An Evaluation of Approaches to Derive Effluent Requirements for Wastewater Treatment Plants in Ontario

by

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A Thesis presented to The University of Guelph

In partial fulfillment of the requirements for the degree of Master of Science in Geography

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ABSTRACT

AN EVALUATION OF APPROACHES TO DERIVE EFFLUENT REQUIREMENTS FOR WASTEWATER TREATMENT PLANTS IN ONTARIO

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The objectives of this project are to rate three approaches for deriving effluent requirements; create a prioritized list of improvement steps; apply a watershed-level model to determine treatment plant requirements; and provide recommendations for deriving effluent requirements in Ontario.

Results of a two-part stakeholder survey show that until advancements are made, compromise is necessary when selecting an approach for deriving effluent requirements, as no one approach meets all the evaluation criteria. However, the necessary steps toward improvement are relatively clear and require multi-disciplinary input. When the watershed-level modelling approach was applied, it was found that although there are challenges that must be addressed, overall, it appears advantageous to use a tool such as watershed-level models for the purpose of deriving effluent requirements in Ontario.
ACKNOWLEDGEMENTS

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CHAPTER 1

1.0 INTRODUCTION

1.1 Project Background

As cities expand and agricultural production intensifies, there are growing concerns about the impact of human development on surface water quality. Efforts to address these concerns have led to important advancements in municipal wastewater treatment and to increased utilization of agricultural conservation practices. In Ontario, improvements in water quality by enhanced wastewater treatment are limited by state-of-the-art technology, but there is potential for water quality improvement through increased adoption of agricultural conservation practices. Accordingly, there is interest in programs that allow wastewater treatment plants to compensate agricultural land users for implementing conservation programs that have an effect comparable to treatment at the plant. However, a major regulatory challenge is to determine satisfactory effluent requirements for wastewater treatment plants participating in integrated wastewater management programs.

1.2 Study Objectives

Employing watershed-level models to determine effluent requirements may be the most promising means of addressing emerging regulatory challenges in the wastewater and watershed management sectors. Thus, understanding the strengths of various approaches to setting effluent requirements could have significant watershed management and policy implications. The aim of this study is to evaluate three approaches for deriving effluent requirements for wastewater treatment plants in Ontario. To achieve this aim, four objectives are identified:

1. Establish criteria for evaluating approaches to derive effluent requirements and use the criteria to rate three approaches for deriving requirements.
2. Identify unfulfilled practitioner needs and create a prioritized list of steps to improve the watershed-level approach for setting effluent requirements.

3. Extend and apply a watershed-level model to gain an understanding of the strengths and limitations of the approach for deriving effluent requirements.

4. Provide recommendations for deriving effluent requirements for wastewater treatment plants using watershed-level models in Ontario.

1.3 Thesis Outline

This thesis is prepared in manuscript format and consists of published and unpublished papers. The copyright agreement for the published paper is found in Appendix A. There are four chapters including this chapter. The second chapter reports on the design and results of the survey evaluating various approaches for deriving effluent requirements. The third chapter presents the results of a modelling case study conducted in southwestern Ontario. The fourth chapter summarizes the thesis research and provides overall recommendations.
2.0 CHAPTER 2

SUITABILITY OF WATERSHED-LEVEL MODELLING FOR DERIVING EFFLUENT REQUIREMENTS: RESULTS FROM A PRACTITIONER SURVEY

E. Jane Simmons, Wanhong Yang, Ed McBean

Abstract

The objective of this study is to evaluate approaches for deriving effluent requirements for wastewater treatment plants participating in integrated wastewater management programs. A two-part survey was conducted using a population of 16 individuals representing key stakeholder groups. Survey results indicate that the characteristics of the mass balance approach make it more desirable to practitioners; however, it may not be suitable for applications such as evaluating the effects of cumulative loadings or pollution abatement strategies. Further testing and validation of approaches, modelling and monitoring enhancements, and implementation of data access tools were high priority steps rated as ‘important’ or ‘very important’ by more than 80 percent of the participants. This study also shows a gap between the capabilities of existing approaches and practitioners’ desire for approaches that can evaluate the effects of cumulative loadings and consider impacts on ecological processes. This study reveals a need to develop and incorporate tools that allow for consideration of watershed-wide interactions and complex processes into the derivation of effluent requirements.

