GEORGE MORRIS CENTRE

Canada's Independent Agri-Food Think Tank

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Cordner SCIENCE

WATERLOO NUMERICAL MODELLING CORP.

Cost Benefit Analysis of Source Water Protection Beneficial Management Practices

Final Report - AESI 156

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Date: Updated August 2009

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1. INTRODUCTION

Over the last several years, a great deal of attention and research has been focused on the environmental impacts of agricultural operations, specifically on surface water and groundwater. In Ontario, agricultural landscapes account for a significant proportion of source water eventually used by humans for drinking, recreation, industrial processes and other purposes.

“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.

On the farm, producers can use different beneficial 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 barriers in agricultural landscapes to prevent or decrease the contamination of source water by nutrients, pesticides, pathogens or micro-organisms, and soil and suspended sediment.

The purpose of this research is to conduct a cost benefit analysis of SWP BMPs. The project will follow a case study approach, in order to understand the costs and benefits of SWP BMPs as they relate to agriculture. This approach will allow for presentation of studies in which water contamination occurred, and will provide information on the costs of the contamination (e.g. costs of clean-up, human health costs). Relevant SWP BMPs which might have prevented the contamination will then be identified and their effectiveness in preventing contamination assessed.

As a result, each examination would indirectly assess the costs and benefits of specific SWP BMPs by specifying the costs of putting the BMPs in place and the benefits of the BMPs in terms of avoided costs of contamination.

The results of the research will be used to educate producers, the public, municipalities and government on the costs and benefits of BMPs that protect source water.

1.1 PURPOSE AND OBJECTIVES

The purpose of this research is to conduct a cost benefit analysis of existing source water protection beneficial management practices.

The specific objectives of the research are as follows:

- Review literature to understand
    - the public and private economic and environmental costs and benefits of SWP BMPs
    - the evaluation of these costs and benefits

[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.

- o the link between SWP BMPs, economic and environmental impacts, risks, costs, and benefits, and associated ecosystem services, with a specific focus on human health
- o the scientific basis describing the actions and effectiveness of SWP BMPs

- Consult stakeholders to identify the watershed, contamination and SWP BMP(s) for evaluation
- Estimate all types of public and private costs from the identified contamination
- Estimate the private and public costs and benefits of the SWP BMP(s) that could have prevented the contamination, and compare these results to the above objective
- Provide a summary of results, lessons learned and policy implications
- Prepare the information in a format that can be presented to the public, agricultural producers, local SWP planning committees, municipalities, and researchers focused on related topics

2. SELECTION AND DESCRIPTION OF THE CASE STUDY WATERSHED

This section reviews the selection process used for the case study watershed in which water contamination originated from agricultural production. Relevant SWP BMPs that could have reduced or prevented the contamination will be identified.

2.1 OBJECTIVES

A brainstorming workshop was chosen as the primary means to select an Ontario watershed that has experienced instances of agricultural water contamination requiring remediation. The objectives of the brainstorming workshop were as follows:

- Gain insight from key stakeholders from government (municipal, provincial and federal), academia (experts on the issue), industry (livestock and crop producers and associations), conservation authorities, the Ontario Soil Crop Improvement Association (OSCIA) and NGOs (e.g. Ducks Unlimited Canada).
- Work through fact sheets (discussion papers prepared in advance), which provide key stakeholders with background information on potential watersheds and contamination and BMPs, and invite them to bring new ideas to the table.
  - o Where possible, a list of potential watersheds and contamination issues that had occurred in Ontario would be identified as a starting point for discussion.
- Identify potential sites (watersheds) for consideration and whether the required data is available.

2.2 METHODS

2.2.1 Preparation for the Workshop

The brainstorming workshop took place at the Halton Region Museum in Milton, Ontario on April 19th, 2007.

An invitation to the brainstorming workshop was sent to 63 stakeholders (including the project team) on February 28th, 2007. Of those stakeholders, 28 were able to attend the workshop (including the project team). A complete list of attendees has been included in Appendix A.

In order to provide stakeholders with background information in preparation for the workshop, the research team conducted preliminary research on potential watersheds affected by instances of agricultural contamination in Ontario. The initial search of the Internet, news articles and literature yielded the following sites[3]:

[3] Note that Walkerton has not been included as a potential site since the research team felt that sufficient information is known about the contamination and that further research in the area would add little value.

Contamination				
Location	**Types**	**Causes**	**Impacts (Costs and Health)**	**Responses**
Bay of Quinte Watershed[4]	• Nutrient enrichment (large amounts of phosphorus) • Bacterial contamination • Toxic contamination from chemicals used for industrial, agricultural and domestic purposes • Habitat destruction	• Fertilizers from agricultural runoff, sewage from residential sources, and industrial wastes • Untreated septic waste, agricultural practices and industrial wastes • Industrial waste by-products, ineffective removal of industry and household chemicals by sewage treatment plants, sludge from water treatment plants and others sources • Shoreline development	• Not found	• Development of a Remedial Action Plan for the Bay of Quinte in 1986. • Improvements on agricultural operations such as conversion to conservation tillage, manure and milkhouse management projects, improved farming practices, fencing projects, retirement of marginal land • 50 km of shoreline and 354 hectares of wetlands have been restored
Strathroy[5]	• Elevated levels of nitrates found in municipal well water.	• Predominant use of land around municipal wells identified as agricultural.	• Had to establish a pipeline to surface water at an estimated cost of $16-20 million	• A drinking water advisory was put in effect by the Middlesex-London Health Unit. • Established some BMPs but municipality felt they could not control the nitrates and an alternative water supply was established.
Alvinston[6]	• Commercial fertilizer contaminated water treatment plant.	• Commercial fertilizer spill occurred in 2002 that affected 401 homes. • Nitrates were starting to	• Had to establish an alternative	• The township had to truck water to Alvinston for three weeks after the community's water plant was ordered temporarily closed following

[4] Sources: (Lower Trent Conservation, 2007) and (Environment Canada, 2005a).
[5] Source: Brian McDougall, Director of Watershed Services, St. Clair Region Conservation Authority, 2007
[6] Source: Brian McDougall, Director of Watershed Services, St. Clair Region Conservation Authority, 2007

Contamination				
Location	**Types**	**Causes**	**Impacts (Costs and Health)**	**Responses**
		accumulate in the river fed plant prior to the spill.	water supply via a pipeline. Estimated capital cost of $1.7 million.	the commercial fertilizer spill. • Township officials learned it would cost $2 million to upgrade the river-fed plant to meet provincial drinking water standards. • Decided to connect the community to the Lambton system which already had lines established.
Severn Sound Watershed[7]	• Excessive algae growth resulting in eutrophication[8] due to high phosphorus levels • Degradation of aquatic habitat, bottom dwellers, and plankton populations • Drinking water had bad taste and smell	• Sewage treatment plant effluents, agricultural activities and shoreline development	• Inability to swim and fish	• Development of a Remedial Action Plan • 80 on-farm projects such as better manure storage and handling methods, switching to conservation tillage, treating milk house wash water, controlling barnyard runoff, and upgrading private sewage disposal systems
Ausable Bayfield Watershed[9]	• Manure spill from a hog operation	• Manure spill from a hog operation (March 17, 2005)	• Not found	• The Ministry of the Environment laid charges under the Ontario Water Resources Act
Ausable Bayfield Watershed[10]	• Hog manure spill (5,000 gallons) which leaked into	• Rupture during manure pumping (September 17, 2004)	• Affected beach	• Signs posted at beaches • Manure (4,000 gallons) was

[7] Sources: (Environment Canada, 2001), (Environment Canada, 2005b), (International Joint Commission, 2007) and (Environment Canada, 2005c).

[8] Eutrophication is a process whereby water bodies, such as lakes, estuaries, or slow-moving streams receive excess nutrients that stimulate excessive plant growth (algae, periphyton attached algae, and nuisance plants weeds). This enhanced plant growth, often called an algal bloom, reduces dissolved oxygen in the water when dead plant material decomposes and can cause other organisms to die. Nutrients can come from many sources, such as fertilizers applied to agricultural fields, golf courses, and suburban lawns; deposition of nitrogen from the atmosphere; erosion of soil containing nutrients; and sewage treatment plant discharges (Source: http://toxics.usgs.gov/definitions/eutrophication.html).

[9] Source: (Ministry of the Environment, 2006).

Contamination				
Location	**Types**	**Causes**	**Impacts (Costs and Health)**	**Responses**
	Walker Drain which flows into the Ausable River and ultimately Lake Huron		users, fish, and a golf course	pumped out of the drain
St. Joseph Watershed[11]	• Hog manure spill (allegedly 500 gallons)	• Run-off from the field due to rain (July 13, 2006)	• Affected beach users, some fish kills	• Signs posted at beaches • Residents built a sand dam across the ravine to prevent more contaminated water from entering the lake

[10] Sources: (Poirier, 2004) and (Belanger, 2004).
[11] Sources: (Bluewater Shoreline Residents' Association, 2006) and (Hillman-Rapley, 2006).

After reviewing the various sources of contamination, the research team decided that one-time instances of contamination (typically point sources of pollution[12]), such as a manure spill, were not ideal for a cost-benefit analysis. The research team felt that one-time spills were anomalies, and that greater value would be achieved from the examination of ongoing or re-occurring instances of water contamination (more likely to be non-point source pollution[13]).

Given the instances of water contamination reviewed, the research team developed a background paper for workshop participants. The paper listed key criteria to consider when selecting a watershed for evaluation as well as the expected types of data that will be required to conduct the analysis. It also cited two potential sites with accompanying information for consideration (based on the initial search) including Strathroy and a sub-watershed within the Bay of Quinte.

2.2.2 Description of the Workshop

Workshop participants were told the purpose of the research, the main objectives and the current methods for conducting the research. As well, facilitators reviewed the structure of the brainstorming sessions, the main goals of the breakout sessions and the preliminary sites identified for evaluation. Further, participants were given information on the specific data requirements for the scientific portion of this evaluation. The outline was as follows:

- Purpose and objectives of the research
- Phases of Research
    - Literature review
        - Preliminary results (from interim report)
    - Research methods
    - Policy implications and communications
- Brainstorming Workshop
    - Purpose and objectives of the day
    - Data requirements
    - Key criteria for watershed selection
        - Proposed sites
        - Brainstorming sessions I & II

Brainstorming Session I

In the first brainstorming session, participants discussed potential watersheds for evaluation, as well as the proposed locations of Strathroy and a sub-watershed of the Bay of Quinte. The participants were asked to report information on the work sheets

[12] Point source pollution enters the environment at a specific place from an identifiable source. Examples of point source pollution include industrial discharges, municipal wastewater effluents, landfill site leachate, wastes from mining sites, on-site septic systems, and leaking oil and gas storage tanks (Blundell, Papa, and Edwards, 2004).

[13] Non-point source pollution comes from many diffuse sources. Examples of non-point sources of pollution include agricultural runoff (e.g. fertilizers, pesticides, oil, bacteria and nutrients from livestock and manure), urban runoff, products from recreational boating, saltwater intrusion and acid precipitation (Blundell, Papa, & Edwards, 2004).

provided (refer to Appendix B for an outline). The main information requested from the participants during the first session was as follows:

- Location of contamination (county and watershed)
- Description of non-point source of contamination:
  - Type of agricultural pollution
  - Cause of agricultural pollution
  - Date that contamination first occurred (i.e., month and year of contamination)
  - Duration (i.e., length of time the problem existed)
  - Number of individuals affected (if applicable)
  - Health impacts of contamination (if applicable)
  - Economic impacts (e.g., estimated costs of contamination)
  - How the community addressed the contamination
  - Suggested source water protection beneficial management practices (SWP BMPs) for evaluation
  - Sources of available data and information

Brainstorming Session II

In the second brainstorming session, participants presented their suggestions for watersheds (to the entire group), in addition to any sources of data/information they were aware of. The results of this discussion were used to develop section 2.2.3 (potential sites for consideration) below.

Based on the information gathered during the workshop, the following watershed sites were identified as possibilities for evaluation:

- South Nation
- Oxford County
- Strathroy
- A sub-watershed within the Bay of Quinte

Four additional watersheds were identified as requiring follow-up to determine their applicability:

- Ausable River, Exeter
- Bonnechere River, Renfrew County
- Maitland Valley
- Paris

The creation of a steering committee of interested participants to help with the final site selection and data assumptions for the research was suggested. Three participants indicated interest; two from the Ontario Ministry of Agriculture Food and Rural Affairs and one from Agriculture and Agri-food Canada.

2.2.3 Potential Sites for Consideration

Using information from the brainstorming workshop and follow-up discussions, section 2.2.3 provides preliminary background information on the top four sites that were isolated for consideration. These were South Nation, Oxford County, Strathroy, and a sub-watershed of the Bay of Quinte.

South Nation

The South Nation River watershed is located in Eastern Ontario and comprises an area of 3,900 km^2. This area is a WEBs[14]/MST (microbial source tracking) study area.

The South Nation River watershed is a sensitive area and has a difficult geological setting.

There is a surface water intake in the town of Casselman on the South Nation River.

Type of agricultural pollution

Soil in this area is clay-based and pollution occurs from non-point sources. The main agricultural contaminants in this area are phosphorus, sediments, nitrates and bacteria.

The South Nation River also has water quantity issues. In the spring, there is sufficient water and in some cases too much (flooding concerns), while in the summer there are often water shortages. Water quality concerns can be exacerbated during times of water shortage (as identified above).

Cause of agricultural pollution

Sixty percent of the land in this watershed region is used for agriculture, mainly for the production of milk, beef, soybeans and corn.

How the community addressed the contamination

A number of actions have been undertaken to control contamination. The Clean Water Program was established to improve water quality across the watershed and, to date, more than 400 projects valued at $5.7 million have been made possible by over $1.6 million in grants from the Clean Water Program since 1993.

Phosphorus reduction can be tied to trading programs, and there are no heavy metal issues.

In addition to the projects identified above, Casselman's typical response to water quality issues has been to adjust the water treatment levels at the plant.

Suggested SWP BMPs for evaluation

BMPs encouraged by the South Nation Conservation Authority include nutrient management planning, installation of tile drainage structures, fencing, and establishment of alternative water sources. The CA is also trying to establish a buffer strip BMP program, but to date has had minimal success obtaining funding.

[14] WEBs stands for Watershed Evaluation of Beneficial Management Practices

Sources of available data and information

Data are available and being generated within the area. There are between 15 and 20 surface water sampling stations and 13 provincial water quality monitoring stations. However, there is little groundwater information.

Through the Clean Water Program, there have been several projects conducted that could provide required data, including BMP implementation costs and phosphorus reduction calculations for BMP effectiveness analysis. Previous studies have only focused on two BMPs, so there is still room to investigate additional BMPs.

The municipality also has a good relationship with local farmers and rural landowners.

<u>Oxford County</u>

The location of the contamination was the city of Woodstock and surrounding area. The city of Woodstock is located in Oxford County, which is part of the Southern Ontario Region.

Type of agricultural pollution

Samples of the groundwater supply indicated nitrate contamination. This nitrate contamination extended to the municipal wells.

Cause of agricultural pollution

Nitrate in groundwater may originate from point or non-point sources. Agricultural practices and septic systems are potential sources of nitrate pollution in the groundwater in the Woodstock area.

Hog production and crop farming are the predominant agricultural activities in this area and may have contributed to the groundwater pollution.

Date that contamination first occurred (i.e. month and year of contamination)

Contamination began in the early 1990's.

Duration (i.e. length of time the problem existed)

The problem still exists today.

Number of individuals affected (if applicable)

Unaware of the number of individuals affected

Health impacts of contamination (if applicable)

Not aware of any specific health impacts

Economic impacts (i.e. estimated costs of contamination)

To deal with the issue in Oxford County, the municipality has largely taken a land management approach, as discussed below. Direct costs to deal with the contamination include land purchases and BMP subsidies.

How the community addressed the contamination

The community attempted to address the contamination by responding immediately to the problem once it was discovered. The first initiative was to change agricultural production in the well field area so that the concentration of nitrates in the water meets standards. Further to that, land was purchased by the municipality around the municipal wells and some of that land has been leased back to the farmers who are now required to comply with strict nutrient management requirements. The community is now considering purchasing more land, and paying farmers to implement BMPs.

There is no pipeline available, thus water supply is a key issue.

Suggested SWP BMPs for evaluation

Currently, there are nutrient application requirements.

There are numerous BMPs that could be implemented around the well field, including buffers, nutrient management plans, conservation tillage practices, cover crops, etc. The most appropriate BMPs will be determined, should Oxford be the site selected.

Sources of available data and information

Data are available for this watershed. There have been four theses done at the University of Waterloo on the following topics: the effectiveness of BMPs, a cost-benefit analysis of purchasing land versus paying farmers for BMP implementation, and two hydro-geological studies.

There are geospatial data available for this site and modelling of data has been done.

One disadvantage of this site is that no contact has been made with the private sector farmers, other than those who have been considered for land acquirement.

<u>Strathroy</u>

Location of the contamination was in the town of Strathroy in Middlesex County.

The Lake Huron Primary Water Supply System serves the communities of London, Lambton Shores, North Middlesex, South Huron, Bluewater, Middlesex Centre, Lucan-Biddulph and Strathroy-Caradoc from a water treatment plant located east of the village of Grand Bend in South Huron.

Type of agricultural pollution

Samples of Strathroy municipal water contain slightly elevated levels of nitrates. The acceptable level is 10 mg/L. Samples in 2005 suggested that nitrate levels were between 10.2 and 10.7 mg/L.

Cause of agricultural pollution

Nitrates are chemicals produced in soil and groundwater when plant and animal matter rot on the ground.

It is usual to find small amounts of nitrates in well water, but levels can be elevated in farming areas where fertilizers are used, or in neighbourhoods where there are many septic tanks. The concentration of nitrates is generally higher in water obtained from shallow wells (less than 25 feet deep). Water with nitrate levels in excess of 10 mg/L is unhealthy for infants younger than six months of age.

The areas around the contaminated well fields are predominantly used for agriculture. There is intensive horticulture production in the Strathroy area.

Date that contamination first occurred

Between March 23rd and December 23rd 2005 a drinking water advisory was put in effect by the Middlesex-London Health Unit.

Number of individuals affected

No record of anyone affected.

Estimated costs of contamination

If Strathroy is selected as the watershed for evaluation, Lake Huron and Elgin Water Supply Systems will be contacted (authority under the City of London that tendered the project) to estimate the cost of the pipeline. Documentation from their website suggests the project was completed below projected cost[15]. The St Clair Region Conservation Authority suggests that the cost of the pipeline was in the range of $16-20 million dollars (actual figures are available).

How the community addressed the contamination

In addition to the advisory for infants under six months (not permitted to drink the water while advisory was in effect), in late 2006 the municipality switched to pipeline water from Lake Huron at a significant cost. At that time, it was believed to be too costly to lower the nitrate concentrationin the groundwater.

At the request of the township, the Joint Board of Management for the Lake Huron Primary Water Supply System agreed to construct, own and operate the pipeline connection to the Township of Strathroy-Caradoc, and initiated the construction process

[15] Source: http://www.watersupply.london.ca/projects.html.

for the pipeline. In December 2004, the Huron water board awarded the contract for the design and construction of the Strathroy pipeline to the team of D'Orazio Infrastructure Group and Dillon Consulting. Groundbreaking for the projects start of construction took place in May 2005 at the Strathroy Reservoir site on Second Street.

The 26km pipeline extending from the Huron pipeline near Ailsa Craig to Strathroy, constructed using 600mm diameter reinforced concrete pipe, was completed in late October 2005. Two primary control chambers on the new Strathroy pipeline were completed in early December 2005.[16]

In 2006, the Township of Strathroy-Caradoc completed an expansion of the Second Street reservoir and constructed a second transmission water main from the reservoir in order to complete the necessary upgrades to the Township's water distribution system.[17]

SWP BMPs for evaluation

Strathroy did attempt to implement BMPs including land retirement and tree plantings around the wells, which initially reduced the nitrate levels. However, it is believed there were changes in the cropping practices in the surrounding area that resulted in the nitrate levels increasing again. This prompted the municipality to look for alternative water sources.

Bay of Quinte Subwatersheds[18]

Location of contamination

Watershed name: Bay of Quinte. The Bay's watershed covers more than 18,000 square kilometres, and includes lands drained by the Trent, Moira, and Napanee rivers, and a host of smaller tributaries.

