methods and results associated with estimates of the effectiveness of N beneficial management practices and N in groundwater, refer to the pending report by Stantec Consulting Ltd. for the Region of Waterloo.

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8 APPENDIX:

Table 27 Manure Application Costs

	Manure Application		
Year	**$/hour**	**$/acre**	**$/ha**
1981	$33	$17	$42
1982	$39	$20	$49
1983	$42	$21	$52
1984	$42	$21	$52
1985	$45	$22	$54
1986	$46	$23	$57
1987	$46	$23	$57
1988	$47	$24	$59
1989	$49	$24	$59
1990	$49	$24	$59
1991	$50	$25	$62
1992	$57	$28	$69
1993	$57	$28	$69
1994	$63	$32	$79
1995	$62	$31	$77
1996	$62	$31	$77
1997	$61	$30	$74
1998	$71	$36	$89
1999	$71	$36	$89
2000	$82	$41	$101
2001	$89	$44	$109
2002	$89	$44	$109
2003	$95	$48	$119
2004	$102	$51	$126
2005	$102	$51	$126
2006	$108	$54	$133
2007	$108	$54	$133
2008	$108	$54	$133

Table 28 Pasture Rental Rates

Year	$/acre	$/ha
1981	$48.58	$120
1982	$50.13	$124
1983	$50.49	$125
1984	$51.76	$128
1985	$51.76	$128
1986	$52.67	$130
1987	$52.63	$130
1988	$54.70	$135
1989	$57.08	$141
1990	$57.98	$143
1991	$57.17	$141
1992	$56.98	$141
1993	$59.77	$148
1994	$61.78	$153
1995	$64.11	$158
1996	$67.06	$166
1997	$68.21	$169
1998	$66.48	$164
1999	$66.71	$165
2000	$70.76	$175
2001	$73.84	$182
2002	$73.27	$181
2003	$75.72	$187
2004	$73.90	$183
2005	$76.92	$190
2006	$79.43	$196
2007	$85.36	$211
2008	$85.36	$211

Table 29 Costs of red Clover

Year	$/acre	$/ha
1981	6.4	$16
1982	6.61	$16
1983	6.65	$16
1984	6.82	$17
1985	6.82	$17
1986	6.94	$17
1987	6.94	$17
1988	7.21	$18
1989	7.52	$19
1990	7.64	$19
1991	7.54	$19
1992	7.51	$19
1993	7.88	$19
1994	8.14	$20
1995	8.45	$21
1996	8.84	$22
1997	8.99	$22
1998	8.76	$22
1999	8.79	$22
2000	9.33	$23
2001	9.73	$24
2002	9.66	$24
2003	9.98	$25
2004	9.74	$24
2005	10.14	$25
2006	10.47	$26
2007	11.25	$28
2008	12	$30

Table 30 BMP costs (discounted)

	Crop consultant	NMP Plan	NMP Plan	Soil Sampling (for nitrogen)	Crop consultant & tissue analysis (for nitrogen)
Year	**$/field**	**$/acre**	**$/ha**	**$/field**	**$/field**
1981	$34.15	$2.85	$7	$28.45	$91.05
1982	$35.24	$2.94	$7	$29.36	$93.97
1983	$35.49	$2.96	$7	$29.57	$94.63
1984	$36.39	$3.03	$7	$30.32	$97.03
1985	$36.39	$3.03	$7	$30.32	$97.03
1986	$37.02	$3.09	$8	$30.85	$98.73
1987	$37.00	$3.08	$8	$30.83	$98.66
1988	$38.45	$3.20	$8	$32.04	$102.53
1989	$40.12	$3.34	$8	$33.44	$107.00
1990	$40.75	$3.40	$8	$33.96	$108.68
1991	$40.19	$3.35	$8	$33.49	$107.17
1992	$40.05	$3.34	$8	$33.38	$106.80
1993	$42.01	$3.50	$9	$35.01	$112.03
1994	$43.43	$3.62	$9	$36.19	$115.81
1995	$45.07	$3.76	$9	$37.56	$120.18
1996	$47.14	$3.93	$10	$39.28	$125.71
1997	$47.95	$4.00	$10	$39.96	$127.86
1998	$46.73	$3.89	$10	$38.94	$124.62
1999	$46.89	$3.91	$10	$39.08	$125.05
2000	$49.74	$4.14	$10	$41.45	$132.64
2001	$51.90	$4.33	$11	$43.25	$138.41
2002	$51.50	$4.29	$11	$42.92	$137.34
2003	$53.23	$4.44	$11	$44.36	$141.94
2004	$51.94	$4.33	$11	$43.29	$138.52
2005	$54.07	$4.51	$11	$45.06	$144.18
2006	$55.83	$4.65	$11	$46.53	$148.88
2007	$60.00	$5.00	$12	$50.00	$160.00