2.1 Introduction

As cities expand and agricultural production intensifies, there are growing concerns about the impact of human development on surface water quality. Efforts to address these concerns have led to important advancements in municipal wastewater treatment and to increased utilization of agricultural conservation practices. As an extension of these efforts, there has been interest...
in programs that allow wastewater treatment plants to compensate agricultural land users for implementing conservation programs that have an effect comparable to treatment at the plant (O’Grady, 2011; Rafanan et al., 2013; Ribaudo and Nickerson, 2009; Selman et al., 2009). However, a major regulatory challenge is to determine satisfactory effluent requirements for wastewater treatment plants participating in integrated wastewater management programs.

A number of studies have been undertaken, which comprehensively evaluate water quality models for nutrient management (Greenland International Consulting, 2003) and integrated wastewater treatment (Kirsch et al., 2002; Bruce et al., 2009). However, these evaluations focus primarily on a model’s ability to develop Total Maximum Daily Loads (TMDL) for nutrients and neglect broader considerations when selecting an approach for deriving effluent requirements. Additionally, these studies compare various watershed-level models but generally do not investigate the applicability of simpler statistical approaches (i.e., 7Q20 flow\(^1\)). There is a need to understand what tools are required to confidently derive effluent requirements in Ontario and identify steps that can be taken towards improving these tools.

Key stakeholders with expertise related to water quality modelling, agricultural conservation, or wastewater projects can provide much of the required information. In this study, a two-part survey was conducted which had participants identify criteria for evaluating approaches and rate three different approaches for deriving effluent requirements. This survey provides insight into the need for, and feasibility of, three approaches for deriving effluent requirements for integrated wastewater management programs. This paper reports the design and results of the survey evaluating various approaches for deriving effluent requirements.

\(^1\) The low flow statistic 7Q20 (the minimum 7-day average flow with a recurrence period of 20 years) is typically used as the design basis for the receiving stream in the development of effluent requirements for continuous point source discharges. It is described in Procedure B-1-5 Deriving receiving-water based, point-source effluent requirements for Ontario waters (MOEE, 1994).
2.2 Methods

2.2.1 Survey Design

A population of 21 individuals representing key stakeholder groups including the private sector, government, academia, conservation authorities, and non-governmental organizations was identified. These experts with a range of experience in Ontario regions were selected through their involvement with local and/or regional modelling, agricultural conservation or wastewater projects, and through discussions with staff and managers at organizations such as the Ontario Ministry of the Environment, Conservation Ontario, and the University of Guelph.

Through a literature review, seven preliminary evaluation criteria were identified (Greenland International Consulting, 2003; McBean et al., 1995). The criteria focused on technical, environmental, and regulatory issues of wastewater treatment and water quality management. Participants were asked to weigh the importance of each criterion on a scale from 0 (criterion is unimportant) to 3 (criterion is critical). Survey respondents had the opportunity to provide comments and add criteria. The results of the criteria identification survey were used to develop the final evaluation criteria. Ultimately, three modelling approaches for setting effluent limits were evaluated by participants. The following descriptions were provided to participants:

- Mass Balance Modelling – Background concentrations and flow are determined as well as the effluent concentration and flow. A low flow statistic (i.e., 7Q20 flow) is then used to evaluate the effect of discharge on surface water quality and/or quantity.
- Watershed Modelling – A dynamic simulation model is set up which includes the effects of multiple point and non-point sources. This model is then applied to predict stream flow and water quality that can be used to evaluate the effect of discharge on surface water quality and/or quantity.
Although many watershed level models exist, the participants were asked to consider watershed level modelling in a general sense.