City/town: Trenton, Bath, Belleville, Quinte West, Frankford, Napanee, Picton, Batawa, among others.

Type of contamination

- Nutrient enrichment (large amounts of phosphorous)
- Bacterial contamination
- Toxic contamination from chemicals used in the Bay of Quinte area for industrial, agriculture, and domestic purposes

[16] Source: http://www.watersupply.london.ca/Notice/NRF_Strathroy_supply_transition_051222.pdf
`[17] Source: http://www.watersupply.london.ca/Notice/NRF_Strathroy_supply_transition_051222.pdf
[18] Sources: The Big Cleanup: Bay of Quinte Remedial Action Plan website. Retrieved February 28, 2007 from: http://www.bqrap.ca/index.htm
Environment Canada. 2005. "Remedial Action Plans (RAPs). Bay of Quinte: Area of Concern." Retrieved February 28, 2007 from: http://www.on.ec.gc.ca/water/raps/quinte/intro_e.html

- Habitat destruction (An estimated 12,000 hectares of wetland in the Bay of Quinte have been destroyed; only 7,000 hectares remain).

Cause of contamination

- Nutrient enrichment is attributed to fertilizers from agricultural runoff, sewage from residential sources, and some industrial wastes.
- Bacterial contamination is attributed to untreated septic waste, agricultural practices and industrial wastes.
- Toxic contamination is attributed to industrial waste by-products, ineffective removal of industry and household chemicals by sewage treatment plants, sludge from water treatment plants and others sources.
- Habitat destruction is attributed to shoreline development.

Date that contamination first occurred

An International Joint Commission identified Bay of Quinte as an Area of Concern in 1986. However, the contamination is likely to have occurred earlier and gotten worse over time.

Duration of contamination

- Over the past 30 years, summer point source phosphorous inputs have declined by more that 90%, from 175 kg/day down to 16 kg/day.
- Bacteria inputs have decreased.
- The Bay of Quinte has not been delisted yet as an Area of Concern.

How the community addressed the contamination

- The Government of Canada and Province of Ontario, in cooperation with Quinte Conservation Authority, Lower Trent Conservation Authority and Quinte Watershed Cleanup Inc., developed a Remedial Action Plan for Bay of Quinte in 1986.
- Actions specific to agricultural activities:
    - Farming operations have prevented over 16,500 kilograms of phosphorus from reaching watercourses.
    - Rural landowners have helped to restore 50 kilometres of shoreline and rehabilitate 354 hectares of wetlands.
    - Rural sources of bacteria have been lowered resulting in reduced beach closings.
    - 27,000 hectares of cropland have been converted from conventional to reduced or conservation tillage.
    - 50 manure and milk house management projects have reduced nutrient inputs and bacterial contamination.
    - Farming practices have been improved at 400 farms.
    - 55 fencing projects have restricted cattle from waterways.
    - 49 hectares of fragile riverside farmland has been retired from agricultural use.

2.3 FINAL SELECTION OF STUDY AREA

After reviewing the above candidates, it was determined that the Strathroy/Caradoc case study was the most appropriate for this study. This was based on the observation that the nitrate issues experienced in the Bosquart well field near Strathroy were significantly influenced by agricultural factors, and the strong probability that beneficial management practices (BMPs) could have had a positive impact on nitrogen levels in the groundwater. It was also a case where key scientific and economic expertise and information were available to the study team. In particular, the actual costs associated with addressing the source water issue, i.e. construction of a drinking water pipeline to Lake Huron, were well documented and the full range of information relative to the case could be presented.

2.4 DESCRIPTION OF THE STUDY AREA

This section is adapted from the Strathroy-Caradoc Groundwater Management Study (IWC *et al.* 2001). The full document is available in electronic file format.

2.4.1 Regional Characteristics

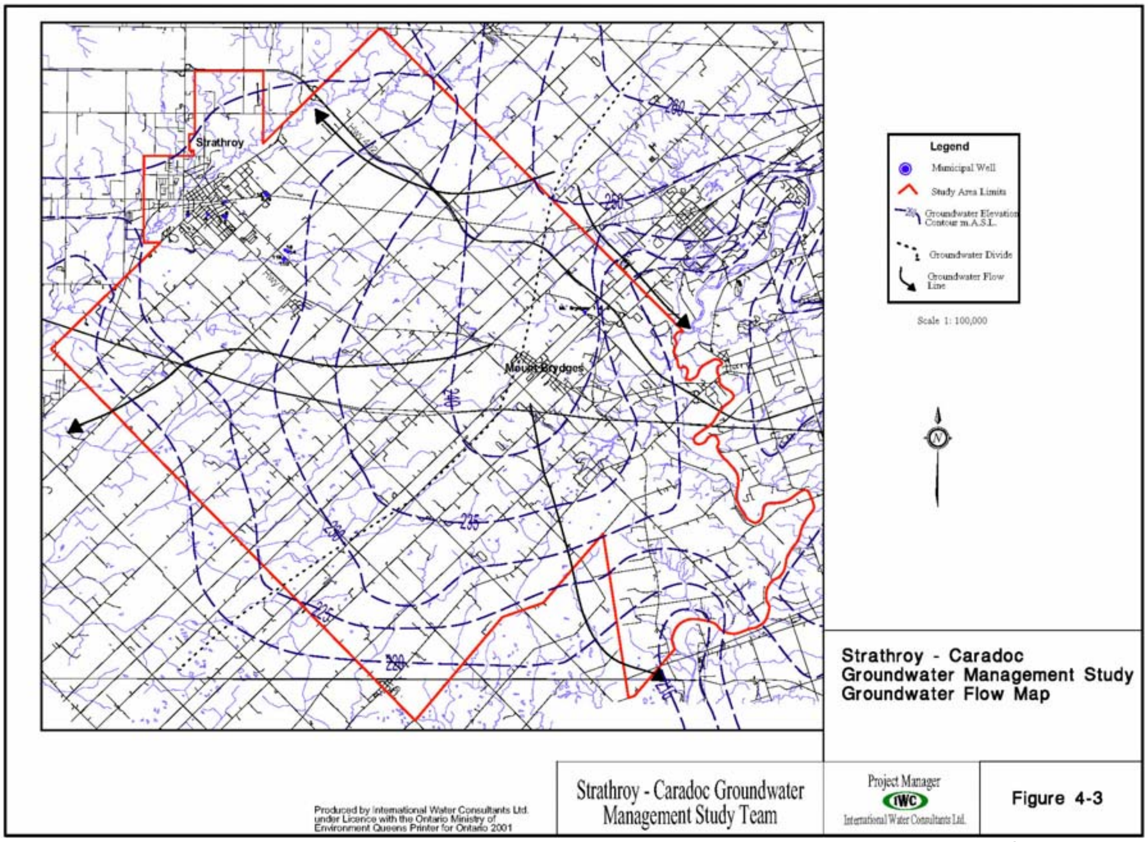
The focus of the Strathroy-Caradoc Groundwater Management Study (2001) was on the municipal groundwater supplies in the urban centres of Strathroy and Mount Brydges, Ontario. The purpose of the regional study was to define the hydrogeology, establish municipal well capture zones, identify existing and potential threats to the groundwater resource, and prepare a strategy for the protection and management of the groundwater resources within the regional study area (IWC *et al.* 2001).

The region consists of the former Town of Strathroy and Township of Caradoc which is now referred to as the Township of Strathroy-Caradoc. At the time of the 2001 Groundwater Study, essentially all of the study area was reliant on groundwater for the supply of domestic, commercial, and industrial water. Prior to the establishment of the pipeline water system in the mid-2000s, the Strathroy municipal system consisted of 13 well or well point systems located in seven well fields. The majority of the rural domestic supply was groundwater from individual wells or well points (IWC *et al.* 2001).

The main aquifer in the study area, referred to as the Caradoc Aquifer, consists of saturated medium to fine-grained sands of the Caradoc Sand Plain. Surficial clay deposits overlie the Caradoc Aquifer in some areas. However, the aquifer is exposed at the surface throughout much of the region. The aquifer is highly vulnerable as contaminants introduced by surficial activities can readily infiltrate and cause degradation of the water quality due to the unconfined nature of the aquifer and its limited protective clay layers (IWC *et al.* 2001).

Based on groundwater contours and geologic conditions (Figure 2.1), about two-thirds of the groundwater in the regional study area eventually discharges into the Sydenham River system. There is less groundwater discharging to the Thames River due to the low hydraulic conductivity materials that separate the sand aquifer from the river. The sand aquifer appears to be in direct connection with the Sydenham River.

Figure 2.1 Regional Groundwater Flow, Strathroy, ON



(IWC *et al.* 2001).

A three-dimensional groundwater MODFLOW model (Harbaugh and McDonald 1996) and MODPATH model (Pollock 1994) were developed to delineate the capture zones of the Strathroy municipal wells in the 2001 Groundwater Study. The model was calibrated using water level data from municipal observation wells and stream flow data, along with the MOE digital water well record database. The model was verified through a transient calibration to pump test data at the Bosquart Well Field. The verification proves a high confidence can be given to the model predictions in the area of the Bosquart Well Field.

The water use in the region, as of 2001, was well below sustainable levels. The groundwater resource appeared to be sufficient to support projected growth for about 20 years and to allow sharing of the groundwater resource with agricultural, commercial, rural residential and base flow maintenance of streams and rivers (IWC *et al.* 2001).

Water quality from wells developed in the Caradoc Aquifer in most cases met the Ontario Drinking Water Standards. However, some locations within the aquifer had elevated iron and manganese concentrations. The main water quality concern within the regional study area was the nitrate content of the groundwater in the Caradoc Aquifer. The regional study determined that the nitrate was derived from both agricultural and urban land uses including barnyards, septic systems, and fertilizers. Elevated nitrate concentrations were observed throughout the region with some of the highest concentrations correlating with areas where the aquifer is unconfined. The 2001

Groundwater Study recommended a strong focus on the reduction of nitrogen inputs (IWC *et al.* 2001).

2.4.2 Case Study Area: Bosquart Well Field

2.4.2.1 Location

The Bosquart Well Field, which includes Bosquart Well Field #1 (Wells 11B and 11D) and Bosquart Well Field #2 (Wells 14 and 15) is located just south of the town of Strathroy, in the northwest portion of the Strathroy-Caradoc groundwater study region. The steady state capture zones for the Bosquart Well Field were delineated as part of the 2001 Groundwater Study (Figure 2.2) (IWC *et al.* 2001). The 10-year capture zone shows the estimated groundwater area supplying the Bosquart Well Field over a 10 year pumping period using permitted pumping rates for the wells. The permitted rates were approximately twice the actual pump rates of the wells and were used to develop conservative estimates for the capture zones. The 10-year, steady state capture zone defined the study area for this report. This was refined during the study to include the transient-state capture zone on which the subsequent analyses were completed. Rates based on the pump history of the wells were used in the transient-state model to best represent the actual well capture zone versus the conservative estimate capture zones presented in the Strathroy-Caradoc groundwater study (IWC *et al.* 2001.)

About Zones and Models

Capture zone: the area that contributes groundwater to a well. For example, the 10-year capture zone includes the area that contributes groundwater that could take up to 10 years to reach the well.

Steady state capture zone: the capture area where average values are used to describe the groundwater system during a specific time period. For example, the Bosquart well field #2 (i.e., wells 14 and 15) was pumped at an average rate of 900 m^3/d from June 1999 to January 2000.

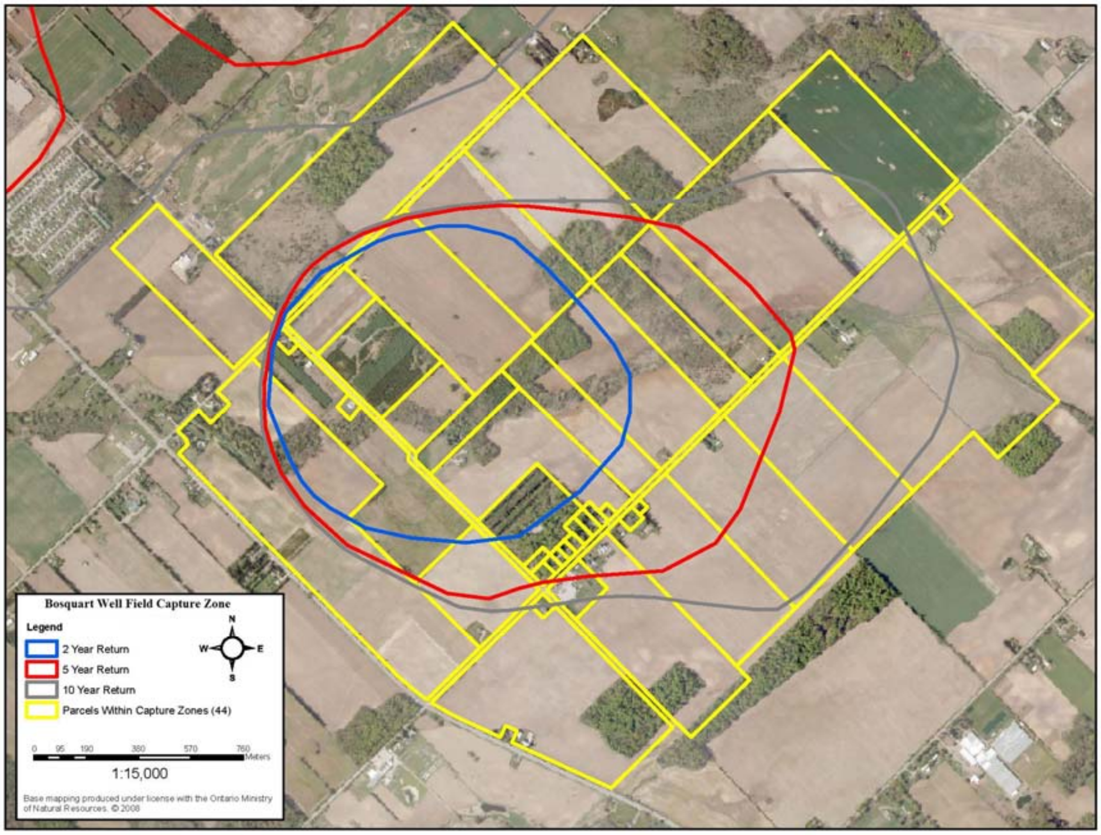
Transient-state capture zone: represents a refinement of the steady state capture zone where values describing the groundwater system vary during a specific time period. For example, the Bosquart well field #2 (i.e., wells 14 and 15) pumped at a rate that ranged between 0 and 1968 m^3/d from June 1999 to January 2000.

Conservative Estimate Capture Zones include larger than necessary parameter estimates, as a safety factor, to ensure the resulting capture zones account for variations in the model inputs.

Groundwater flow i.e., the movement of water through soil or rock, may be sufficiently represented by steady state models that use average values over time to describe the groundwater system.

Contaminant transport e.g., the movement of nitrates in groundwater, is sometimes best represented by transient-state models that use values that change over time to more closely describe the groundwater system.

Figure 2.2 Steady State Capture Zones, Bosquart Well Field, Strathroy, ON



(IWC *et al.* 2001).

The transient-state capture zone for the Bosquart Well Field (Figure 2.3) was used during the application of the nitrogen transport model. Twelve property parcels were identified inside the transient-state capture zone, of which 66.1 ha were identified as cropland (Table 2.1).

Figure 2.3 Transient-State Capture Zone, Bosquart Well Field, Strathroy, ON

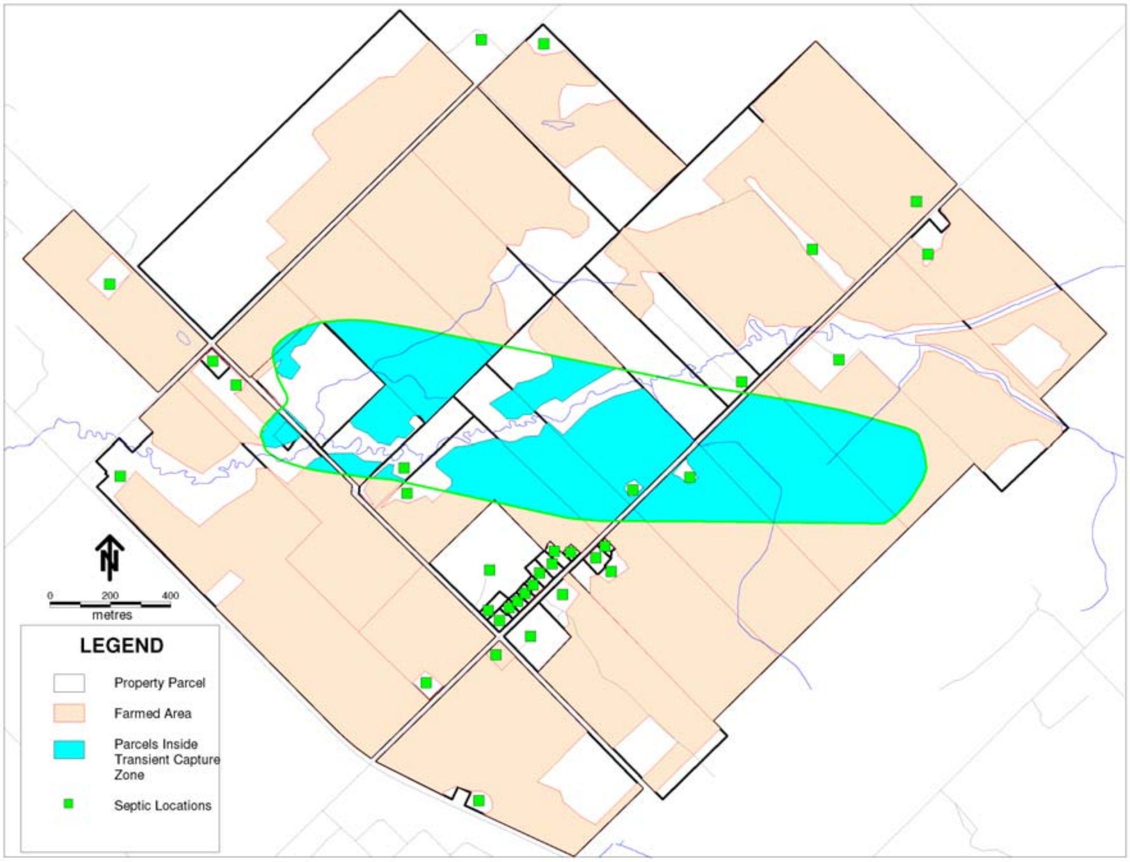


Table 2.1 Cropland In The Study Area, Bosquart Well Field, Strathroy, ON

Farm Property ID#	Total Parcel Area (ha)	Cropland Area (ha)	Cropland Area In Transient-State Capture Zone (ha)
39	19.8	18.8	0.2
31	4.8	4.8	0.2
34	19.7	16.8	0.2
3	19.6	15.8	0.8
32	5.3	3.3	3.2
28	20.3	19.9	5.8
8	15.7	13.0	6.0
20	9.8	6.6	6.3
42	44.9	34.8	7.7
33	20.6	20.5	9.1
37	20.5	14.9	11.6
41	20.7	20.7	15.0
			TOTAL: 66.1 ha

2.4.2.2 Characteristics

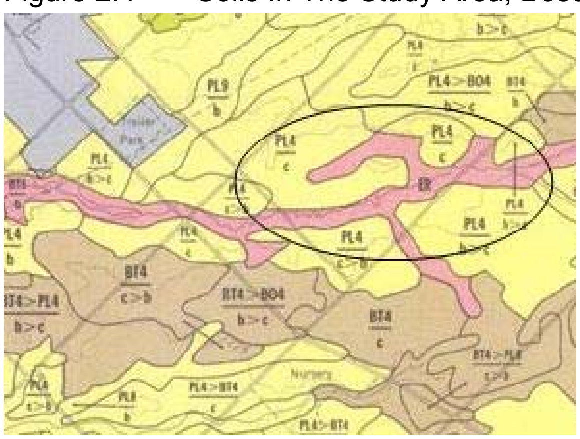
The study area is located within the Caradoc Sand Plains and London Annex physiographic region (Chapman and Putnam 1984). These areas, as the name suggests, differ from the surrounding areas in that they are covered with sand or other light-textured, water laid deposits instead of the adjacent moraines or clay plain deposits. The sand deposits are up to 20 m thick in the area of the Bosquart Well Field to the southeast of Strathroy. Bedrock in the study area consists of limestone, dolostone and shales of the Middle Devonian age Hamilton Group (IWC *et al.* 2001).