Table 31 Sensitivity Analysis Results (3%)

	BMP21	BMP22	BMP23	BMP24	BMP25
	A fields				
Reduction in leachable nitrogen (%)	14	49	64	76	63
Costs/acre/year	($1)	$27	$42	($24)	$93
Costs/ha/year	($2.47)	$66.72	$103.78	($59.31)	$229.81
Cost/acre of percentage reduction in nitrogen		($0.56)	($0.67)		($1.47)
Ranking	2	3	4	1	5
	B fields				
Reduction in leachable nitrogen (%)	12	73	70	80	77
Costs/acre/year	($5.88)	$5.34	$37.88	($43.07)	$30.34
Costs/ha/year	($14.53)	$13.20	$93.60	($106.43)	$74.97
Cost/acre of percentage reduction in nitrogen		$0.07	$0.54		
Ranking	3	4	5	1	2
	C fields				
Reduction in leachable nitrogen (%)	25	14	17	66	43
Costs/acre/year	($7.06)	$20.99	$29.84	$0.42	$41.19
Costs/ha/year	($17.45)	$51.87	$73.74	$1.04	$101.78
Cost/acre of percentage reduction in nitrogen		$1.50	$1.76	$0.01	$0.96

Ranking	1	4	5	2	3
	D fields				
Reduction in leachable nitrogen (%)	28	22	2	0	23
Costs/acre/year	($2)	$1	$2		$14
Costs/ha/year	($4.94)	$2.47	$4.94	$0.00	$34.59
Cost/acre of percentage reduction in nitrogen		$0.03	$1.00		$0.61
Ranking	1	2	4		3

Table 32 Sensitivity Analysis Results (8%)

	BMP21	BMP22	BMP23	BMP24	BMP25
	A fields				
Reduction in leachable nitrogen (%)	14	49	64	76	63
Costs/acre/year	$0	$63	$97	($49)	$210
Costs/ha/year	$0.00	$155.68	$239.69	($121.08)	$518.92
Cost of percentage reduction in nitrogen/acre		$1.28	$1.53		$3.31
Ranking	2	3	4	1	5
	B fields				
Reduction in leachable nitrogen (%)	12	73	70	80	77
Costs/acre/year	($15)	$6	$49	($94)	($55)
Costs/ha/year	($37.07)	$14.83	$121.08	($232.28)	($135.91)
Cost of percentage reduction in nitrogen/acre		$0.08	$0.70		
Ranking	3	4	5	1	2
	C fields				
Reduction in leachable nitrogen (%)	25	14	17	66	43
Costs/acre/year	($35)	$28	$58	($6)	$93
Costs/ha/year	($86.49)	$69.19	$143.32	($14.83)	$229.81
Cost of percentage reduction in nitrogen/acre		$2.00	$3.41		$2.16
Ranking	1	3	5	2	4
	D fields				

Reduction in leachable nitrogen (%)	28	22	2	0	23
Costs/acre/year		($2)	$6		$22
Costs/ha/year		($4.94)	$14.83		$54.36
Cost of percentage reduction in nitrogen/acre		$0.09	$3.00		$0.96
Ranking	1	2	3		4