- Combined Approach – Watershed modelling can be applied to predict stream flow and water quality, and then the watershed modelling outputs can be used in conjunction with the mass balance modelling approach (i.e., 7Q20 flow) to evaluate the effect of discharge on surface water quality and/or quantity.

There were ten evaluation criteria in total and participants were asked to rate how well each of the three approaches meets the criteria using a scale from 1 (very poorly meets the criteria) to 5 (meets the criteria very well). Additionally, follow-up questions were asked which had participants rank from 1 (not important) to 5 (very important) the importance of various steps that could be taken to improve approaches for deriving effluent requirements for Ontario waters and additional considerations when deriving effluent limits. Participants were provided with an opportunity to add criteria and offer comments. Copies of the survey sheets sent to participants are included in Appendix B.

2.2.2 Survey Implementation

A population of 21 potential survey participants was sent an explanatory recruitment letter and a maximum of two follow-up emails. In total, 16 participants agreed to take part in the survey. For each part of the survey, participants received the survey and a maximum of two follow-up emails. The only reason provided for not participating in the survey was a lack of appropriate expertise; as such, the results of the survey represent the opinions of 16 water resources experts/stakeholders in Ontario.

2.2.3 Survey Analysis

Results were analysed using Microsoft Excel software. An average rating was computed for each criterion. An overall rating for the two categories of criteria, characteristics of the approach and applications of the approach, was also
calculated. In addition, the level of “consensus” for each criterion rating was assessed by determining the standard deviation of counts within each response rating. High standard deviation suggests an uneven distribution of ratings across the scale (i.e., low consensus); whereas, low standard deviation indicates that responses were concentrated around one point on the scale (i.e., high consensus). Additionally, participants were divided into groups according to the sector they represented to investigate the possibility of rating differences between and among groups of participants.

2.3 Results and Discussion

2.3.1 Characteristics of Respondents

Demographic information was not explicitly collected from survey respondents; but based on their field of practice, the majority of respondents were in water resources management and/or engineering. Respondents had considerable experience working in Ontario and four practiced in or around rural southwestern Ontario. Respondents were from government agencies, consulting companies, academic institutions, conservation authorities, and non-governmental organizations. The majority, however, worked for government agencies or consulting companies.

2.3.2 Criteria Rating

Differences in how well each approach meets the selection criteria. The ten criteria used in the survey fit broadly into two categories—characteristics of the approach and applications of the approach. There were slightly more characteristics criteria than applications criteria (6:4) selected, based on survey input from participants. This suggests that experts in the field may be more familiar with criteria related to the characteristics of the approach for setting effluent limits than the applications of it. This is supported by the predominantly characteristics criteria appearing in similar evaluations (Greenland International Consulting, 2003; McBean et al., 1995). Characteristics criteria as a group were
rated highest (Table 2.1) for the mass balance modelling approach. The opposite was true for the applications rating. Here the watershed modelling approach had the highest rating followed by the combined and mass balance approaches. These results suggest that the characteristics of the mass balance approach make it more desirable to practitioners; however, it may not be suitable for applications such as evaluating the effects of cumulative loadings or pollution abatement strategies.

The greatest ranking difference between the mass balance model and the watershed model occurred for the low cost criterion, as watershed level modelling requires a much higher expenditure than the mass balance modelling. Additionally, characteristics criterion related to data availability and expertise was rated almost two levels higher for the mass balance rating. In contrast, the watershed model was rated one and a half levels higher than the mass balance approach for applications criteria assessing evaluation of cumulative loading, pollution abatement strategies, and impacts on ecological processes. This indicates neither approach is superior for all criteria and that there are trade-offs when selecting a mass balance modelling approach or the watershed modelling approach.