The average annual precipitation is 957.9 mm of which 766.4 mm is rain and 191.8 cm is snowfall. The mean daily temperature is 7.9° C with the daily mean temperatures ranging from a low of -6.2° C in January to a high of 21.0 ° C in July. Evapotranspiration was estimated at 622.4 mm and a potential water surplus of 335.5 mm. Some of this surplus infiltrates and recharges the groundwater and the rest is lost as surface runoff (IWC *et al.* 2001).

2.4.2.3 Soil Types and Land Use

The soils in the study area were developed on eolian deposits and consist of fine sand parent materials. They are included in the Plainfield Association (PL) and are rapidly to imperfectly drained (PL4) (Figures 2.4 [Hagerty and Kingston 1992] and 2.5).

Figure 2.4 Soils In The Study Area, Bosquart Well Field, Strathroy, ON



(Hagerty and Kingston 1992)

Figure 2.5 Plainfield Sand Soil Type In The Study Area, Bosquart Well Field, Strathroy, ON

The land use in the study area is predominantly agricultural. A land use survey of the 10-year, steady state capture zone for the time step 1994 to 2007 was conducted in 2008. The results were used to identify nitrogen management practices affecting the transient-state capture zone from 1994 to 2007.

2.4.2.4 Well Field Water Pumping Capacity and Treatment Specifications

The production capabilities of the wells were as follows:

Bosquart Well Fields	Bosquart Well	Operating Capacity (m^3/day)
Well Field #1	11B	2618
	11D	
Well Field #2	14	1968
	15	

Pumping rate records for the well field were obtained for the 1995 to 2000 period from the 2001 Groundwater Study. During this time, Bosquart #1 pumped at an approximate average rate of 1700 m^3/d. The records show Bosquart #2 did not operate from 1995 to May 1999 but started pumping in June 1999. From June 1999 to January 2000 the Bosquart #2 pumped at average rate of 900 m^3/d.

Bosquart wells 11B and 11D were associated with high iron, manganese, and organic nitrogen. The raw water from these wells was treated to sequester the iron and manganese to prevent precipitates from discolouring the water. Bosquart wells 14 and 15 were associated with high nitrate levels. Significant testing was conducted at this well field to assess nitrate concentrations (IWC *et al.* 2001). Because there was a history of brief, occasional elevated nitrate conditions at these wells, the water from these wells was either not used or was blended with the water from wells with lower nitrate levels prior to reaching the first consumer, resulting in an acceptable level of nitrate in the drinking water (Ian D.Wilson Associates Limited 2001b).

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

The main water quality issue within the regional study area and, specifically the Bosquart Well Field, is the nitrate content of the groundwater in the Caradoc Aquifer. Nitrate is one of several nitrogen compounds found in groundwater. Nitrogen in the nitrate form does not interact strongly with soil and moves readily in the subsurface environment. The Ontario Drinking Water Standard (ODWS) is 10 mg/L (or 10 ppm) as nitrogen (N), primarily because of the threat of methaemoglobinaemia to infants or "blue baby" syndrome (IWC *et al.* 2001).

The source of nitrate in groundwater can come from leakage and infiltration from cesspools, barnyards, or sewage lagoons, as well as the use of fertilizers. The elevated nitrate concentrations in the Bosquart Well Field suggest a non point source over the study area. Other sources include septic systems and the application of nitrogen in the urban environment by homeowners, businesses, and municipalities. Factors affecting nitrate concentrations in groundwater include the hydrogeologic setting, time of year the sampling was conducted, depth to sampling point, and land use in the area (IWC *et al.* 2001).

2.4.2.6 Nitrates in Groundwater in the Bosquart Well Field

Extensive monitoring and assessment were conducted by the Middlesex Power Distribution Corporation (MPDC) (formerly the Strathroy Public Utilities Commission) at the Bosquart #2 Well Field. Wilson Associates conducted an assessment of the nitrate levels at this well field during 2000. The following discussion is taken from their reported findings. It appears that a plume of high nitrate content groundwater extends in a west-southwest direction with the core of the plume passing over the north portion of the Bosquart #2 Well Field. The nitrate levels found in the area have limited vertical distribution. The highest levels were found in the 11 to 13 m below grade range and appeared to be limited to above 17 m below grade. It is thought that the high nitrate plume is from heavy fertilizer application in fields located to the north-northeast of the municipal wells. Since the production wells have nitrate levels in the range of 7 - 9 mg/L it is thought that the composite sample is a mixture of water from the nitrate plume and from lower nitrate content water from the south and deeper formations (IWC *et al.* 2001).

As part of the 2001 Groundwater Study, samples were collected further from the Bosquart Well Fields to assess offsite conditions. Three samples were collected along Scotchmere Drive and approximately within the 5-year capture zone of the Bosquart wells. Results from these samples showed elevated nitrate-N concentrations in the range of 12 - 19 mg/L. Considering the total aquifer thickness, average nitrate concentrations at these locations may be lower, however, they do indicate that elevated nitrates are relatively extensive over the unconfined area of the aquifer and the possibility of increasing nitrate levels at the Bosquart wells over the next five years [ie as of 2000] (IWC *et al.* 2001).

A compilation of water quality data obtained from the water monitoring program (Ian D.Wilson Associates Limited 2003a; Ian D.Wilson Associates Limited 2003b; Ian D.Wilson Associates Limited 2003c; Ian D.Wilson Associates Limited 2002a; Ian D.Wilson Associates Limited 2002b; Ian D.Wilson Associates Limited 2002c; Ian D.Wilson Associates Limited 2002d; IWC *et al.* 2001; Ian D.Wilson Associates Limited 2001a; Ian D.Wilson Associates Limited 2001b; Ian D.Wilson Associates Limited 2001c; Ian D.Wilson Associates Limited 2001d; Ian D.Wilson Associates Limited 2000) shows that unblended water from wells 14 and 15 contained concentrations of nitrates ranging from 1.87 to 10.7 and 1.79 to 13.4 mg/L, respectively (Table 2.2). Nitrate levels in wells 11B and 11D were relatively lower and ranged from 0.28 to 7.97 and <0.5 to 7.63 mg/L, respectively. The Ontario Drinking Water Standard (ODWS) for nitrate-N is 10 mg/L (or 10 ppm). The Bosquart #2 Well Field was developed in 1997. Therefore, nitrate concentrations at the well field were not available prior to 1997. Given that in 1997, the concentration of nitrate-N in the water was already higher than 10 mg/L, one can assume that there had been a high concentration of nitrates for some time. In fact, based on the cropping history of the region, it is likely that nitrates had been problematic for at least 20 years.

Table 2.2 Nitrate in Water from the Bosquart Well Field, Strathroy, ON

Date Sampled	Nitrate in Water (mg/L)			
	Well 11B	Well 11D	Well 14	Well 15
28-Jun-94	2.2	1.3		
13-Sep-94	2.72	1.27		
20-Dec-94	2.67	1.39		
16-Aug-95	3.8	2		
24-Oct-96	2.66	0.78		
15-Aug-97	2.64	1.13	10.3	9.14
04-Sep-97	2.27	0.77		
09-Oct-97	2.07			
11-Dec-97	2.71	<0.5		
09-Sep-98	2.75	1.57		
02-Sep-99	<0.5	<0.5		
29-Oct-99	1.17	<0.5	6.27	7.99
25-Oct-00	1.22	2.78	3.45	
06-Dec-00	1.51	0.3	5.25	
19-Feb-01	0.64	0.89	5.14	
16-May-01	0.84	1	6.43	13.4
06-Jun-01	0.28	1.01	5.49	11.4
10-Aug-01	1.42	0.87	6.32	10.1
22-Aug-01	1.52	1.02	5.53	11
25-Oct-01	1.67	1.46	5.52	12.4
21-Nov-01	0.58	1.25	4.95	10.6
27-Feb-02	2.17	1.9	1.87	1.79
Mar 02				10.9
Apr 02			2.72	9.7
29-May-02	4.9	4.73	4.86	4.86
Jun 02	1.34	1.97	2.72	9.7
29-Aug-02	7.97	7.63	5.53	5.69
09-Sep-02	6.56			
10-Sep-02		6.56		
11-Sep-02			6.6	
12-Sep-02				5.92
05-Dec-02	1.02	2.3	2.07	10.6
05-Mar-03	0.57	2.82	5.55	11.6
04-Jun-03	0.39	1.83	4.47	7.68

2.4.2.7 Options for Managing Nitrates in Groundwater

The Strathroy-Caradoc Groundwater Management Study (IWC *et al.* 2001) recommended that, due to the identified concern of elevated nitrate in the groundwater within the study area, a strong focus be placed on attempting to reduce the loading of nitrogen, especially in the cash crop sector. The study recommended that agricultural sectors be encouraged to follow Best Management Practices and to develop Environmental Farm and Nutrient Management Plans as well as Environmental Management Systems. Other recommendations included regulatory and non-regulatory approaches to land use and management within the regional study area, including compensation for farmers most affected by restrictions (IWC *et al.* 2001).

3. LITERATURE ON AGRICULTURAL WATER CONTAMINATION AND REMEDIATION

3.1 SOURCE WATER PROTECTION IN AGRICULTURAL LANDSCAPES

Water is an essential resource for all elements of life. Water sustains people, our environment, and the Canadian economy (Ducks Unlimited Canada, 2005). A safe and reliable water supply is critical to the sustainability of Canada's industries, ecosystems, and the quality of life of its citizens.

Compared to the rest of the world, Canada has a relative abundance of freshwater. However, increasing population density, particularly along the US border, has placed a heavy burden on water supplies in Canada. As such, the quality and quantity of water resources are threatened, resulting in increased water shortages and contamination problems in communities such as Walkerton, Ontario and North Battleford, Saskatchewan (Ducks Unlimited Canada, 2005).

The contamination of water bodies with pollutants can occur from both point or non-point sources of pollution. Point source pollution enters the environment at a specific place from an identifiable source. Examples of point source pollution include industrial discharges, municipal wastewater effluents, landfill site leachate, wastes from mining sites, on-site septic systems, and leaking oil and gas storage tanks. Non-point source pollution comes from many diffuse sources. Examples of non-point sources of pollution include agricultural runoff containing fertilizers, pesticides, oil, bacteria and nutrients from livestock and manure, urban runoff, products from recreational boating, saltwater intrusion and acid precipitation(Blundell *et al.*, 2004).

Over the last several years, a great deal of attention and research has been focused on the environmental impacts of agricultural operations, specifically on surface water and groundwater. In Ontario, agricultural landscapes account for a significant proportion of source water that is eventually used by humans for drinking, recreation, industrial processes and other purposes. Water also plays a central role in the agriculture and agri-food industry due to its various functions in crop and livestock production including watering animals and irrigation. Agricultural activities may contribute to excess levels of nutrients such as nitrogen (N) and phosphorus (P) in the environment.

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 using 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."[19] Source water protection (SWP) involves protecting both the quality and quantity of source water[20] 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.

3.2 BMPS IN AGRICULTURAL LANDSCAPES

3.2.1 Defining BMPs

This section was adapted from a previously published report by the George Morris Centre entitled “An Economic Evaluation of Beneficial Management Practices for Crop Nutrients in Canadian Agriculture”, prepared for the Nutrient Council of Canada (Brethour, 2007)

A number of definitions of ‘best’ or ‘beneficial’ management practices were identified in the literature. Commonalities across these definitions were the protection of the environment and economic sustainability at the farm level. The following paragraphs provide a summary of the definitions obtained from industry, government and academia. Definitions of BMPs include:

---

[19] Source: Justice Dennis O’Connor, Walkerton Inquiry 2002 as cited in Conservation Ontario, 2005.

[20] Source water is untreated water from streams, lakes or underground aquifers that people use to supply private wells and public drinking water systems.

- "Management practices can be qualified as "beneficial" if they are economically sustainable for farmers while contributing to food quality and/or quantity and the protection of environmental resources (Canadian Fertilizer Institute, 2005)."
- "A farming method that minimizes risk to the environment without sacrificing economic productivity (Hilliard et al, 2002)."
- "A practice or combination of practices that are determined by an appropriate agency to be the most effective and practicable (including technological, economic and institutional considerations) means of controlling point and non-point source pollutants at levels compatible with environmental quality goals (SWCS, 1982)."
- "A practical, affordable approach to conserving a farm's soil and water resources without sacrificing productivity (OMAF, 2003)."
- "An agricultural management practice that: mitigates or minimizes negative impacts and risk to the environment; ensures the long term health of land related resources used for agriculture and does not negatively impact the long term economic viability of producers (McGarry, PFRA, 2004)."
- a beneficial management practice considers the balance of nutrients for agricultural production with the goal of protecting environmental resources and ensuring profitable crop production (Crop Nutrients Council, 2005)

The environmental, economic and social objectives of BMPs are also important to note as these aspects are generally inherent to BMP definitions. These objectives, as defined by the Canadian Fertilizer Institute (2005), are as follows:

- Environmental
    - Sustain soil quality
    - Avoid the need for additional farmland, especially production on marginal lands
    - Maintain nutrient levels appropriate for the sustainability of natural ecosystems
- Economic
    - Produce sufficient returns to sustain farm operations
    - Enable investment in BMPs
    - Preserve quality of life
    - Make efficient use of crop nutrients
- Social
    - Produce nutritious, abundant and affordable food
    - Support programs for strong and caring communities
    - Help meet global food needs
    - Provide ongoing employment opportunities in agriculture and related services

For the purpose of this research, the Crop Nutrients Council's definition of beneficial management practices was used, which considers balancing the use of nutrients for agricultural production with environmental quality goals and profitable crop production. This definition was chosen since it is specific to crop nutrient BMPs, many of which are suitable for managing nitrogen in the environment.

3.2.2 Identifying Appropriate BMPs

Since 1993, 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. The plans include realistic action items with time tables, which are aimed at improving environmental conditions. Cost-share programs are often available to assist with adoption of these practices (OSCIA, 2006).

The EFP is based on a workbook that includes two parts: the Farm Review and the Action Plan (OFEC, 2004). During the review, each landowner rates their soils and their ability to offset, or increase, potential risks to the environment. The Farm Review portion of the plan includes 23 worksheets that assist the landowner in rating the different situations that may occur on a farm (i.e. best starting at 4, 3, 2, 1). The ratings are used to develop the Action Plan (OFEC, 2004).

Information sheets provide additional information (AFEC, 2004) and are, in turn, supported by a series of BMP manuals e.g., Best Management Practices: Water Management (Maaskant, 1994). The list of EFP work/information sheets is as follows:

2 - Water Wells
3 - Pesticide Handling and Storage
4 - Fertilizer Handling and Storage
5 - Storage of Petroleum Products
6 - Disposal of Farm Wastes
7 - Treatment of Household Waste
8 - On-Farm Storage of Livestock Manure and Other Prescribed Materials
9 - Livestock Yards and Outdoor Confinement Areas (OCAs)
10 - Silage Storage
11 - Milking Centre Wash water
12 - Nuisances under the Farming and Food Production Protection Act, 1998
13 - Water Efficiency
14 - Energy Efficiency
15 - Soil Management
16 - Nutrient Management in Growing Crops
17 - Manure Use and Management
18 - Horticultural Production
19 - Field Crop Management
20 - Pest Management
21 - Stream, Ditch and Floodplain Management
22 - Wetlands and Wildlife Ponds
23 - Woodlands and Wildlife

The information sheets and BMP manuals represent one of several ways land managers can gain knowledge and understanding that will assist them in making environmentally sound decisions.

Mostaghimi *et al.* (2001) provide a summary of 14 BMPs used to control nonpoint source pollution. Discussions of each BMP include definitions, situational appropriateness, potential negative effects and limitations, and effectiveness when combined with other complementary practices. BMPs were categorized as source reduction, transport interruption or a combination of the two and classified as either managerial or structural

Mostaghimi *et al.* (2001). The *National Handbook of Conservation Practices* (NHCP) was listed as an appropriate reference providing detailed descriptions of each practice (updates available on the internet (NRCS USDA, 2008).

3.3 BMPS FOR NITROGEN IN AGRICULTURAL LANDSCAPES

In agricultural landscapes it is difficult to effectively manage nitrogen when the objective is maximizing the amount of nitrate in the root zone that is available to produce crop yield while minimizing the amount of nitrate in the soil that could to leach into the groundwater. Striking the right balance can be difficult for the following reasons:

- 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 (Keeney, 1991).

Many of the BMPs identified in the EFP program address issues related to source water protection and nitrogen management in agricultural landscapes (AAFC, 2004). 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 best management practices (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 nitrates leaching into the groundwater (Keeney, 1991), (Ritter, 2001), (McKague, 2005). These practices are referred to as either Beneficial or Best Management Practices (BMPs).

A list of recommended BMPs deemed appropriate for managing nitrogen in a specific agricultural landscape requires information on land characteristics and use (see section 2) and an understanding of where nitrogen enters and exits the system (Meisinger, 1991).

3.3.1 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 3.1) (Di, 2002).

Figure 3.1 Nitrogen Cycle

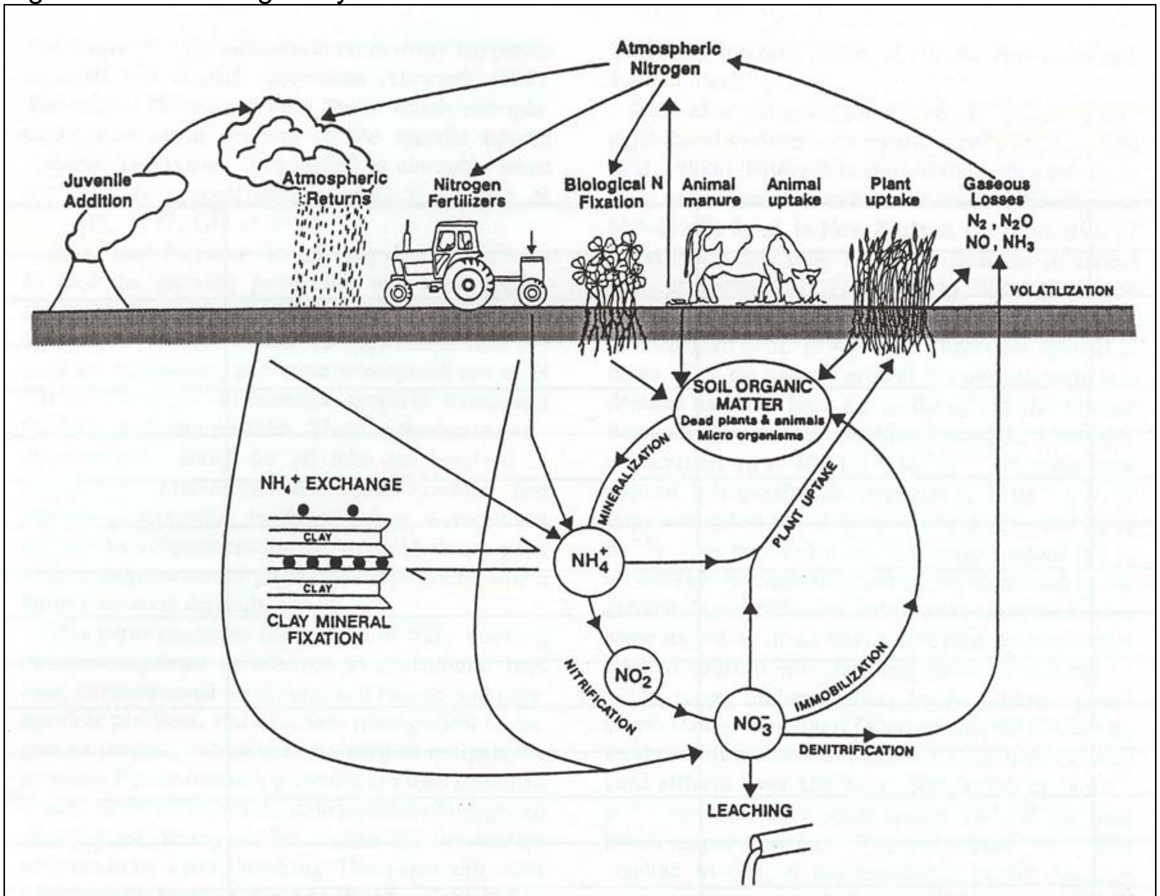


Figure 1. Nitrogen cycling in the soil–plant system (after McLaren and Cameron 1990).