### Table 2-1 Average Rating of Criteria for Three Effluent Setting Approaches, Ranked by Mass Balance Approach Rating.

<table>
<thead>
<tr>
<th>Criterion No.</th>
<th>Criterion Description</th>
<th>Nature of criterion</th>
<th>Mass balance rating</th>
<th>Watershed model rating</th>
<th>Combined approach rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Transferable to different types of watersheds</td>
<td>Characteristic</td>
<td>4.27</td>
<td>3.36</td>
<td>3.73</td>
</tr>
<tr>
<td>1</td>
<td>Highly tested and proven</td>
<td>Characteristic</td>
<td>4.18</td>
<td>3.27</td>
<td>3.27</td>
</tr>
<tr>
<td>6</td>
<td>Low cost to setup and use</td>
<td>Characteristic</td>
<td>4.18</td>
<td>2.09</td>
<td>2.27</td>
</tr>
<tr>
<td>3</td>
<td>Requires readily-available or easy-to-obtain data</td>
<td>Characteristic</td>
<td>4.09</td>
<td>2.27</td>
<td>2.45</td>
</tr>
<tr>
<td>5</td>
<td>Easy to use and does not require specialized experience</td>
<td>Characteristic</td>
<td>3.91</td>
<td>2.00</td>
<td>2.27</td>
</tr>
<tr>
<td>2</td>
<td>Performs well when difficult to characterize the receiver</td>
<td>Characteristic</td>
<td>3.55</td>
<td>2.64</td>
<td>2.82</td>
</tr>
<tr>
<td>8</td>
<td>Evaluate the effects of cumulative loadings</td>
<td>Application</td>
<td>2.60</td>
<td>4.10</td>
<td>3.90</td>
</tr>
<tr>
<td>7</td>
<td>Assess the impact of climate change</td>
<td>Application</td>
<td>2.40</td>
<td>3.80</td>
<td>3.60</td>
</tr>
<tr>
<td>10</td>
<td>Simulate the effects of pollution abatement strategies</td>
<td>Application</td>
<td>2.18</td>
<td>4.00</td>
<td>3.73</td>
</tr>
<tr>
<td>9</td>
<td>Consider impacts on ecological processes</td>
<td>Application</td>
<td>1.90</td>
<td>3.40</td>
<td>3.20</td>
</tr>
</tbody>
</table>

Overall average rating: 3.33, 3.09, 3.12
Characteristic rating: 4.03, 2.61, 2.80
Application rating: 2.27, 3.83, 3.61

Consensus (std. deviation): 0.95, 0.79, 0.63

Note: A high average rating indicates an approach that better meets the criteria. Average rating corresponds to a 1, 2, 3, 4, or 5 (where 5 indicated 'very well').
Important steps toward improvement. Respondents put forward only four steps not listed in the survey. This suggests that the distributed list was comprehensive. Moreover, at least one participant (Fig. 2.1) rated each proposed step ‘important’ or ‘very important’. However, only three steps – further testing and validation of approaches, modelling and monitoring enhancements, and implementation of data access tools were rated as ‘important’ or ‘very important’ by more than 80 percent of participants. Only development of approaches for deriving effluent requirements in small or northern watersheds was ranked as ‘important’ or ‘very important’ by fewer than 20 percent of respondents. This finding may reflect the fact that most respondents were not working in small or northern watersheds.

Figure 2-1 Proportion of respondents rating a given step as important or very important (N = 15-16).
Respondents were then asked to identify the three most important steps in improving effluent setting approaches. This information, combined with the average ranking for each step, was used to determine the top three most important steps. The results were divided into groupings to see if discrepancies existed between types of participants (Table 2.2). The relative importance of the proposed steps may be used to inform policy and research directions. It is interesting to note that while there is general agreement among groups of participants, there are some differences in the grouped rankings. Consultants rated specialized training for practitioners higher than other groups. This is likely explained by their direct role in conducting studies for clients and government review. When looking at the importance of cost offsetting programs, the average score was lowest in the government subgroup, whereas, it was in the top three for academics. Notably, the highest average score, a score two levels higher than the government group rating for cost offsetting programs, came from the NGO subgroup. This discrepancy underscores the importance of communication among groups. A larger sample size would help to identify differences in opinions between subgroups.

**Table 2-2 Top three important steps that could be taken to improve derivation of effluent requirements in Ontario, based on the importance rating for the complete sample and subgroups.**

<table>
<thead>
<tr>
<th>No.</th>
<th>Grouping by Segment of profession</th>
<th>Complete Sample</th>
<th>Government</th>
<th>Academia</th>
<th>Consulting</th>
<th>NGO/Others</th>
<th>Local</th>
<th>Regional/Provincial</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>15 - 16</td>
<td>5 - 5</td>
<td>2 - 2</td>
<td>4 - 4</td>
<td>4 - 5</td>
<td>3 - 4</td>
<td>3 - 8</td>
</tr>
<tr>
<td>1</td>
<td>Further testing and validation</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>2</td>
<td>Modelling and monitoring enhancements</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Tools that make data easy to access</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Development of approaches for deriving in small/north</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Specialized training for practitioners</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Programs to offset the cost of expensive approaches</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: 1. There was a tie for the third-most important rated category in this category. 2. There was a three-way tie based on average score; however, specialized training was selected in the top three by a greater number of practitioners, so it is shown here.
Strengths of approach compared to importance of additional considerations.

By combining the evaluation results of application-based criteria with the ranking of the importance of these considerations, it is possible to see where gaps exist between the best available approach and the needs of practitioners (Fig. 2.2). The only area where the best-rated approach, watershed modelling, exceeds the importance of the additional consideration is for its ability to assess the impact of climate change. For the evaluation of the effects of cumulative loadings and consideration of the impact on ecological processes, the importance rating falls in the ‘important’ to ‘very important’ range while the rating of the watershed model approach is ‘neutral’ to ‘well’ at meeting the criteria. This reveals a need to develop and incorporate tools that allow for consideration of watershed-wide interactions and complex processes into the derivation of effluent requirements.
2.3.3 Limitations

The most significant limitation of this study is the small sample size; however, every respondent was an expert or very familiar with the field. The majority of respondents were active at the regional or provincial level and worked in government or consulting. The addition of experts working in academia and non-governmental organizations would improve future studies investigating the desired and actual characteristics of approaches for deriving effluent requirements in Ontario.

2.4 Conclusion

To conclude, there are differences in how well the mass balance modelling approach and watershed-level modelling approach meet evaluation criteria. As the derivation of effluent requirements becomes more complex, a watershed modelling approach may be necessary, despite the additional cost and expertise required. That is not to say, however, that a watershed-level modelling approach is always required. In situations where the characteristics of the approach are more important than the applications, the results of this survey suggest that the mass balance method may be more appropriate.

There is general agreement across disciplines and scales that further testing and validation of approaches and modelling and monitoring enhancements are required to improve approaches for deriving effluent requirements. There also appears to be a need to develop or incorporate tools that consider cumulative loadings and ecological effects when deriving effluent limits in Ontario.

With growing concern about the impact of human activities on receiving water bodies, it is increasingly important to ensure that approaches are available and implemented to derive effluent requirements for meeting the needs of government agencies, consultants, conservationists, and other project stakeholders. This study shows that until advancements are made compromise is necessary when selecting an approach for deriving effluent requirements, as no
one approach meets all the evaluation criteria. However, the necessary steps toward improvement are relatively clear and require multi-disciplinary input.
References


CHAPTER 3

APPLICATION OF WATERSHED-LEVEL MODELLING FOR DERIVING EFFLUENT REQUIREMENTS IN AN AGRICULTURAL WATERSHED IN SOUTHWESTERN ONTARIO, CANADA