(Di and Cameron, 2002)

It is difficult to determine the relationships between 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 exiting a system by leaching into groundwater for the following reasons: a) there are many possible sources of nitrate in every system, 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 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).

Rising concentrations of nitrate in surface 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 nitrate is important to protecting source water originating from agricultural landscapes. Di and Cameron (2002) reviewed nitrate leaching in temperate agro-ecosystems around the world. The authors determined that the potential for causing nitrate leaching in different land use systems was typically as follows: forest< cut grassland < grazed pastures, arable cropping < ploughing of pasture

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

3.3.2 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.

3.3.2.1 Farmstead and Single Dwelling Management Practices

Point sources of pollution generally have a specific discharge location e.g. the end of a pipe. They are often associated with industry involving manufacturing, processing, power generation and waste treatment facilities (Wolfe, 2001). Point sources of nitrate contamination of groundwater are also 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 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 the 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 and groundwater.

The 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 the 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 southern 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.

3.3.2.2 In-Field Management Practices

Positive changes in groundwater quality associated with BMPs may take several decades to be realized in some watersheds. 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). In one such case, however, 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 the following 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, 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 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 nitrate. 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 best management practice 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 metres, the author suggested a lack of nitrate concentration data from the deep unsaturated zone and excess rainfall (> 30% of normal) contributed to the unexpected finding. The author observed that nitrate in the unsaturated zone assumed to be affected by the BMPs ranged from 3.4 to 13.2 g/yr/m2, 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 and groundwater quality (Power *et al*., 2000). Research occurred across nine Midwestern states in the US. Pre-plant and pre-sidedress soil nitrate testing to determine (Shipitalo, 1998) appropriate nitrogen fertilizer rates was used effectively and 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 the groundwater. Conservation tillage can increase the number of macropores[21] in the soil, which transmit water to lower soil depths. 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. Nitrate, however, 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 in the 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.

3.3.2.3 Off-Field Management Practices

At least three reviews of the impacts of agricultural drainage were published during the last decade (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)

[21] 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.

identified several BMPs from the literature that provide effective mitigation of pollution in drainage of water from agricultural lands:

- 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 (Rudy, 2004).

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

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).

The effectiveness of buffers in mitigating problems associated with nitrogen and groundwater infiltration is driven by the functions performed by buffers (Table 3.1). These functions are explained in greater detail by (Dosskey, 2001).

Table 3.1 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

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) (USDA-NRCS, 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, 2002). 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 3.2.

Table 3.2 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).

3.3.3 Recommended BMPs for Nitrogen

Di and Cameron (2002) identified several BMPs in the literature that could be used effectively to manage nitrogen and minimize the potential for nitrates to leach:

- 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
- 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
- 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

The George Morris Centre prepared a report for the Nutrient Council of Canada entitled "An Economic Evaluation of Beneficial Management Practices for Crop Nutrients in Canadian Agriculture" (Brethour *et al*., 2007). The report listed 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 p.3)." 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 p. 13; Morris, 1994 p. 39).
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 p. 29). 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 (The Fertilizer Institute).
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 p. 55).
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 p. 56).
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 p. 54)."
    b. No-till/Zero-till – "the practice of planting/seeding crops with no primary or secondary tillage separate from planting/seeding operations" (Lane, 1997 p. 63).
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 3.3. The table also identifies the resource protected when these BMPs are used.

Table 3.3 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		

Source: CFI, 2005

3.4 ECONOMIC COSTS AND BENEFITS

The purpose of this section is to review economic and environmental studies that haveevaluated costs and benefits of BMPs both from a private (i.e. individual farm) and public (i.e. societal) perspective. This section reviews literature from 1990 to 2008.

3.4.1 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 nutrient management planning 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 nutrient management planning 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).

A 1990 State of Maryland study estimated that nutrient management planning would save farmers $55/ha (USEPA, 1993, p. 2–60 as cited in Cestii, 2003).

Brethour *et al.* (2007) used a national survey of producers to estimate the economic costs and benefits of participation in BMPs. The BMPs selected for evaluation included: soil testing, variable rate fertilization, buffer strips, no-till, minimum till and nutrient management planning. 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.[22] The BMPs selected for evaluation included soil testing, variable rate fertilization, buffer strips, no-till, minimum till and nutrient management planning. Table 3.4 shows the results by province and soil zone of the national survey and farm models related to the adoption of a nutrient management plan (NMP). Overall, the survey respondents indicated that nutrient management planning 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 expected net revenue 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 3.4). Brethour *et al.* (2007) concluded that, based on producer perceptions and the assumptions used

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

in the analysis, the results of the study indicated that nutrient management planning improved profitability for the representative farms (Brethour *et al*., 2007).

Table 3.4 Change in Expected Net Revenue with the Adoption of a Nutrient Management Plan

	Range of Increase in Yields (depending on the crops in rotation)	Change in Operating Costs	Cost to Develop a NMP[23]	% Change in ENR due to NMP[24]
	(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%

Source: (Brethour, 2007).

Nutrient management planning 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).

3.4.2 Willingness to Pay for Reductions in Chemical Contamination

Crutchfield *et al.* (1995, p. 13) 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. (Appendix C). 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.* 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, p. 14)

[23] Note that cost of nutrient management plan (NMP) was annualized over 5 years.
[24] 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.

Of the eight studies Crutchfield *et al.* 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.* 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.* found aggregate 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).

3.4.3 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. The research team intends to interview the Ontario Soil and Crop Improvement Association (Ontario BMP program administrators) regarding program administration costs and funding expenditures during phase 3.

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, 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 also reported, based on the Interstate Commission for the Potomac River Basin, that best management practices that removed 20 percent of nutrient runoff cost 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, 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 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[25] (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 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).

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

In their inventory of ecological services, Boyd and Banzhaf (2006, p. 12) 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

[25] 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.

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 because of their ability to provide flood damage avoidance (Boyd and Banzhaf, 2006).

Surface, near surface 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 physicochemistry 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, reaching 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, as an ecosystem service. Several studies have examined health benefits associated with drinking water quality.

Krantzberg and de Boer (2006), is a study of the economic values of the Great Lakes, quantified social/lifetime health costs due to water quality problems in the Great Lakes. Results indicated 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 stays, to be more than $5 billion in Ontario (Krantzberg and de Boer, 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 50mg/L. Hanley (1991) reports that 35% of households returned the survey. Hanley (1991) estimated the mean willingness-to-pay to be ₤12.97 per household/annum. Hanley (1991) also aggregated the result to the study population and estimated benefits to be ₤10,832,707 per annum (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 10mg/L. The village of Hensall has had nitrate-N levels higher than 10 mg/L. Giraldez and Fox (1995) considered three approaches to estimate the cost of human health risks from exposure to nitrate in drinking water. The first approach used treated 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 and Fox, 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 concentration in the water 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 *et al.* (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 a groundwater pollution program to be US$641 (1989 dollars) with 95% confidence interval of US$493 to US$890 (1989 dollars) (Sun *et al*., 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. There were concerns in both areas about 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 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 who were affected by water contamination in the fall of 1990. The response rate was 43 percent (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 3.5 specifies the annual costs incurred by households in averting water contamination in 1990 US dollars. Table 3.6 specifies annual household willingness to pay for a reduction in water contamination in 1990 US dollars.

Table 3.5 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
Note: *Values are assumed to be 1990 dollars since the survey was administered in 1990.				

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

Table 3.6 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.				

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

3.6 SUMMARY OF THE ECONOMIC AND ENVIRONMENTAL LITERATURE

A range of 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 can result in a reduction in the amount of agricultural pollutants reaching waterways. 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 reviewed above suggests that measures to mitigate source water pollution have been successful. The literature makes reference to beneficial management practices along with nutrient management plans as making a material difference in farm profitability and to source water endpoints. It is clear in the literature that beneficial management practices can positively influence ecosystem outcomes.
There are costs and benefits to establishing and maintaining beneficial management practices at the farm level for the protection of surface and groundwater. In addition to the private costs and benefits, the literature also illustrates that there are costs and benefits to society of these associated practices. Although the literature does not evaluate the societal benefits of specific BMP practices, it illustrates the value of a more general result that could be derived from the use BMPs, for example, a reduction in chemical or nutrient contamination or improvements from wetland enhancement or restoration.

4. METHODS

Development of a representative cost benefit analysis of existing source water protection beneficial management practices (SWP BMP) for managing nitrogen in an agricultural landscape relied on development of a representative estimate of the effectiveness of BMPs in managing nitrogen within agricultural landscapes. The relative effectiveness of the BMPs was determined using a nitrogen budget to estimate long-term potentially leachable nitrogen (LPLN), i.e. nitrogen below the root zone that could escape into the groundwater, and a nitrogen transport model to estimate the change in nitrogen concentration in drinking water obtained from groundwater at the Bosquart Well Field.

4.1 DETERMINATION OF CASE STUDY SCENARIOS

The study aimed to include three scenarios:

1. a base scenario or case, which best represented actual field conditions from 1994 to 2007
2. a moderate case, where changes to nitrogen management could be made by a producer without having to invest in additional equipment or change their preferred crop rotation
3. a major case, where changes to nitrogen management could require a producer to invest in additional equipment or change their preferred crop rotation but still farm within a ‘normal practice’ framework

Case study profiles, including identification of appropriate BMPs for managing nitrogen in the transient-capture zone of the study area, were determined as follows:

1. Information on the problem, i.e. nitrates in the drinking water, and the characteristics of the study area were reviewed using available studies from local agencies (St. Clair Region Conservation Authority (SCRCA), Middlesex Power Distribution Corporation (MPDC) (formerly the Strathroy Public Utilities Commission)), and reputable web sites
2. A survey was conducted in 2008 by personal interview of land owners or managers of properties with land inside the 10-year, steady state capture zone, which was identified previously in the 2001 Groundwater Study (IWC *et al.* 2001) (Figure 2.2). The survey documented land use and nitrogen management practices from 1994 to 2007
3. Results of the survey were extrapolated across the remainder of the study area;
4. A literature review provided up-to-date information on nitrogen and effective nitrogen management options in agricultural landscapes
5. An experienced scientist (Dr. Jane Sadler Richards PAg) and crop consultant (Mr. Stephen Redmond CCA, PAg) reviewed the results and decided on two nitrogen management scenarios or case studies (referred to as the **Rate Case** and the **Rotation Rase**) that could be compared with the actual nitrogen management (referred to as the **Base Case**) practices used in the capture zone from 1994 to 2007
6. Additional, more intensive options for nitrogen management were identified but held in reserve for use, only if the most obvious and practical management strategies did not achieve a significant reduction in nitrates in the drinking water

4.2 ESTIMATING NITRATE MASS LOAD IN THE CAPTURE ZONE

4.2.1 Development of Nitrogen Budgets

The goal of this component of the work was to develop an "approximate N budget 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 this approach do not provide a quantitative assessment of nitrate-N loss: there is no replacement for site-specific study, which is required to determine actual nitrate loss to the groundwater.

The nitrogen (N) budget in this study was adapted from the literature (Cole 2008; Havlin 2004; Barry *et al.* 1993; Meisinger and Randall 1991). Values for nitrogen input and output items were based on published local and provincial information and/or scientific literature. Author knowledge and experience were used to make assumptions when a published source was not available, or when the published information required modification to reflect site-specific conditions. The framework for the N budget is provided in Table 4.1. N budgets were developed for croplands since these were considered a major source of nitrogen in the capture zone. N budgets for septic systems within the 10-year capture zone were developed to assess their relative nitrogen input, i.e. minor or major N source (Table 4.2). N budgets were not developed for woodlots and natural areas as these were considered minor sources of nitrogen (Rudolph 2008; Di and Cameron 2002).

4.2.2 Estimating Relative Long-Term Potentially Leachable Nitrogen (LPLN) From Cropland

The results of the N budget for each property were added in order to calculate the long-term potentially leachable nitrogen (LPLN) per year. The total annual values per property per case were subdivided across the months of the year to calculate the potentially leachable nitrogen per property per month per year within the transient-state capture zone. The monthly subdivisions of the annual values were based on published local and provincial information and/or scientific literature. Author knowledge and experience were used to make assumptions when a published source was not available, or when the published information required modification to reflect site-specific conditions. The framework for the monthly distribution of LPLN is provided in Table 4.3.

4.2.3 Estimating Relative Long-Term Potentially Leachable Nitrogen (LPLN) From Private Septic Systems

Aerial photography revealed 35 single dwellings within the 10-year capture zone. Four septic systems were identified in the land use survey as requiring attention or having been fixed between 1994 and 2007. These septic systems, however, were not located in the transient-state capture zone, although three other septic systems were present. As a result, it was assumed there was no change in septic nitrogen loading during the study period and LPLN from private septic systems was a minor source of nitrogen in this study. The results of the N budget for each of the three septic systems were added to calculate the long-term potentially leachable nitrogen (LPLN) per year. The total annual values per property were subdivided equally across the months of the year to calculate the potentially leachable nitrogen per property per month per year within the transient-state capture zone. These values were held constant regardless of the cropland case under assessment.

Table 4.1 Nitrogen (N) Budget Framework For Cropland

Item	Units	Notes
Crop type		Based on land use survey and extrapolation (an 'X' after the crop indicates data were extrapolated from the land use survey results)
Crop ID#		An assigned number
Yield	kg/ha	Based on land use survey, extrapolation, and author experience
Nmanure (prev fall)	kg N/ha	Nitrogen in manure applied in fall of previous year
Nmanure (spring)	kg N/ha	Nitrogen in manure applied in spring of current year
Nfert (starter)	kg N/ha	Nitrogen in starter fertilizer applied at planting with the seed
Nfert (broadcast)	kg N/ha	Nitrogen in fertilizer applied as a broadcast before planting
Nfert (sidedress)	kg N/ha	Nitrogen in fertilizer applied after the corn crop emerged
Napplied	kg N/ha	TOTAL nitrogen applied by producer
Nminer (prev crop	kg	Nitrogen released or mineralized from the breakdown of

Item	Units	Notes
residues)	N/ha	residues from the previous crop
Nminer (prev manure)	kg N/ha	Nitrogen released or mineralized from the breakdown of residues from previously-applied manure
Nminer (cover crop)	kg N/ha	Nitrogen released or mineralized from the breakdown of residues from a previous cover crop
Natmdep (precip; dry)	kg N/ha	Nitrogen accumulated in the soil from the atmosphere by wet (i.e. in precipitation) or dry deposition
Nseed	kg N/ha	Nitrogen content of the seed that was planted to grow the current crop
Nsymfix	kg N/ha	Nitrogen accumulated in the crop by symbiotic microorganisms that fix nitrogen from the air
Nnonsymfix	kg N/ha	Nitrogen accumulated in the soil by non-symbiotic microorganisms that fix nitrogen from the air
Total N Inputs	kg N/ha	TOTAL nitrogen entering or available in the soil-crop system
Ngrain (harvest)	kg N/ha	Nitrogen removed in the grain harvested from the field
Nimmob (crop residue)	kg N/ha	Nitrogen tied up or immobilized in residues from the previous crop
Nimmob (manure)	kg N/ha	Nitrogen tied up or immobilized in residues from previously-applied manure
Nimmob (cover crop)	kg N/ha	Nitrogen tied up or immobilized in residues from a previous cover crop
Nvol (fert)	kg N/ha	Nitrogen lost or volatilized as a gas from applied fertilizer
Nvol (manure)	kg N/ha	Nitrogen lost or volatilized as a gas from applied manure
Nvol (senesc; misc)	kg N/ha	Nitrogen lost or volatilized as a gas from natural plant senescence (die-off) and miscellaneous sources
Nerosion	kg N/ha	Nitrogen lost in soil eroded from the soil surface
Nrunoff	kg N/ha	Nitrogen lost in water running off the soil surface
Ndenit	kg N/ha	Nitrogen lost from low oxygen/poorly aerated soils (i.e. water saturated soils) after conversion by denitrification to a gas
Total N Outputs	kg N/ha	TOTAL nitrogen leaving or not available in the soil-crop system
$\Delta Nsi+\Delta Nso_{(OM)}$	kg N/ha	Overall change in nitrogen stored within the soil-crop system (ΔNst) from beginning to end of the study time step (includes change in soil inorganic nitrogen (ΔNsi), which is essentially nitrate-N, and change in soil organic nitrogen ($\Delta Nso_{(OM)}$), which is essentially organic matter-N) i.e., Nst = total N in the soil-crop system at end of time step (2007) less total N at beginning of time step (1994); Nst components include inorganic and organic N forms. Nst is often assumed to be at steady state i.e., no change overall unless a 'soil building' management strategy is introduced (as in the Rotation Case in this study)
Nleach	kg N/ha	Nitrogen potentially available below the plant root zone to leach into the groundwater over the long-term (called long-term potentially leachable nitrogen (LPLN))

Item	Units	Notes
Nleach/TotalNip	%	Ratio of potentially leachable nitrogen to total nitrogen input to the soil-crop system
Published References: (Reid 2007) (OMAFRA 2006) (Janzen *et al.* 2003) (Kraft and Stites 2003)	(Mosier *et al.* 2002) (OMAFRA 2002) (Anonymous 2001) (Ritter and Bergstrom 2001) (Huang and Uri 1999)	(Neeteson 1995) (Peoples *et al.* 1995) (Barry *et al.* 1993) (Hagerty and Kingston 1992)

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.

Table 4.2 Nitrogen (N) Budget Framework for Septic Systems

Item	Units	Notes
Nseptic	extrapolation	Based on land use survey and extrapolation (an 'X' indicates the data were extrapolated from the land use survey results)
Persons/household	#	Based on land use survey and extrapolation
Water consumption	L/pers/day	Water use estimate per person per day for a given household
Nseptic leakage	kg N/yr	Nitrogen that could leak into the groundwater if the system is not functioning properly; no sites within the transient-state capture zone
Nseptic effluent	kg N/yr	Nitrogen in effluent from the septic system
Total N Inputs	kg N/yr	TOTAL nitrogen available through the septic system
Total N Outputs	kg N/yr	TOTAL nitrogen leaving the septic system by other means
ΔNsi+ΔNso	kg N/yr	Overall change in nitrogen in the septic system from beginning to end of the time step
Nleach	kg N/yr	Nitrogen potentially available below the septic bed to leach into the groundwater over the long-term (called long-term potentially leachable nitrogen (LPLN))
Nleach/TotalNip	%	Ratio of potentially leachable nitrogen to total nitrogen input to the septic system
Published References: (Environmental Protection Division 2009) (OMMAH 2008) (Health Impact Assessment Task Force 2004) (Addiscott *et al.* 1991)		

Table 4.3 Long-Term Potentially Leachable Nitrogen (LPLN) Monthly Distribution Framework

ID#	Row Order	Mo	Month	Item	Units	Example Value	Notes
41	30	1	Jan	Nleach	kg N/ha/mo	3.5	Assumptions: 1. one monthly N loss profile used with all cases 2. main growing season is from May to September, which is time of highest N demand by plants, therefore assumed no
41	30	2	Feb	Nleach	kg N/ha/mo	3.5	
41	30	3	Mar	Nleach	kg N/ha/mo	6.9	
41	30	4	Apr	Nleach	kg N/ha/mo	6.9	

ID#	Row Order	Mo	Month	Item	Units	Example Value	Notes
41	30	5	May	Nleach	kg N/ha/mo	0.0	N loss 3. main groundwater recharge is from October to April, which includes times of highest precipitation and snow melt; therefore assumed all N loss during 8 months of year 4. frozen soil conditions in winter may slow water infiltration, therefore assumed half monthly N loss during January and February
41	30	6	Jun	Nleach	kg N/ha/mo	0.0	
41	30	7	Jul	Nleach	kg N/ha/mo	0.0	
41	30	8	Aug	Nleach	kg N/ha/mo	0.0	
41	30	9	Sep	Nleach	kg N/ha/mo	0.0	
41	30	10	Oct	Nleach	kg N/ha/mo	6.9	
41	30	11	Nov	Nleach	kg N/ha/mo	6.9	
41	30	12	Dec	Nleach	kg N/ha/mo	6.9	
41	30	13	Yr	**Nleach**	kg N/ha/yr	41.6	

Published References:
(OMAFRA 2006)
(Ritter and Bergstrom 2001)
(Neeteson 1995)

4.2.4 Estimating Nitrate Mass Flux in the Capture Zone

The MT3DMS software package (Zheng and Wang 1999) was used to develop the contaminate transport model. The transport model was used in conjunction with the MODFLOW groundwater flow model to simulate the migration of nitrates from the input locations to the Bosquart Well Field. Both MODFLOW and MT3DMS software packages have been extensively tested and proven, and are widely accepted by regulatory and judicial bodies in North America.