E. Jane Simmons, Wanhong Yang, Yongbo Liu

Abstract

The objective of the study is to understand barriers to using a watershed-level model to determine effluent requirements for integrated wastewater management programs and look for ways to overcome them. The Soil and Water Assessment Tool (SWAT) was applied to the 497 km$^2$ Bayfield River watershed, which is located in an agricultural region of southwestern Ontario. The model was calibrated (2007 to 2011) and validated (2002 to 2006) for stream flow, sediment, and phosphorous loadings at a monitoring station located 15 km from the watershed outlet. Two scenarios for deriving effluent requirements were evaluated including one scenario examining the effect of water and sediment control basins and one examining the effect of climate change. Results from the modelling show marginal positive impact of water and sediment control basins on phosphorous loadings at the watershed scale due to a limited number of control basins in the watershed. When a simple climate change scenario is considered, a decrease in annual phosphorous loading but an increase in phosphorous concentration is observed. This study provides insight into the advantages of considering the effects of water and sediment control basins and climate change on water quality when deriving effluent requirements in Ontario.

3.1 Introduction

There are growing concerns in the global community about the impact of urban expansion and agricultural intensification on surface water quality. In response to these concerns, regulations concerning contaminant loadings to sensitive or
impaired water bodies have become more stringent in Ontario. This is especially true for nutrients such as nitrogen and phosphorus, which can have both point and non-point source origins. As improvements in water quality become limited by the state-of-the-art wastewater treatment technology, there is interest in compensating agricultural land users for implementing conservation programs. However, deriving effluent requirements for wastewater plants participating in integrated wastewater management programs poses a challenge for practitioners in this field.

Uncertainty in the effects of conservation practices is widely recognized as a primary challenge for regulating integrated wastewater management programs (O’Grady, 2011; Ribaudo & Nickerson, 2009; Selman et al., 2009). Previous research to improve the estimation of conservation effects has led to the development of direct measurement and monitoring techniques (Bishop et al., 2005; Bishop et al., 2003; Spooner & Line, 1993), site-specific calculations (Gross et al., 2008; US-EPA, 2012a; World Resources Institute, 2007), and watershed-level models (Arnold et al., 1998; Young et al., 1989, US-EPA, 2012b). Direct measurement provides certainty when an adequate number of samples are collected; however, in most cases, data is impractical and expensive to obtain (Selman et al., 2009). Computer modelling can reduce the number of site-specific measurements required and provides a reasonable level of certainty with validation from monitoring data. The Soil and Water Assessment Tool (SWAT) developed by Arnold et al., (1998) is designed to provide watershed-level modelling of the effects of agricultural conservation practices. The use of SWAT to characterize conservation practices is well-documented (Gassman et al., 2007). The model offers at least part of the confidence required for regulatory purposes; however, simulation of certain conservation practices using SWAT is limited by algorithm availability. Research has improved the capabilities of SWAT for modelling both riparian wetlands (Liu et al., 2008) and tillage operations (Ullrich & Volk, 2009). Yet the same capabilities have not been extended to model the effects of the water and sediment control basins constructed throughout Ontario that control erosion and runoff.
An understanding of the effects of weather variability and climate change on pollutant loads is the second important condition affecting the regulation of watershed-wide wastewater management programs (XCG Consultants Ltd. et al., 2010). Previously, SWAT has been used to evaluate stream water quality under high flow or flooding conditions (Benaman & Shoemaker, 2005) and under low flow or drought conditions (Jayakrishnan et al., 2005). Moreover, there is a growing body of literature examining climate change effects on water quality at the watershed level (Ficklin et al., 2009; Rahman et al., 2010; Wu & Johnston, 2007). While watershed-level models provide insight into the seasonal variability of water quality, the application of these models for determining effluent requirements is infrequent. Furthermore, the existing model (i.e., 7Q20 flow) prescribed for deriving effluent requirements in Ontario (MOE, 1994) is increasingly recognized as a barrier to innovation in wastewater management. As a result, understanding these barriers and looking for ways to overcome them has merit.