The input for nitrate loading on the groundwater system came from potentially leachable nitrogen values estimated from the N budgets. Nitrogen inputs were identified for agriculture properties and septic systems within the transient-state capture zone (Figure 2.3). Nitrogen inputs were given for three scenarios: Base Case, Rate Case, and Rotation Case, as described. The leachable nitrogen values were assumed to define the nitrate input for the transport model. Nitrates are assumed in the model to enter the groundwater system at the water table. The dynamics of the unsaturated zone were not included in the transport model.

Nitrate inputs from agricultural activities were applied aerially over the foot print for each property area. For example, property #41 had an estimated nitrogen loading value of 449.2 kg/ha and a cropland area of 20.7 ha. Therefore, a nitrate load of 9298.4 kg was used as an input for property #41 and was applied evenly over the cropland area within the transport model.

Nitrate inputs from septic systems were applied as a point source at the estimated location of the septic system, as is shown in Figure 2.3.

The main input parameters of the nitrate transport model were as follows:

- groundwater flow field (provided by the MODFLOW model);
- dispersivity; and
- porosity

The groundwater flow field describes the average velocity and direction of the contaminant migration, i.e. how fast and where the nitrate-N moves. Dispersivity describes how the plume spreads longitudinally and transversely in the direction of groundwater flow while migrating. Higher dispersivity values indicate more spreading and dilution of the concentration front of a plume. Porosity describes the amount of void space within the groundwater system, with lower porosity values resulting in higher velocities of the contaminant.

No field values exist for the dispersivity and porosity parameters. Therefore, the best representative values were chosen from the literature (Domenico and Schwartz 1991; Freeze and Cherry 1979), considering the hydrogeologic setting of the Bosquart Well Field area. In addition, the possible range for the two parameters was also identified, defining their upper and lower limits. The best estimate was determined to be 30% value for porosity and 10 m value for dispersivity. The possible range for porosity was determined to be 25 – 37%. The possible range for dispersivity was determined to be 5 – 100 m.

The parameters of the flow model were not included in the uncertainty analysis because good confidence was established for the parameters of the flow model through its verification process.

Nitrate is a conservative groundwater constituent and does not significantly degrade or absorb/adsorb in typical subsurface conditions. Therefore, decay and sorption parameters were not applied.

The Base Case scenario best represented the actual nitrogen applications from the period 1994 – 2007, based on fertilizer and septic flow estimates. Therefore, it was assumed that the Base Case also best represented the nitrate concentrations at the well field resulting from these applications. A direct calibration of nitrate concentrations was not possible in this study since nitrate applications prior to 1994 were not part of the scope of the study. It was assumed that nitrogen application prior to 1994 was responsible for the nitrate plume at Bosquart #2 Well Field identified in the 1990s.

The results of the Base Case scenario were used to evaluate whether the transport model predictions were reasonable, since a direct calibration was beyond the scope of this study. The transport model was considered reasonably calibrated as long as the following objectives were met in the Base Case scenario:

1. Simulated concentrations at Bosquart #2 Well Field should be higher than Bosquart #1 Well Field (wells 11B and 11D) because of the closer proximity of #2 Well Field (wells 14 and 15) to the nitrate sources.
2. Simulated nitrate concentrations at the well field should approach the observed values by the end of the simulation period, since model application rates should closely represent typical historic application rates.

3. Simulated nitrate concentrations should not exceed observed values, since nitrogen input prior to 1994 was not included as inputs.

The main objective of this project was to determine if BMPs could be effective at reducing nitrate impacts. Therefore, the focus of the model effort was to determine how the BMPs reduced nitrate levels in the Bosquart Well Field. The model was used to simulate the migration of nitrates for the three scenarios, and comparisons were made of the model output. These are identified as the best estimate predictions.

Finally, an uncertainty analysis was performed to determine the variability of the model predictions based on the confidence of the porosity and dispersivity values. This was done by varying the model parameters from their lower to upper limits and assessing the change in the model predictions. This generated the following subset scenarios:

- High Dispersivity (100 m)
- High Porosity (37%)
- Low Dispersivity (5 m)
- Low Porosity (25%)

As in the best estimate prediction case, each case was simulated for the subset scenario. For example, the three cases were simulated assuming the dispersivity value was 100 m (High Dispersivity) instead of the best estimate of 10 m. The results of the High Dispersivity Rate Case and Rotation Case were compared to the High Dispersivity Base Case to determine the nitrate impact reduction of the BMPs, assuming a higher dispersivity. The same procedure was performed for the other three subset scenarios.

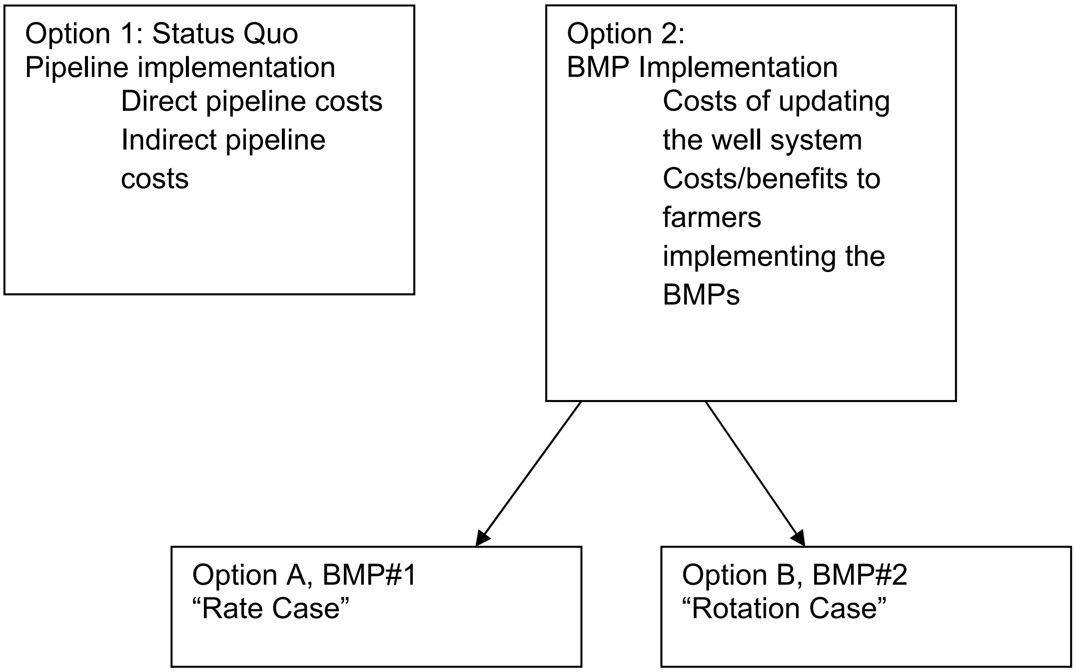
Using the above approach, the model simulated the best estimate of nitrate reduction at the Bosquart Well Field and the uncertainty of the predictions. This evaluated the effectiveness of the BMPs at reducing nitrates in groundwater and also defined the confidence intervals for the predictions.

4.3 ECONOMIC METHODS

The purpose of this analysis was to determine the costs of implementing the BMPs and compare them with the implementation of the pipeline. It was, thus, 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.

Figure 4.1 below provides an overview of the framework for the analysis. The status quo was the implementation of the pipeline, measured in terms of its direct and indirect costs. The costs of the BMP implementation would have been essentially two-fold. First, private costs would have been incurred by farmers changing their crop rotation and/or management practices. Second, the well system in the Municipality of Strathroy-Caradoc was in need of upgrading and these upgrades would have been required in addition to the BMP implementation. The reference year was 2005, as this was the year the pipeline was built and in this year the BMPs would have been effective in reducing the nitrate level. The analysis was performed on the Bosquart well system, which supplied roughly 27% of the total water to the town of Strathroy. The pipeline replaced the entire well system that serviced Strathroy. The costs of upgrading the well system and the implementation costs of the pipeline analysis were adjusted to reflect the partial water supply replacement.

Figure 4.1 Framework for analysis



4.3.1 Pipeline costs

According to information received from the Municipality of Strathroy-Caradoc, the decision to build the pipeline was based on a variety of problems with the water system in Strathroy. An environmental assessment was undertaken in 2004 and tests revealed high concentrations of nitrates, iron and manganese in the water. In 2005, the municipality received 98 water quality complaints, mostly about stained laundry due to the elevated levels of iron and manganese.

At the request of the township, the Joint Board of Management for the Lake Huron Primary Water Supply System agreed to construct, own and operate a pipeline connection to the Township of Strathroy-Caradoc and initiated the construction process for the pipeline. In December 2004, the Huron water board awarded the contract for the design and construction of the Strathroy pipeline to the team of D'Orazio Infrastructure Group and Dillon Consulting. Groundbreaking for the project's start of construction took place in May 2005 at the Strathroy Reservoir site on Second Street. The 26km pipeline extending from the Huron pipeline near Ailsa Craig to Strathroy, constructed using 600mm diameter reinforced concrete pipe, was completed in late October 2005. Two primary control chambers on the new Strathroy pipeline were completed in early December 2005.[26] The water from Lake Huron was treated to comply with drinking water standards: "The Lake Huron Water Treatment Plant (WTP) employs pre-chlorination, screening, powder activated carbon addition (seasonally on an as-required

[26] Source:
http://www.watersupply.london.ca/Notice/NRF_Strathroy_supply_transition_051222.pdf

basis), coagulation, flocculation, sedimentation, dual-media filtration, post-chlorination, and sodium hydroxide addition to treat raw water obtained from Lake Huron." [27]

Table 4.4 lists the direct costs of the pipeline as received from the municipality. The annual operational cost of the pipeline is minimal as the municipality takes water off the pipeline as it flows toward London. No additional pumping is required to get the water into the reservoir as the elevation actually causes this water to increase in pressure by 20 psi. The only added cost is chlorine to increase the residual prior to pumping into the system from the reservoir.

Table 4.4 Direct Costs - Strathroy-Caradoc Pipeline/Reservoir Cost Summary

Item	Cost
Pipeline	$12,441,155
Reservoir	$2,094,820
Engineering	$250,000
Lake Huron Capacity Buy-In	$3,800,000
Total Pipeline Cost	$18,585,975

Source: Strathroy-Caradoc Municipality

The Strathroy-Caradoc wells that were replaced by the pipeline had to be decommissioned in line with environmental regulations. According to the Municipality of Strathroy-Caradoc, the costs to decommission the 13 wells and associated observation wells was $75,035. In addition, some areas were running into the problem of basement flooding because of the elevated groundwater level; this was expected before the pipeline was built in 2005.To alleviate the problem, a 700 foot perforated drainage till had to be implemented. That resulted in costs of $20,000 in 2006. Table 4.5 lists the total costs of implementing the pipeline.

Table 4.5 Total Costs of Pipeline

Item	Costs
Direct Costs	$18,585,975
Decommission of wells	$75,035
Measures against Flooding	$20,000
Total	$18,681,010

The annualized costs of the pipeline are $953,285 (applying a 5% discount rate over 80 years, with the pipeline fully depreciating). According to information received from the municipality, the annual operation and maintenance costs of the pipeline are minimal as only chlorine has to be added to the water. An annual cost of $5,000 is assumed. Hence, the total annual costs for the pipeline are $958,285, as shown in Table 4.6.

[27] Source:
http://www.watersupply.london.ca/Annual_Reports/2008/2008_Huron_AnnualReport.pdf

Table 4.6 Annual costs of pipeline

Item	Costs
Pipeline costs	-$18,681,010
Annual Cost of Pipeline	-$953,285
Annual operational cost of pipeline	-$5,000
Total annual cost	-$958,285

This analysis only considered the Bosquart well system, which was among the largest of the well systems that supplied Strathroy. The volume of water delivered by the pipeline is significantly larger than the capacity of the Bosquart Well Field; thus, for the purposes of analyzing alternatives, the costs of building the pipeline should only be attributed to the capacity of water that was substituted for that of the Bosquart well field. According to information received from the municipality, the Bosquart Well Field had a rated capacity of 4999 m^3/day or 1,824,635 m^3 /year, whereas capacity of the pipeline was 18,835 m^3/day or 6,874,775. Hence, the capacity of the well was roughly 27% that of the pipeline. Taking the partial supply of water into consideration, the costs of the pipeline that can be attributed to the well system are $4,958,129, which results in an annualized cost of $253,011 (applying a 5% discount rate). The access cost for water from Lake Huron is $0.2671/$m^3$. Assuming an average annual water supply from the Bosquart well of 658,116 m^3, that results in annual water costs of $175,848. The attributed and annualized pipeline costs are listed in table 4.7.

Table 4.7 Allocated pipeline costs on equivalent volume to Bosquart well

Item	Costs
Allocated pipeline costs	$4,958,129
Annualized costs of pipeline	$253,011
Water access costs	$175,848
Operation/Maintenance	$1,327
Total annual costs	**$430,186**

4.3.2 Health costs

Nitrate is an ion that occurs naturally and can be reduced to the reactive nitrite ion. Nitrates have been related to a number of health effects. As mentioned before, between March 23rd and December 23rd 2005, a drinking water advisory was put in effect by the Middlesex-London Health Unit because of the increased nitrate levels in the drinking water. According to the Municipality of Strathroy-Caradoc, nobody was affected during the water advisory. Therefore, no health costs were incurred.

4.4 COSTS AND BENEFITS TO FARMERS OF IMPLEMENTING BENEFICIAL MANAGEMENT PRACTICES IN THE STUDY AREA

The purpose of this section was to measure the costs of BMP adoption, in terms of foregone profit per acre before and after adoption of BMPs. The study area for the nitrogen management modeling exercise was 66 hectares. However, the BMPs would not have been implemented on just parts of fields, but rather on entire fields, so in fact the area affected by BMPs exceeded 66 ha. Table 4.8 gives an overview of the study area. While the area in the transient-state capture zone was 66 hectares, the total area farmed was 189 hectares, or 469 acres. Thus, the two BMP cases would have been applied to 469 acres.

Table 4.8 Overview of study area

Property ID#	Total Property area	area farmed and in capture zone	area farmed	area farmed
	(ha)	(ha)	(ha)	(acres)
39	19.8	0.2	18.8	46.5
31	4.8	0.2	4.8	11.9
34	19.7	0.2	16.8	41.5
3	19.6	0.8	15.8	39.0
32	5.3	3.2	3.3	8.2
28	20.3	5.8	19.9	49.2
8	15.7	6	13	32.1
20	9.8	6.3	6.6	16.3
42	44.9	7.7	34.8	86.0
33	20.6	9.1	20.5	50.7
37	20.5	11.6	14.9	36.8
41	20.7	15	20.7	51.2
	221	**66**	**189**	**469**

Under the base case, a crop rotation of corn and soybeans was maintained (some fields had kidney beans in the rotation). Under BMP#1, split applications of nitrogen were applied with improved timing under the assistance of a crop consultant (rate case). Under BMP#2, the crop rotation was expanded to include wheat under-seeded to clover (rotation case). Table 4.9 shows the crop rotation according to the fields studied in the nitrogen modeling scenarios.

The rotation models were developed using crop enterprise budgets obtained from the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA). The enterprise budgets provided an estimate of variable costs and fixed costs (before land and operator labour) for individual crops on a per acre basis. The prices for each commodity were obtained from OMAFRA as well. Conventional tillage was assumed for all three cases as earlier OMAFRA budgets do not account for reduced tillage. This assumption allowed for a consistent comparison across the three cases. The cost of adopting the BMPs was measured as the difference in net returns under each BMP, compared with the base case; in other words, the cost associated with adopting the BMP was the opportunity cost associated with substituting the BMP for the base case.

Following the nitrogen simulation modeling described above, the yield was held constant across the study period and the fertilizer applications were kept variable across years and fields. The fertilizer costs were calculated according to OMAFRA crop budget values in the respective years, and the amounts adjusted to the modeling exercise accordingly. Prices were nominal in this model. Table 4.10 shows a sample of the crop budgeting model for the base case scenario for the years 1994 to 1999.

Table 4.9 Crop Rotations Evaluated

Fields	Base Case	BMP #1 Reduced N rate and Improved Application Timing	BMP #2 Change in Crop Rotation with Red Clover Cover Crop
8, 39, 34, 3, 28, 20, 42, 37, 41	Soybeans, Corn	Soybeans, Corn	Soybeans, Corn , Wheat with under seeded clover
31, 32, 33	Soybeans, Corn, Kidney Beans	Soybeans, Corn, Kidney Beans	Soybeans, Corn , Wheat with under seeded clover, Kidney Beans

Table 4.10 Sample of crop budgeting model for field number 8

Item	Units	1999	1998	1997	1996	1995	1994
Crop type		soybeans	field corn	soybeans	field corn	soybeans	field corn
Yield	kg/ha	2688.00	8780.80	2688.00	8780.80	2688.00	8780.80
Applied N	kg N/ha	11.20	156.80	11.20	156.80	11.20	156.80
	kg N/acre	4.53	63.45	4.53	63.45	4.53	63.45
Cost w/o Fert.	$/acre	160.75	218.05	144.00	206.00	145.00	203.50
Fertilizer	$/acre	15.67	69.99	14.90	69.08	12.52	55.47
Total costs	$/acre	176.42	288.04	158.90	275.08	157.52	258.97
Yield	t/ha	2.69	8.78	2.69	8.78	2.69	8.78
Price	$/t	263.00	118.00	337.00	153.00	323.00	118.00
Revenue	$/ha	706.94	1036.13	905.86	1343.46	868.22	1036.13
	$/acre	286.09	419.31	366.59	543.68	351.36	419.31
Profit	$/acre	109.67	131.27	207.69	268.60	193.84	160.34

4.4.1 BMP Details

For the budget rate case scenario, it was assumed that a crop consultant would have been hired to conduct soil testing for nitrogen and plant tissue tests in addition to the customary crop consultant services. After consultation with a crop consultant with extensive experience in the Strathroy area, it was determined that costs of the consultation and testing would vary between $6 and $7 per acre. This assumption was made under the consideration that crop consultants usually charge their fees per farm or, in some cases, per field. However, since we had only isolated fields, this value should be understood to be a conservative estimate. For the second BMP (rotation case) wheat and red clover, which was under-seeded as a cover crop, were incorporated into the crop budgeting model. The production costs of wheat were increased by the seed and production costs of clover and the burning down of the clover with a herbicide. The services of a crop consultant were included as well, at a per acre cost of $4 to $5.

Table 4.11 presents the differences in profits between the BMP scenarios and the base case scenario for all fields combined. The difference was calculated by taking the profit per acre with the BMP in place minus the profit per acre of the base case scenario for each year individually (1994 to 2005) and then by multiplying by the approximate number of acres. The annual profit differences over the time period were compounded up to the year 2005. A sensitivity analysis was conducted for 3%, 5% and 8% discount rates. The table shows that, under a 5% discount rate, it would have cost $15,291 to implement the rate case, and $148,147 to implement the rotation case over a period of 12 years for an area of 469 acres.

Table 4.11 Aggregate implementation cost/benefits to farmers 1994-2005

Discount rate	**BMP Profit Difference to Base Case**	
	BMP#1	**BMP#2**
	Rate Case	**Rotation Case**
5%	-$15,291	-$148,147
3%	-$13,600	-$125,103
8%	-$19,763	-$182,176

WELL UPGRADE COSTS

According to information received from the Municipality of Strathroy-Caradoc, a study was undertaken in 2004 to determine the costs of improving the water quality within the existing well system. The results showed that it would cost the community about $4.5 million to update the entire well system to alleviate the problems (some of the measures included disinfection of water, UV lights, and blending of well water).