Employing watershed-level models to determine effluent requirements may be the most promising means of addressing emerging regulatory challenges in the wastewater management sector. In this study, a watershed-level model that considers the effects of agricultural conservation practices and explicitly accounts for weather variability will be extended and applied to determine effluent requirements for wastewater treatment plants in Ontario. This extension and application enables an improved understanding of how a watershed-level model could be used effectively for determining effluent requirements.

3.2 Methods

3.2.1 Bayfield River Watershed

The Bayfield River watershed is located in southwestern Ontario, draining approximately 497 km$^2$ above its outlet to Lake Huron (Fig. 3.1). The watershed is located in the Lake Erie Lowland ecoregion; the area, characterized by low-relief topography, is one of the warmest climates in Ontario with predominantly
cropped land cover (Ecological Framework of Canada, 2012). Soils consist mainly of well-drained clay loams and sandy loams overlaying shale and limestone bedrock (Schaus, 1982). The average annual precipitation in the watershed is 980 mm. As of 2011, land use in the Bayfield River watershed consists of 75% row crop, 15% forests, 10% urban, roads, water, and other unclassified land covers. Approximately two thirds of the watershed is level or nearly level, with a slope less than 2%. Four municipal wastewater treatment plants in the Bayfield River watershed have outlets to the Bayfield River or one of its tributaries. From upstream to downstream, the wastewater treatment plants are located at Seaforth, Clinton, Vanastra, and Bayfield. Respectively, the plants are rated to treat 693,500 m$^3$, 1,131,500 m$^3$, 521,800 m$^3$, and 391,000 m$^3$ of wastewater annually (MOE, 2003a; MOE, 2003b; MOE, 2011; MOE, 1991). Healthy Lake Huron recognizes the main Bayfield sub-watershed as a priority watershed requiring immediate action (Healthy Lake Huron, 2013).

![Figure 3-1 Bayfield River Watershed, Ontario, Canada](Image)
3.2.2 Monitoring Data

The Water Survey of Canada maintains three water-gauging stations in the watershed. The gauging stations are located upstream of the Village of Bayfield at the intersection of the Bayfield River and Parr Line, north of Varna (43°33'04" N, 81°35'22" W), on Silver Creek at Seaforth (43°32'43" N, 81°23'46" W), and on Trick's Creek near Clinton (43°35'25" N, 81°35'02" W). Hourly mean discharge data is used in this study to compute daily and monthly totals for model calibration.

As part of the Provincial Water Quality Monitoring Network, the Ausable Bayfield Conservation Authority at two provincial water quality monitoring network stations has collected surface water samples on a monthly basis since 1967. The water quality stations are located on Kippen Road at Egmondville (43°32'16" N, 81°24'23" W) and near Huron County Road 31, north of Varna (43°33'02" N, 81°35'21" W). In 2005, another station was added at Silver Creek near Seaforth (43°32'43" N, 81°23'46" W). The conservation authority also maintains four enhanced sampling locations tested for nutrients and suspended sediments. Approximately 15 km from the watershed outlet, the median and upper quartile phosphorous concentrations, in the period 1976 to 2008, were 0.021 mg/L and 0.042 mg/L, and 65 percent of samples exceeded the Provincial Water Quality Objective (PWQO) of 0.03 mg/L. Nitrate median and upper quartile concentrations were 5.3 mg/L and 8.6 mg/L. Suspended solid median and upper quartile concentrations were 4.0 mg/L and 7.4 mg/L. During the same period, the median and upper quartile concentrations of E. coli were 99 cfu/100 mL to 300 cfu/100 mL and 55 percent of samples exceeded the PWQO of 100 cfc/100 mL recommended for swimming and bathing. When data collected between 1975 to 1995 is compared to 2000 to 2011, analysis based on the 75th percentile values shows a 0.02 mg/L decrease in total phosphorus, a 0.4 mg/L decrease in nitrates, 3 mg/L decrease in total suspended solids, and a 60 cfu/100 mL increase in E. coli counts (ABCA, 2012).