The Bosquart well system was only a portion of the well system that supplied water to Strathroy. According to information received from the municipality, the update of just the Bosquart well system would have cost $2,482,100. This upgrade would have been necessary regardless of the nitrate concentration in the water; therefore, its cost would have been added to the cost of the BMP implementation. The annual operation and maintenance costs for the Bosquart well system was structured as follows (based on 2004 costs). The following data were received from the municipality:

Water Treatment:	$100,000
Sodium Hypochlorite:	$14,683
Hydro:	$42,179
Pumps and Plant Maintenance:	$30,769
Wells Maintenance:	$33,800
Total	**$221,431**
Cost/m3 of water	**$0.334/m3**

It should be noted that the Bosquart well was an exceptionally expensive well to operate and maintain, due to the additional water treatment costs of $100,000 to mitigate iron and manganese problems. This problem is further explored in section 5.5.1. Table 4.12 presents the costs associated with an update of the Bosquart well system. It would have cost almost $2.5 million in capital upgrades in 2005 to conform to water regulations. Furthermore, an additional upgrade was required to ensure the functionality of the well system. These updates encompassed, necessary pipes, pumps, pumping stations and transmission mains. According to an estimate from the Municipality these updates for the Bosquart well system would cost $731,180.

Table 4.12 Costs of Bosquart well system

Item	Costs
Well update (regulatory compliance)	$2,482,100
Well update (system upgrades)	$731,180
Well update - Total	$3,213,280
Annualized well capital costs	$187,264
Annual operation and maintenance costs	$221,413
Total Annual cost	$408,677

To identify the opportunity costs associated with the BMPs (Rate and Rotation case), the profits of the BMP scenarios were compared to the base case of existing crop management patterns established from the producer survey. To interpret these opportunity costs relative to the costs of the pipeline, they needed to be placed in a timeframe comparable to that of the pipeline, and indexed to a given period. To facilitate this, average opportunity costs per year were determined. The approach followed in the analysis was based on the Equivalent Annual Net Benefit method (EANB[28]), separately calculating the Equivalent Annual Benefits and Costs for each project, based initially on a social discount rate of 5%, and applying a sensitivity analysis for 3% and 8%.

It was impossible to project the annual profit gains or losses of the BMP implementation over the lifetime of the pipeline (80 years) or the well system (40 years). However, in order to project the profits of the BMPs to the lifetime of the well system, the historic average annual benefit over the period 1997-2007 was used to project the annual net benefits/costs to farmers. The main advantage of doing so was that the annuity calculated in this manner was independent of the initial crop chosen in the rotation. Table 4.13 provides an illustration the annual profits per case. Using Field 8 as an

[28] By using the Equivalent Annual Net Benefit method (EANB), two projects with different time frames can be compared with each other. The EANB is the Net Present Value (NPV) divided by the annuity factor that has the same discount rate and term of the project (Boardman *et al,* 2006).

$$EANB = \frac{NPV}{a_i^n} \qquad (1)$$

Where

$$a_i^n = \frac{1-(1+i)^{-1}}{i} \qquad (2)$$

example under the base case, projected steady-state annual profitability under its rotation was $163.10/acre; under the budget rate case, it fell to a steady-state profitability of $160.20/acre, and under the rotation case, the projected steady-state profitability was $161.13/acre.

Table 4.13 Average Annual Profits for Base case and BMP Scenarios, $/acre

Field Number	Base	Rate Case	Rotation Case
8	$163.10	$160.20	$161.13
31, 32	$171.35	$163.56	$155.28
33	$177.88	$167.28	$162.71
3, 37, 42	$180.30	$178.82	$161.25
28, 39	$156.95	$155.93	$141.56
20, 34, 41	$169.42	$167.81	$167.87

The total annual cost of BMP adoption was determined by multiplying the per acre differences in profitability by field by the appropriate field acreage. This is presented in Table 4.14. The implementation of BMP#1 would have resulted in an annual net cost of -$1300 in 2005 terms, whereas implementation of BMP#2 would have resulted in an annual net cost of -$5,879 in 2005 terms. To state these values differently, implementing BMP#1 would have, on average, an opportunity cost of $2.77 per acre ($1300/469 acres) and for BMP #2, $12.54 per acre ($5879/469 acres).

Table 4.14 BMP profit differences to base case

Field number	BMP Profit Difference to Base Case	
	BMP#1 **Rate Case**	**BMP#2** **Rotation Case**
8	-$93	-$63
28, 39	-$97	-$1,473
20, 34, 41	-$175	-$169
31, 32	-$157	-$323
33	-$538	-$769
3, 37, 42	-$239	-$3,082
Total	**-$1,300**	**-$5,879**

4.5 ECONOMIC SUMMARY

Based on the discussion of the pipeline and well system costs above, several observations, which are summarized in table 4.15, can be made. First, the pipeline construction cost of about $18.6 million equated to about $5 million on a comparable volume basis to the Bosquart wells which, when converted to an annualized basis and including small operating costs, amounted to just over $253,000 per year. There was also a water access fee from the lake that amounted to about $176,000 per year, on a comparable volume basis to the wells.

Secondly, to make a BMP solution to the nitrogen in water quality feasible, the wells would have required retrofitting and operational costs would have to be applied, in addition to the opportunity costs associated with the BMPs themselves. The annualized value of well investments and operating costs was about $ 408,677. The future BMP opportunity costs for the fields affected by the BMPs are $1,300 per year for the Rate Case and about $5,900 per year for the Rotation Case.

Finally, in order for the BMPs to have been effective, they would have needed to be implemented in 1994 and maintained until 2005. The present value of these opportunity costs, converted to 2005 terms to be comparable with the future costs listed above, was about $15,300for the Rate case and just over $148,100for the Rotation case.

Table 4.15 Summary of Comparative Net Benefits Observed Above

	BMP Rate Case	BMP Rotation Case	Pipeline
Equivalent Annual Cost Pipeline	$0	$0	-$253,011
Annual water access cost	$0	$0	-$175,848
Equivalent Annual Cost Well	-$408,677	-$408,677	$0.00
Annual Cost to farmers	-$1,300	-$5,879	$0.00
Accrued value of BMP adoption, 1994-2005 (2005 terms, 5% discount rate)	-$15,291	-$148,147	

5. RESULTS AND DISCUSSION

5.1 LAND USE SURVEY RESULTS

The study area included 43 properties with land inside the 10-year steady state capture zone of the Bosquart Well Field. Resources were focused on obtaining information about nitrogen management practices on cropland. During the interviews, survey data were obtained for 14 of 17 farm properties and 11 of 35 single dwellings. These results were extrapolated as needed across the transient-state capture zone, which was identified during the nitrogen transport modeling component of this study.

The land use survey indicated that the transient-state capture zone for the Bosquart Well Field was farmed in a 2 year, field corn/soybean rotation from 1994 to 2007. Kidney beans were grown three times during this period. Cover crops, manure, and biosolids were not used or applied to these lands. Reduced tillage practices were common. Standard soil testing for macro- and micro-nutrients was customary and soil nitrate testing was used by one respondent in the transient-state capture zone. The same respondent was using a formal nutrient management plan. Most respondents indicated that a split application of fertilizer during corn production was a standard practice: fertilizer was banded with the planter and side-dressed after the corn emerged. None of the respondents indicated a crop consultant was used to assist with nutrient management.

No significant agricultural point sources of nitrogen were identified. However, private septic systems were used throughout the capture zone. One respondent indicated a biofilter was used in his septic system. At least 5 m of vegetation surrounded each well discussed in the survey. However, at least three properties with land inside the transient-state capture zone had septic beds within 30 m of a bored or dug well.

5.2 CASE STUDY SCENARIOS

The profiles of the case studies, which list the BMPs for managing nitrogen in the transient-state capture zone of the study area, are summarized in Table 5.1. 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.

5.3 ESTIMATES OF NITRATE MASS LOAD

A nitrogen (N) budget for one crop rotation cycle per scenario, including relative estimates of long-term potentially leachable nitrogen (LPLN), for one example property is provided in Table 5.2. Relative estimates of nitrogen mass load were prepared for each scenario for the Bosquart Well Field transient-state capture zone on a per hectare (Table 5.3) and per total area basis (Table 5.4).

To account for the impact of septic systems on nitrogen in the groundwater, an estimate of LPLN was developed (15.4 kg N/yr/septic system) and used in the contaminant transport model (Table 5.5). Further analysis of the potential impact of septic systems on LPLN due to a change in nitrogen management was not pursued because (a) only three septic systems were involved in this study and, therefore, considered a minor potential source of nitrogen, (b) BMPs for septic systems currently focus on reducing water use and not on reducing nitrogen loss to the groundwater (Environmental Protection Division 2009; OMMAH 2008), and (c) major reductions in nitrogen loads could be achieved through the adoption of BMPs on cropland.

Table 5.1 Summary of Beneficial Management Practices (BMPs) for Each Scenario, Bosquart Well Field, Strathroy, ON

BMP Type	BMP No.	BMPs For Nutrient (i.e. nitrogen) Management	Notes	Case Studies BASE	Case Studies RATE	Case Studies ROTATION
R		**Right Rate: Match Supply and Demand for Crop Nutrients**	▪ Choosing appropriate nutrient application rates			
R	1	Application calibration and upkeep	▪ Maintaining equipment	x (partial)	x	x
R	2	Crop removal balance	▪ Calculating how much nitrogen is needed ▪ Computerized models can help e.g. NMAN	x (partial)	x	x
R	3	Crop scouting / assessment	▪ Crop scouting for visual symptoms of nitrogen deficiencies	x (partial)	x	x
R	4	Nutrient management plans	▪ Accounting for nitrogen from other sources ▪ Using crop response data to determine economically efficient application rates	x (partial)	x	x
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		x	x
R	6	Record keeping	▪ Documenting nitrogen applied and available per field ▪ Mapping and managing soil variability per field	x (partial)	x	x
R	7	Soil testing	▪ Testing soil to confirm nutrient content and adequacy of nutrient program e.g. soil nitrate test for corn	x (partial)	x	x
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		x	x
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	x	x	x
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	x	x	x
P	2	Crop rotation	▪ Alternating forage and/or cereal crops with row crops			x
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	x	x	x
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			x
P	6	Incorporation of fertilizer	▪ Placing nutrients in the plant root zone	x	x	x
A		**Right Advice: Appropriate Professional Advice and Analytical Information**	▪ **Making informed decisions as field conditions change**			

BMP Type	BMP No.	BMPs For Nutrient (i.e. nitrogen) Management	Notes	Case Studies BASE	Case Studies RATE	Case Studies ROTATION
A	1	Advice from a professional agricultural consultant	▪ Using information from specialists to maximize nutrient management results e.g. Certified Crop Advisor (CCA)	x (partial)	x	x
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	x (partial)	x	x

Adapted from (Canadian Fertilizer Institute 2005)

Table 5.2 Example N Budgets For One Crop Rotation Cycle, Bosquart Well Field, Strathroy, ON

Line	Ppty ID#	Item	Units	Base Case 2007	Base Case 2006	Rate Case 2007	Rate Case 2006	Rotation Case 2007	Rotation Case 2006	Rotation Case 2005
1	41	**Crop type**		field cornX	soybeansX	field cornX	soybeansX	field cornX	ww/rcX	soybeansX
2	41	**Crop ID#**		1	2	1	2	1	3	2
3	41	**Yield**	kg/ha	9408.0	3024.0	9408.0	3024.0	9784.3	6050.0	3024.0
4	41	**Nmanure (prev fall)**	kg N/ha	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	41	**Nmanure (spring)**	kg N/ha	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	41	**Nfert (starter)**	kg N/ha	12.3	0.0	12.3	0.0	12.3	9.2	0.0
7	41	**Nfert (broadcast)**	kg N/ha	0.0	11.2	0.0	11.2	0.0	0.0	0.0
8	41	**Nfert (sidedress)**	kg N/ha	144.5	0.0	114.2	0.0	93.8	90.8	0.0
9	41	**Napplied**	kg N/ha	156.8	11.2	126.6	11.2	106.1	100.0	0.0
10	41	**Nminer (prev crop residues)**	kg N/ha	30.2	0.0	30.2	0.0	0.0	30.2	0.0
11	41	**Nminer (prev manure)**	kg N/ha	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	41	**Nminer (cover crop)**	kg N/ha	0.0	0.0	0.0	0.0	50.7	0.0	0.0
13	41	**Natmdep (precip; dry)**	kg N/ha	18.4	18.4	18.4	18.4	18.4	18.4	18.4
14	41	**Nseed**	kg N/ha	0.3	7.2	0.3	7.2	0.3	2.3	7.2
15	41	**Nsymfix**	kg N/ha	0.0	223.3	0.0	223.3	0.0	104.0	234.5
16	41	**Nnonsymfix**	kg N/ha	3.0	3.0	3.0	3.0	3.0	3.0	3.0
17	41	**Total N Inputs**	kg N/ha	208.7	263.1	178.5	263.1	178.5	257.9	263.1
18	41	**Ngrain (harvest)**	kg N/ha	141.1	196.6	141.1	196.6	146.8	121.0	196.6
19	41	**Nimmob (crop residue)**	kg N/ha	0.0	30.2	0.0	30.2	0.0	0.0	30.2

Line	Ppty ID#	Item	Units	Base Case		Rate Case		Rotation Case		
				2007	2006	2007	2006	2007	2006	2005
20	41	**Nimmob (manure)**	kg N/ha	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	41	**Nimmob (cover crop)**	kg N/ha	0.0	0.0	0.0	0.0	0.0	50.7	0.0
22	41	**Nvol (fert)**	kg N/ha	4.3	0.3	3.4	0.3	2.8	2.7	0.0
23	41	**Nvol (manure)**	kg N/ha	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	41	**Nvol (senesc; misc)**	kg N/ha	11.1	11.6	10.8	11.6	10.8	11.6	11.6
25	41	**Nerosion**	kg N/ha	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	41	**Nrunoff**	kg N/ha	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	41	**Ndenit**	kg N/ha	10.5	1.8	8.7	1.8	7.5	7.1	1.1
28	41	**Total N Outputs**	kg N/ha	167.1	240.5	164.0	240.5	167.8	193.1	239.5
29	41	**ΔNsi+ΔNso(OM)**	kg N/ha	0.0	0.0	0.0	0.0	0.0	53.3	0.0
30	41	**Nleach**	kg N/ha	41.6	22.5	14.4	22.5	10.6	11.5	23.6
31	41	**Nleach/TotalNip**	%	20.0	8.6	8.1	8.6	5.9	4.5	9.0

Table 5.3 Relative Estimates Of Mean Annual N Mass Load From Cropland, Bosquart Well Field, Strathroy, ON, 1994-2007

Line	Ppty ID#	Item	Units	Relative Estimates of Mean Annual N per Hectare		
				Base	Rate	Rotation
30	3	Nleach	kg N/ha/yr	31.4	19.7	17.3
31	3	Nleach/TotalNip	%	14.3	9.3	7.8
	3	Decrease in Nleach	%		-37	-45
30	8	Nleach	kg N/ha	32.5	21.4	17.6
31	8	Nleach/TotalNip	%	14.7	10.2	7.9
	8	Decrease in Nleach	%		-34	-46
30	20	Nleach	kg N/ha	32.1	19.3	16.1
31	20	Nleach/TotalNip	%	14.7	9.3	7.2

Line	Ppty ID#	Item	Units	Relative Estimates of Mean Annual N per Hectare		
				Base	Rate	Rotation
	20	Decrease in Nleach	%		-40	-50
30	28	Nleach	kg N/ha	33.8	21.7	17.4
31	28	Nleach/TotalNip	%	16.4	11	8.4
	28	Decrease in Nleach	%		-36	-48
30	31	Nleach	kg N/ha	25.7	15.3	13.1
31	31	Nleach/TotalNip	%	12.1	7.7	6.1
	31	Decrease in Nleach	%		-40	-49
30	32	Nleach	kg N/ha	25.7	15.3	13.1
31	32	Nleach/TotalNip	%	12.1	7.7	6.1
	32	Decrease in Nleach	%		-40	-49
30	33	Nleach	kg N/ha	27.6	15.5	12.5
31	33	Nleach/TotalNip	%	12.9	7.7	5.7
	33	Decrease in Nleach	%		-44	-55
30	34	Nleach	kg N/ha	32.1	19.3	16.1
31	34	Nleach/TotalNip	%	14.7	9.3	7.2
	34	Decrease in Nleach	%		-40	-50
30	37	Nleach	kg N/ha	31.4	19.7	17.3
31	37	Nleach/TotalNip	%	14.3	9.3	7.8
	37	Decrease in Nleach	%		-37	-45
30	39	Nleach	kg N/ha	33.8	21.7	17.4
31	39	Nleach/TotalNip	%	15.4	10.5	8.4
	39	Decrease in Nleach	%		-36	-48
30	41	Nleach	kg N/ha	32.1	19.3	16.1
31	41	Nleach/TotalNip	%	14.7	9.3	7.2
	41	Decrease in Nleach	%		-40	-50
30	42	Nleach	kg N/ha	31.4	19.7	17.3

Line	Ppty ID#	Item	Units	Relative Estimates of Mean Annual N per Hectare		
				Base	Rate	Rotation
31	42	Nleach/TotalNip	%	14.3	9.3	7.8
	42	Decrease in Nleach	%		-37	-45

Nleach – from line 30 of N budget; Relative estimate of nitrogen (compared to Base Case in the study) located below the plant root zone that is potentially available over the long-term to leach into the groundwater; called long-term potentially leachable nitrogen (LPLN)
Nleach/TotalNip – from line 31 of N budget; Ratio of LPLN to total nitrogen input to the soil-crop system

Table 5.4 Relative Estimates of Mean Annual N Load From Cropland In Transient-State Capture Zone, Bosquart Well Field, Strathroy, ON, 1994-2007

Ppty ID#	Cropland in Transient-State Capture Zone (ha)	Relative Estimates of Mean Annual N Load From Cropland in Transient-State Capture Zone per Case Study (kg N/yr/ppty)		
		Base	Rate	Rotation
3	0.8	26.2	16.4	14.4
8	6.0	195.2	128.5	105.7
20	6.3	203.2	122.1	101.9
28	5.8	197.1	126.5	101.5
31	0.2	4.7	2.8	2.4
32	3.2	82.6	49.2	42.1
33	9.1	251.4	141.2	113.9
34	0.2	6.0	3.6	3.0
37	11.6	363.3	228.0	200.2
39	0.2	5.5	3.5	2.8
41	15.0	480.4	288.8	241.0
42	7.7	243.1	152.5	133.9
TOTAL	**66.1**	**2059**	**1263**	**1063**
Relative Estimate of Mean Annual Decrease in N Load From Cropland			**-39%**	**-48%**

Table 5.5 Example N Budget for a Septic System, Bosquart Well Field, Strathroy, ON

Item	Units	2007
Nseptic	extrapolation	x
Persons/household	#	2
Water Use	L/pers/day	136.4
Nseptic leakage	kg N/yr	0.0
Nseptic effluent	kg N/yr	15.4
Total N Inputs	kg N/yr	15.4
Total N Outputs	kg N/yr	0.0
∆Nsi+∆Nso	kg N/yr	0.0
Nleach	kg N/yr	15.4
Nleach/TotalNip	%	100.0

5.4 ESTIMATES OF NITRATE MASS FLUX

Nitrate Concentrations

The nitrate breakthrough curves at the Bosquart Well Field are shown in Figures 5.1, 5.2 and 5.3 for the three case studies. The total nitrate mass loading at the Bosquart Well Field is shown in Figure 5.4 and the relative reductions in total nitrate mass loading (on a percentage basis) from the Rate Case and the Rotation Case compared to the Base Case are shown in Figure 5.5.

Figure 5.1

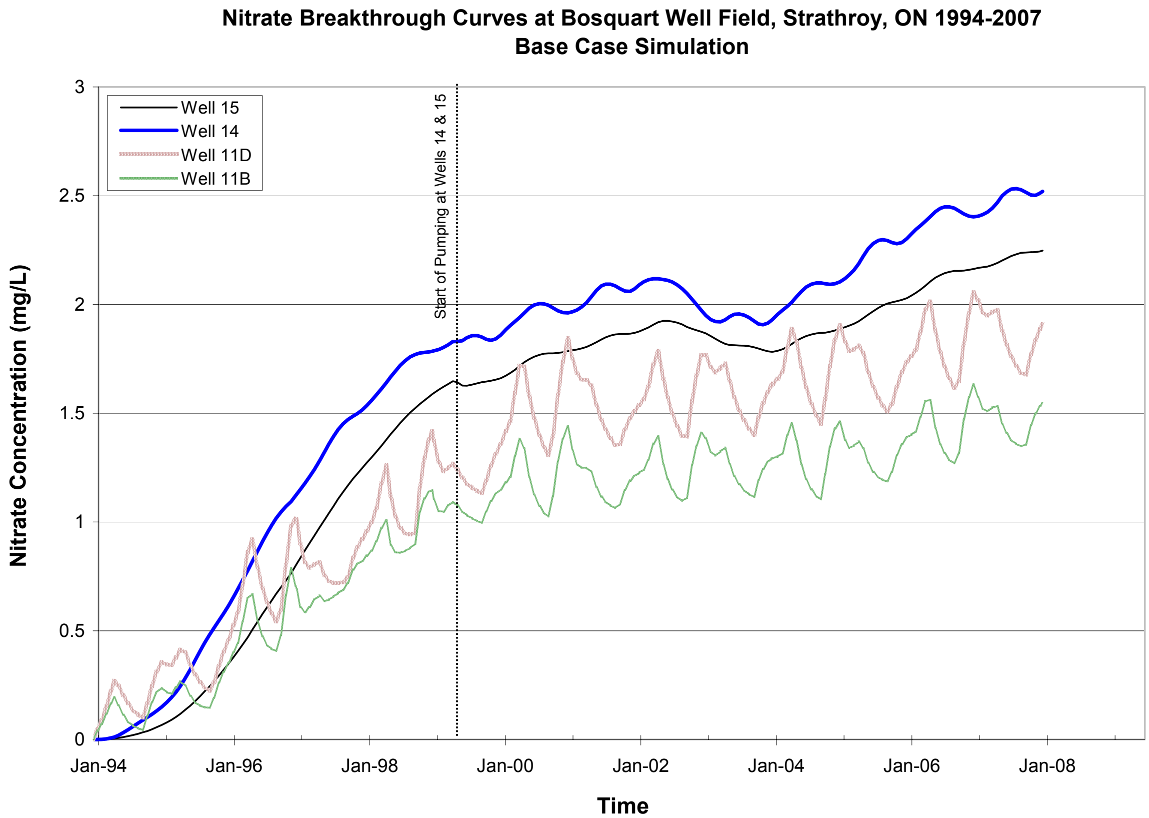

Nitrate Breakthrough Curves at Bosquart Well Field, Strathroy, ON 1994-2007
Base Case Simulation
Well 15
Well 14
Well 11D
Well 11B
Start of Pumping at Wells 14 & 15
Nitrate Concentration (mg/L)
0
0.5
1
1.5
2
2.5
3
Jan-94
Jan-96
Jan-98
Jan-00
Jan-02
Jan-04
Jan-06
Jan-08
Time

Figure 5.2

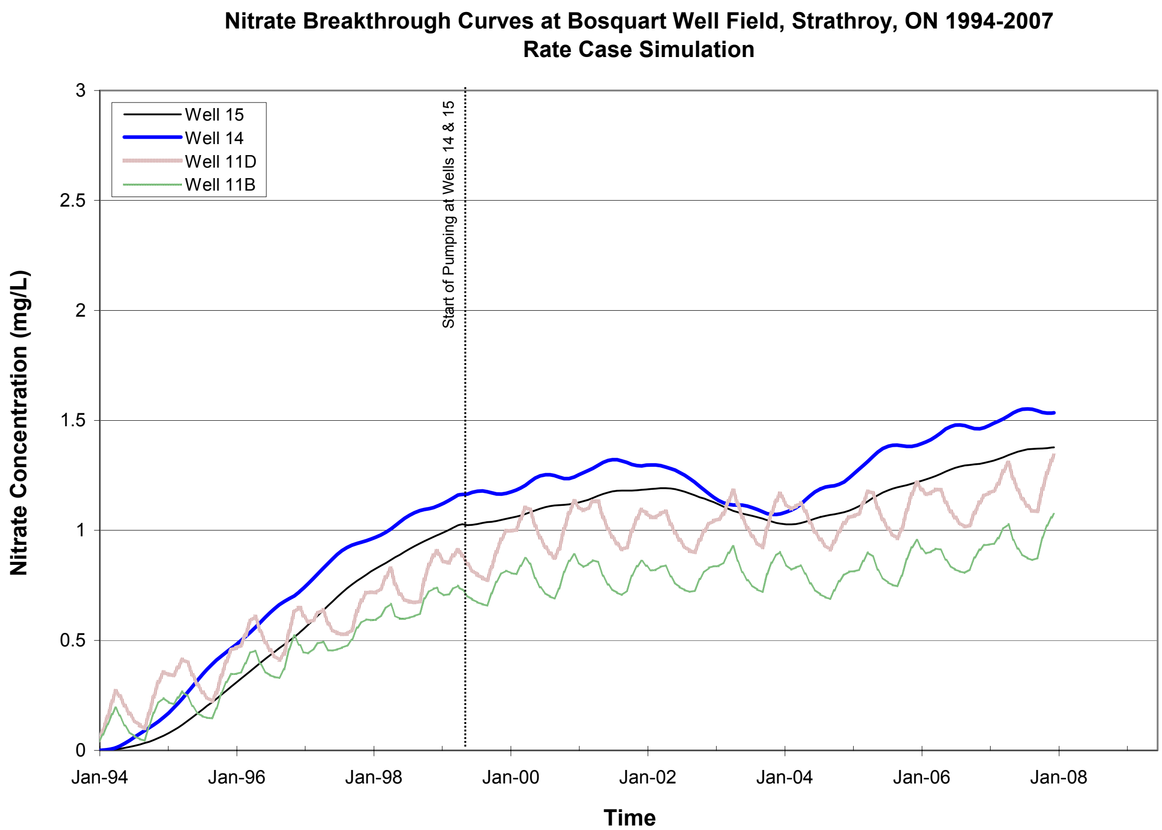

Nitrate Breakthrough Curves at Bosquart Well Field, Strathroy, ON 1994-2007
Rate Case Simulation
Well 15
Well 14
Well 11D
Well 11B
Start of Pumping at Wells 14 & 15
Nitrate Concentration (mg/L)
3
2.5
2
1.5
1
0.5
0
Jan-94
Jan-96
Jan-98
Jan-00
Jan-02
Jan-04
Jan-06
Jan-08
Time

Figure 5.3

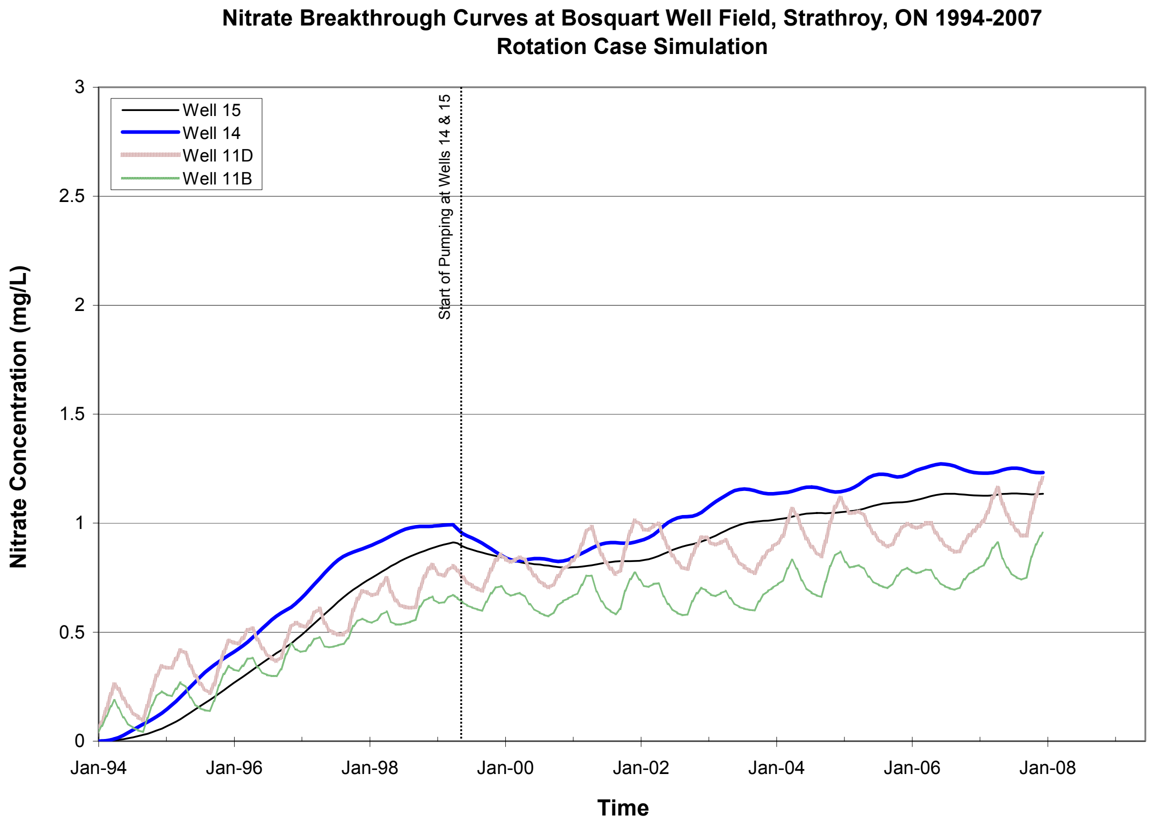

Nitrate Breakthrough Curves at Bosquart Well Field, Strathroy, ON 1994-2007
Rotation Case Simulation
Well 15
Well 14
Well 11D
Well 11B
Start of Pumping at Wells 14 & 15
Nitrate Concentration (mg/L)
3
2.5
2
1.5
1
0.5
0
Jan-94
Jan-96
Jan-98
Jan-00
Jan-02
Jan-04
Jan-06
Jan-08
Time

Figure 5.4

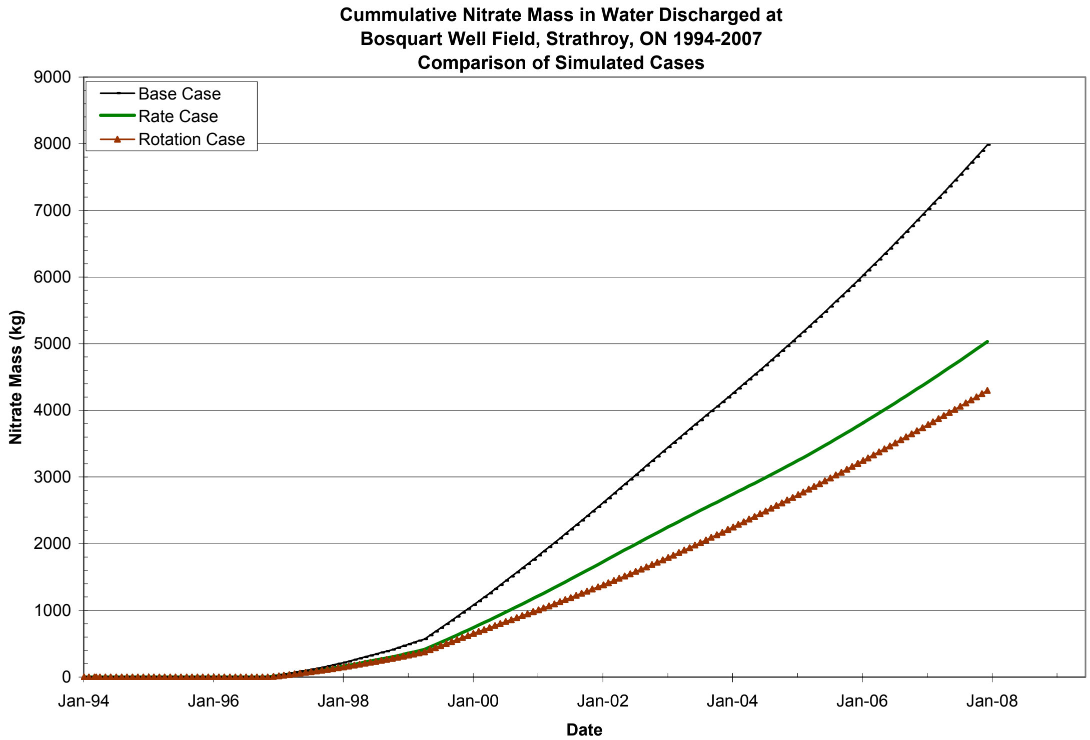
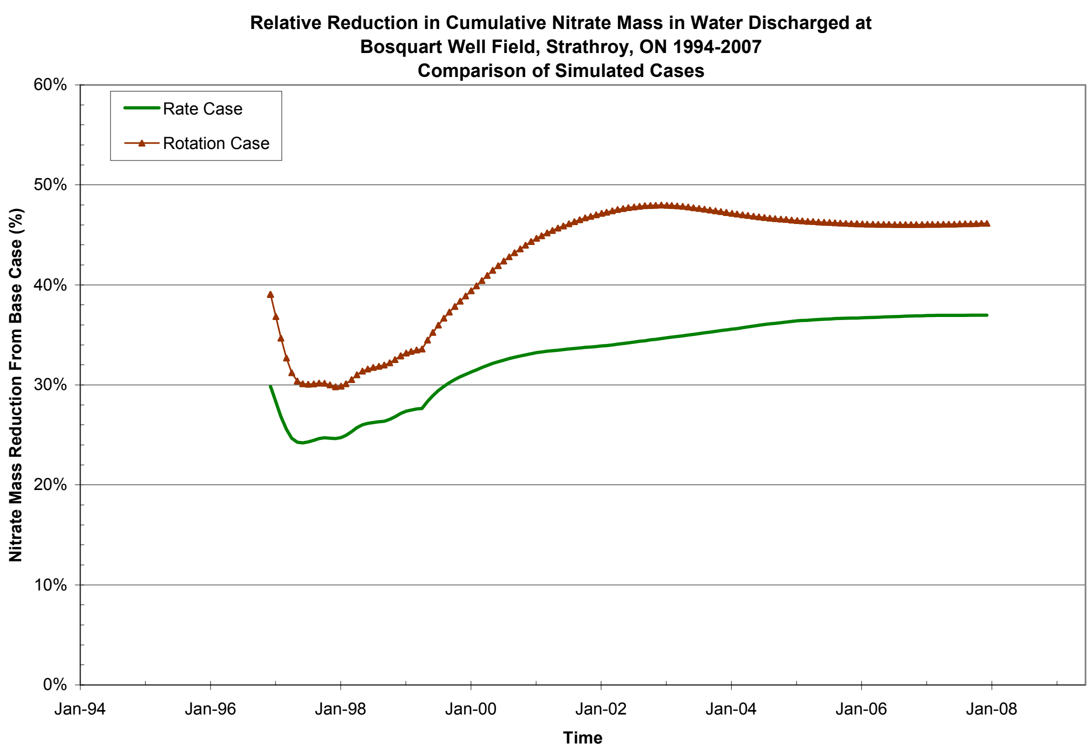


Figure 5.5



The results of the Base Case scenario showed that the model reasonably represented observed nitrate concentrations:

1. Simulated concentrations at Bosquart #2 Well Field (wells 14 and 15) were higher than at Bosquart #1 (wells 11B and 11D).
2. Simulated concentrations at Bosquart #1 Well Field (wells 11B and 11D) approached observed values. However, simulated concentrations at Bosquart #2 Well Field (wells 14 and 15) did not.
3. Simulated concentrations of nitrate at the well field did not exceed observed values.

A review of simulated values compared with actual values showed the following. From 1999 to 2003 (the timeframe when actual data for all wells was available), the actual average nitrate concentration at wells 11B, 11D, 14 and 15 were 2.0, 2.3, 4.8 and 9.1 mg/L, respectively, (Table 2.2), with an overall average of 4.5 mg/L for the Bosquart Well Field. The actual median values at wells 11B, 11D, 14 and 15 were 1.3, 1.6, 5.3 and 10.1 mg/L, respectively, in the same timeframe. In the simulation, the average nitrate-N concentration at wells 11B, 11D, 14 and 15 were 1.2, 1.5, 2.0 and 1.8 mg/L, respectively, (Figure 5.1), with an overall average of 1.6 mg/L in the same timeframe. This indicated that, on average, the simulation under-estimated nitrate concentrations in the Bosquart Well Field by a factor of approximately 3 (i.e., 4.5/1.6 = 2.8) but the major inconsistency occurred relative the Bosquart #2 Well Field. The nature and origin of the high concentration nitrate plume north of Bosquart #2 Well Field (i.e., wells 14 and 15) needs more characterization before a better match between simulated and observed values can be achieved. It was assumed nitrogen applications prior to 1994 were responsible for the difference between actual and simulated nitrate concentrations. Discussion of the simulation results focused on the relative impacts of the different BMP cases on nitrate in water obtained from the Bosquart Well Field.

In comparison to the Base Case, the Rate and Rotation Cases resulted in relative reductions in cumulative nitrate mass in water discharged at the Bosquart Well Field (Figures 5.4 and 5.5). In the Rate Case, total nitrate output from the well field was reduced by 24% (24 kg nitrate-N) at the start of the simulation and by 36% (2917 kg nitrate-N) within 10 years of the start of the simulation. In the Rotation Case, the reductions were greater. Total nitrate output from the well field was reduced by 30% (59 kg nitrate-N) at the start of the simulation, and by 48% (3641 kg nitrate-N) within 10 years of the start of the simulation.

The Ontario Drinking Water Standard (ODWS) for nitrate is 10 mg/L (or 10 ppm). If the nitrate content of water from a well rises above this level, municipalities are required to implement measures, such as blending with other sources that contain a lower concentration of nitrate-N, to ensure the resulting drinking water meets the standard. In the Bosquart Well Field, nitrate concentrations in raw groundwater from wells 14 and 15 regularly approached or exceeded the 10 mg/L standard since pumping was initiated in 1999 (Table 2.2). It was assumed that historical agricultural nitrogen management practices were responsible for the elevated nitrate concentrations in the groundwater (IWC *et al.* 2001).

The Base Case simulation showed that, based on actual and extrapolated agricultural nitrogen management practices over 13 years (1994 – 2007), nitrate-N concentrations increased from 0 mg/L (the start of the study; effects of previous nitrogen management practices not included) to a high of 2.5 mg/L (at well 14). The concentration of nitrate increased to approximately 1.5 – 2 mg/L (overall across all wells) within 10 – 13 years, although values continued to rise at the end of the simulation.

The Rate Case simulation showed that, based on actual and extrapolated agricultural nitrogen management practices over 13 years (1994 – 2007), nitrate-N concentrations increased from 0 mg/L (the start of the study; effects of previous nitrogen management practices not included) to a high of 1.5 mg/L (at well 14). The concentration of nitrate increased to approximately 1 – 1.25 mg/L (overall across all wells) within 10 – 13 years. These findings suggested that if the Rate Case was implemented in 1994, a 17 to 50% (1.5 – 2 mg/L vs. 1 – 1.25 mg/L) reduction in nitrate-N concentration could have been achieved in the raw drinking water obtained from the Bosquart Well Field in 10 – 13 years.

The Rotation Case simulation showed that, based on actual and extrapolated agricultural nitrogen management practices over 13 years (1994 – 2007), nitrate-N concentrations increased from 0 mg/L (the start of the study; effects of previous nitrogen management practices not included) to a high of 1.3 mg/L (at well 14). The concentration of nitrate reached a plateau of approximately 1 mg/L (overall across all wells) within 10 – 13 years. These findings suggested that if the Rotation Case was implemented in 1994, a 30 to 50% (1.5 – 2 mg/L vs.1 mg/L) reduction in nitrate-N concentration could have been achieved in the raw drinking water obtained from the Bosquart Well Field in 10 – 13 years. The relative reduction in nitrate concentration would continue to increase over time if the concentration of nitrate-N evident in the Base Case continued to rise and the nitrate-N evident in the Rotation Case remained the same (Figures 5.1 and 5.3), thus providing increased long-term benefit due to the adoption of the rotation scenario as an agricultural nitrogen BMP.

Uncertainty Analysis

For the Rate Case (Figure 5.6), the overall confidence interval was between -30 and 50% initially, but then dropped to between -12 and 30% by the year 2000, then between -12 and 25% at the end of 2007. The results showed that if actual field porosity was 25%, compared to the best estimate of 30%, then the Rate Case would be less effective at reducing nitrate impacts by 12 to 30%. But if actual field porosity was 37%, compared to the best estimate of 30%, then the Rate Case would be more effective at reducing nitrate impacts by 25 to 50%.

For the Rotation Case (Figure 5.7), the overall confidence interval was between -30 and 40% initially, but then dropped to between -10 and 20% by the year 2000, then between -12 and 25% at the end of 2007. The results showed that if actual field porosity was 25%, compared to the best estimate of 30%, then the Rotation Case would be less effective at reducing nitrate impacts by 12 to 30%. But if actual field porosity was 37%, compared to the best estimate of 30%, then the Rotation Case would be more effective at reducing nitrate impacts by 20 to 40%.

The uncertainty analysis demonstrated that the results from the simulations using the best estimate values of porosity and dispersivity could be considered conservative. Even considering uncertainty, the Rotation Case was the most effective at reducing nitrate in groundwater at the Bosquart Well Field.

Figure 5.6

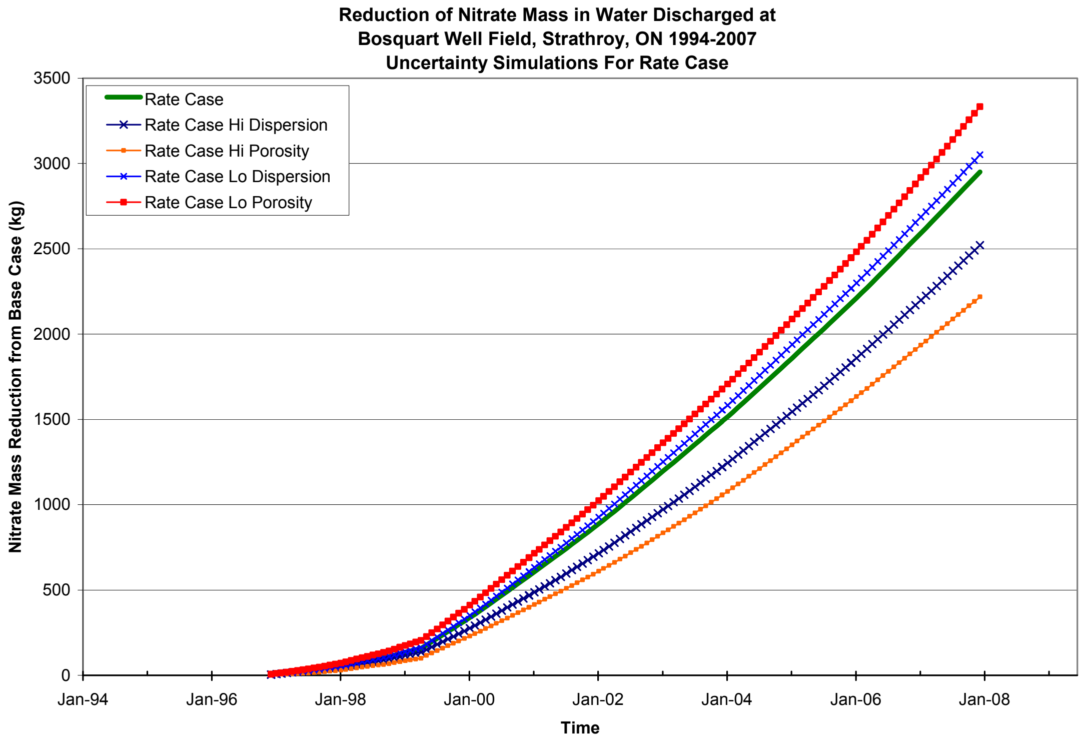
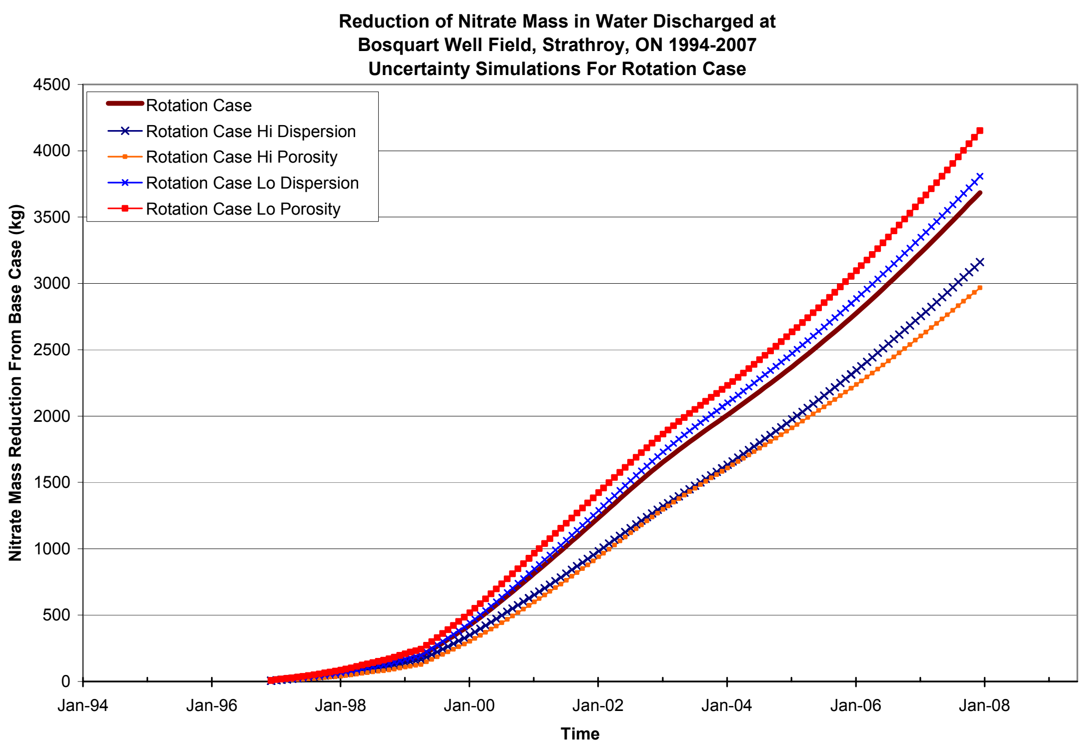


Figure 5.7



5.5 ECONOMIC RESULTS

The above analysis has shown that the implementation of BMPs in lieu of the pipeline would also have provided acceptable level of nitrates in drinking water, if the municipality had implemented the BMPs by the mid-nineties. According to the Municipality of Strathroy-Caradoc, nobody was affected during the water advisory. Therefore, no health costs were incurred. Thus the benefit of both cases, the pipeline and the implementation of the BMPs, is the provision of drinking water with a nitrate level under the critical value. The following section evaluates the economic benefits and costs of the nitrogen management BMPs.

5.5.1 Costs and Benefits to Farmers of implementing Best Management Practices in the Study Area

Summarizing the results from the previous analyses, Table 5.6 shows the results of the cost-benefit analysis. Since the BMP's and the pipeline deliver equivalent benefits in terms of potable water, in effect the analysis relates to relative costs. Thus, the net benefits are by nature negative, and the least costly approach will have the smallest negative net benefit.

The two BMP scenarios are compared to the pipeline scenario. Both BMP cases result in the nitrogen level being below the critical value. Given a discount rate of 5%, the annual net benefits of BMP1 (Rate case) are -$409,977, of BMP2 (Rotation case) are -$414,556 and for the pipeline case are -$430,187. When the present values of accrued BMP adoption are included, this yields net present values of -$8.04 million and -$8.27million for the Rate case and the Rotation case, respectively.

Thus, the analysis shows that both BMP's are very close to the pipeline in terms of net benefit, but that both BMP cases result in higher net benefits (lower costs) than the pipeline option, with BMP#1 (Rate Case) being the highest net benefit option. BMP#1 results in the lowest cost and is, therefore, the economically preferred option. The pipeline ranks last (most costly), which is mainly based on the capital and water buy-in costs.

Table 5.6 also shows the sensitivity of net present values associated with discount rates of 3, and 8 percent. The results in the table show that at an 8% discount rate, the ordering of alternatives is left unchanged. At a 3% rate of discount the BMP's give slightly lower net benefits than the pipeline.

Table 5.6 Equivalent Annual Net Benefits

	BMP Rate Case	BMP Rotation Case	Pipeline
Equivalent Annual Cost Pipeline	$0	$0	-$254,339
Equivalent Annual Cost Well	-$408,677	-$408,677	$0.00
Annual cost to farmers	$1,300	$5,879	$0.00
Annual water costs	$0	$0	-$175,848
Equivalent Annual Costs	-$409,977	-$414,556	-$430,187
NPV of Project over 80 Years (5%)	**-$8,034,090**	**-$8,123,837**	**-$8,430,142**
Agronomic Implementation cost (5%)	-$15,291	-$148,147	$0
Total (5%)	**-$8,049,381**	**-$8,271,984**	**-$8,430,142**

Sensitivity Analysis

NPV of Project over 80 Years (3%)	**-$10,924,421**	**-$11,062,733**	**-$10,308,965**
Agronomic Implementation cost (3%)	-$13,600	-$125,103	$0
Total (3%)	**-$10,938,021**	**-$11,187,836**	**-$10,308,965**
NPV of Project over 80 Years (8%)	**-$6,139,198**	**-$6,196,324**	**-$7,168,131**
Agronomic Implementation cost (8%)	-$19,763	-$182,176	$0
Total (8%)	**-$6,158,961**	**-$6,378,500**	**-$7,168,131**

Note on the Manganese and Iron Problem

It should be noted, that, according to information received from the municipality, the Bosquart well was an exceptionally costly well to maintain, due to the manganese and iron problem. To mitigate this problem, an annual cost of $100,000 would have occurred. Were these costs ignored owing to the fact that they do not relate to nitrogen management, the measured net benefits of the BMPs would have increased markedly. This is illustrated in Table 5.7. Assuming that the annual well maintenance and operation costs would be $100,000 lower, the equivalent annual net benefit would have been reduced to -$309,977, resulting in a NPV of costs over 80 years (5%) of -$6,089,744 for the Rate case. Similarly, the measured net benefit of the Rotation case increases to -$6,312,332.

Table 5.7 Equivalent Annual Net Benefits

	BMP Rate Case	BMP Rotation Case	Pipeline
Equivalent Annual Cost Pipeline	$0	$0	-$254,339
Equivalent Annual Cost Well	-$308,677	-$308,677	$0
Annual Cost to farmers	-$1,300	-$5,879	$0
Annual water costs	$0	$0	-$175,848
Equivalent Annual costs	-$309,977	-$314,556	-$430,187
NPV of Project over 80 Years (5%)	**-$6,074,453**	**-$6,164,185**	**-$8,430,142**
Agronomic Implementation cost (5%)	-$15,291	-$148,147	$0
Total (5%)	**-$6,089,744**	**-$6,312,332**	**-$8,430,142**

Hence, Table 5.7 illustrates that if one ignores away the higher treatment costs for the Bosquart well, the BMP scenarios and the update of the well system result in much lower costs than the pipeline implementation.

5.6 OBSERVATIONS

In the analysis, key characteristics such as soil type, crop rotation, and existing nitrogen management practices (e.g. use of commercial fertilizer only) were relatively uniform across the study area. This made the nitrogen budgeting process less complex than it would be in other settings. The nitrogen budget approach provided a useful framework for conducting a detailed and consistent assessment of nitrogen inputs and outputs within the transient-state capture zone of the Bosquart Well Field.

Relative estimates of nitrogen loss due to leaching below the plant root zone, using a nitrogen budget approach, generally range between 5 and 50% of nitrogen inputs (Meisinger and Randall 1991). Losses tend to be highest if nitrogen inputs greatly exceed crop uptake potential, if nitrogen is applied when there is low plant demand, or if there is a large amount of nitrogen present in the soil during the winter season, which is typically a time for groundwater recharge (Meisinger and Randall 1991). The three cases in this study fell within the above expected range (Base Case at 12.1 to 16.4%; Rate Case at 7.7 to 11.0%; Rotation Case at 5.7 to 8.4%).

The relative estimate of mean annual nitrogen load decreased as the intensity of nitrogen management using BMPs increased (Table 5.3). BMPs were effective in reducing nitrogen load to groundwater by 34 to 44% in the Rate Case and by 45 to 55% in the Rotation Case (Table 5.4). 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 simulation suggested that, if implemented soon enough, agricultural nitrogen management BMPs could qualify as effective measures to ensure that drinking water standards are met. A comparison of the results between the Base Case and the Rotation Case provide support for this statement. The simulation indicated that a 30 to 50% decrease in nitrate concentration, from 1.5 – 2 mg/L to 1 mg/L, could be anticipated if the Rotation Case scenario was adopted. Therefore, at well 15, the most problematic well in the Bosquart Well Field, a 30 to 50% decrease in nitrate concentration, from 9.1 mg/L to 6.0 – 4.5 mg/L (as extrapolated by imposing the simulated reduction on the actual water quality data from well 15) suggested the Rotation Case was an effective measure for maintaining drinking water quality standards (i.e., ≤10 mg nitrate-N/L) within the transient-state capture zone, especially considering the Rotation Case had reached a plateau during the time frame of the study. Although a 17 to 50% decrease in nitrate concentration was predicted for the Rate Case, compared to the Base Case (1.5 – 2 mg/L in the Base Case to 1 – 1.25 mg/L in the Rate Case), a longer time frame is required to better characterize the long term effectiveness of the Rate Case in maintaining drinking water quality standards.

The economic analysis that extends from the nitrogen-groundwater modeling is somewhat atypical, in the sense that it necessarily takes a retrospective approach. While recognizing that either of the BMPs, or the pipeline, satisfies the drinking water standard for nitrogen (10 ppm), the results of the economic analysis provide a different ranking of management scenarios than the nitrogen-water analysis. Using nitrogen reduction in groundwater as a criterion from the nitrogen-water analysis, the Rotation Case gave the greatest reduction compared with the Base Case, followed by the Rate Case. The ranking in economic terms was reversed with the Rate Case less costly, in an opportunity cost sense, than the Rotation Case. Finally, the economic results showed, noting the caveats regarding hindsight and current ability to simulate results, that the beneficial management practices presented an economically viable alternative to the pipeline.

6. CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study was to understand the costs and benefits of using beneficial management practices in source water protection. To do so, an extensive literature review was undertaken, consultations were conducted to determine an appropriate case for evaluation and to determine existing farm practices in the well field of the selected area, alternative beneficial management practices were defined, nitrogen simulation modeling was conducted, and the costs and benefits of the BMPs tested determined.

The results showed the following. First, the literature suggests that BMPs can provide a means of protecting drinking water quality from nitrogen contamination, and that BMPs to protect water quality are associated with a range of costs and benefits. Based on consultations with stakeholders, Strathroy-Caradoc was found to be a suitable context within which to test BMPs as an alternative to past drinking water nitrogen contamination.

The results of the nitrogen-water quality simulation work showed the following:

1. If adopted, the BMP Rate and Rotation Cases would have been very effective in reducing nitrate-N (simulated as 24 to 36% and 30 to 48%, respectively) in the drinking water obtained from the Bosquart Well Field.
2. If adopted, the BMP Rate and Rotation Cases would have been very effective in reducing nitrate loads (estimated as 39 and 48%, respectively) leaching from cropland to groundwater in the transient-state capture zone of the Bosquart Well Field.

3. Nitrogen budgets provided a useful framework for developing relative estimates of nitrogen inputs and outputs, and long-term potentially leachable nitrogen (LPLN) to groundwater.

The results of the economic analysis showed the following:

1. The two BMP alternatives identified resulted in nominal costs compared with existing cropping practices that were observed in producer consultations. Had either of these BMP alternatives been implemented in the early 1990's, 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.
2. 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. Since either approach would have satisfied nitrogen standards in drinking water, it can be concluded that the Rate case is preferred to the Rotation case, based on economics.
3. Implementation of the BMP's in lieu of the pipeline would have marginally increased the net benefits of securing the nitrogen status of drinking water from Bosquart 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.

This study is 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. This extends the knowledge base from existing agronomic practices to feasible alternatives for drinking water management, and evaluates the costs. This approach should find ready application elsewhere.

More broadly, the results suggest 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. This should be of assistance to other municipalities as they grapple with decisions on existing and future groundwater nitrogen-management issues.

With regard to this case study, it should be noted that 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 created an exceptionally high maintenance well system that needed extensive treatment. Without the costs of eliminating manganese and iron problem, both BMP solutions would have provided an even lower cost solution to the pipeline implementation.

It is also relevant in interpreting these results to note that there are unmeasured benefits. These include the benefits of reduced nitrogen contamination in surface water quality and groundwater recharge systems. In particular, while the pipeline effectively addressed the nitrogen (and other) issues in Strathroy drinking water, it did not address drinking water issues in the rural household wells that access the well field. In effect, management of the nitrogen contamination via BMPs could have produced benefits in terms of both municipal water and household well water, while the pipeline addresses only the former. This observation highlights the general effectiveness of fertilizer nutrient management in affecting water quality outcomes, and anticipates policies that use this instrument to protect both municipal and household well water sources.

The results also suggest the following in terms of policies to manage drinking water quality. First, if BMPs are to be used in drinking water quality management, the results suggest appropriate levels of incentive structure for participation or compensatory payment. Second, the results offer the insight that multiple BMPs can present solutions to nitrogen management in groundwater, and that some BMPs are more appropriate and costly than other. Third, the view emerges that crop consultants may play a significant role in successful adoption of BMPs as they guide farmers into nitrogen management strategies that are unfamiliar to them.

Recommendations

Based on the results of the study, the following recommendations are evident:

1. Guidance in developing nitrogen budgets should be published to assist others in obtaining and using the most applicable budget values for Ontario agriculture, when estimating the relative effectiveness of nitrogen management BMPs and their potential impacts on water quality.
2. Additional research should be conducted to determine, given water quality monitoring results, what the necessary lead time is in implementing BMPs.
3. Additional research should be conducted to determine the applicability of BMPs in managing nitrogen/drinking water quality on other soil types.

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APPENDIX A: BRAINSTORMING PARTICIPANTS

Attendee	Affiliation
Jo-Anne Rzadki	Conservation Ontario (project team)
Jane Sadler Richards	Cordner Science (project team)
Tom Muir	Independent Consultant (project team)
Cher Brethour	George Morris Centre (project team)
Maria Klimas	George Morris Centre (project team)
Beth Sparling	George Morris Centre (project team)
Maxine Kingston	Agriculture and Agri-food Canada
Matthew Straub	Agriculture and Agri-food Canada
Darryl Finnigan	Ontario Ministry of Agriculture Food and Rural Affairs
Charlie Lalonde	Recently retired from the Ontario Ministry of Agriculture Food and Rural Affairs
Hugh Simpson	Ontario Ministry of Agriculture Food and Rural Affairs
Clara Tucker	Ontario Ministry of the Environment
Kevin Mercer	Ontario Ministry of the Environment
Irmi Pawlowski	Ontario Ministry of the Environment
Steve Wilkins	Ontario Stewardship – Ministry of Natural Resources
Margaret Misek-Evans	County of Oxford
Klaus Seeger	County of Oxford
Tracey Ryan	Grand River Conservation Authority
Anne Loeffler	Grand River Conservation Authority
Ronda Boutz	South Nation Conservation Authority
Kate Monk	Ausable Bayfield Conservation Authority
Julie Cayley	Ducks Unlimited Canada – Ontario
Nicole Carter	Conservation Ontario
Jane Lewington	Conservation Ontario
Don Pearson	Conservation Ontario
Frank Kains	Ontario Soil and Crop Improvement Association
Cecilia Ferreyra	University of Guelph
Jim Anderson	Independent Policy Advisor

APPENDIX B: BRAINSTORMING SESSION I & II WORK SHEETS

Brainstorming Session I: Work Sheet

Things to Consider when Selecting a Watershed for Evaluation…

Location of contamination (county and watershed):

Type of agricultural pollution:

Cause of agricultural pollution:

Date that contamination first occurred (i.e., month and year of contamination):

Duration (i.e., length of time the problem existed):

Number of individuals affected and any health impacts of the contamination (if applicable):

Economic impacts, e.g., estimated costs of contamination:

How the community addressed the contamination:

Brainstorming Session II: Work Sheet

Suggested SWP BMPs for evaluation:

Sources of available data and information:

Key contacts (names, phone numbers and email addresses if available):