Effluent quality information contained in compliance reports for each of the four wastewater treatment plants was compiled to simulate the wastewater
treatment plant discharge in the study area. Between 2008 and 2011, the average annual total phosphorous concentration from the wastewater treatment plants at Seaforth, Clinton, Vanastra, and Bayfield was 0.18 mg/L, 0.31 mg/L, 0.34 mg/L, and 0.11 mg/L, respectively. Similarly, suspended solids concentration was 5.68 mg/L, 4.99 mg/L, 10.35 mg/L, and 4.98 mg/L.

3.2.3 Soil and Water Assessment Tool

The model applied in this study is the Soil and Water Assessment Tool (SWAT). The SWAT, developed by the USDA Agricultural Research Service, is a watershed-level water quantity and quality simulation model that operates on a daily time step and is capable of simulating a number of land use and land management practices (Douglas-Mankin et al., 2010). The main inputs are land use, soil, topographic, and climatic data; the outputs include stream flow and in-stream water quality estimates. In the SWAT, watersheds are partitioned into a number of subbasins, which are further divided into hydrological response units (HRUs) based on unique combinations of land cover, soil, and slope class. For each HRU, loading of water, sediment, nutrients, and pesticides are determined and routed to the subbasin outlet. The latest version, SWAT2009, is the result of almost 20 years of improvements.

3.2.4 Model Set-up

Topographic information for the study area was obtained from the 10 m x 10 m resolution Provincial Digital Elevation Model (MNR, 2006). This was used to delineate the stream network and subbasins for SWAT simulation. In the model set-up, the stream network was delineated using a 10 ha contributing area threshold, and the location of the outlets was manually defined. Watershed delineation included subbasin outlets at main stream tributaries (contributing area ~1,000 ha), monitoring stations, water and sediment control basin locations, and tile drain outlets. This resulted in 52 subbasins (Fig. 3.1). Additionally, point source inputs were defined for the four municipal wastewater treatment plants in the watershed.
Land use data for this study was compiled from three different geospatial data sources: the Agricultural Resource Inventory (OMAFRA, 1983), Agri 2012 (provided by ABCA), and the Ecological Land Classification System (MNR, 2007a). The ON Soils Map (OMAFRA, 2009) and a custom soil database developed using Soil Landscapes of Canada (SLC, 2010) were used to characterize soil types in the watershed. Based on standard slope classes (Irvine, 2001), three slope classes were defined as 0 - 2%, 2 - 5%, and > 5%. Hydrologic response units were defined for the watershed using a combination of land use, soil type, and slope class with thresholds of 5%, 20%, and 20% respectively. This resulted in 716 hydrologic response units.

Precipitation and temperature data was available from one station located inside the watershed maintained by the conservation authority and three further away – (>20 km) Environment Canada stations. Only the Environment Canada stations have reliable precipitation data during the winter months. Based on discussion with conservation authority staff, the London International Airport station was selected for use during these months.

Point source discharge data for wastewater treatment plants at Seaforth, Clinton, and Vanastra was prepared for SWAT as average monthly loadings. At Bayfield, where discharge does not occur continuously, discharge data was summarized daily. Actual discharge and quality data was prepared from 2008 to 2011. This data was averaged to estimate loading from 2001 to 2007. Not all water quality parameters required for SWAT were reported, so they were calculated or estimated based on available data, technical reports (USEPA, 2007; USEAP 2010), and typical ranges found in Metcalf and Eddy (2003).

Landowner surveys and drive-by field level surveys conducted by the conservation authority from 2008 to 2011 and Agricultural Resource Inventory cropping system information (OMAF, 1983) were used to define five cropping systems in the Bayfield River watershed (Table 3.1). Each cropping system or rotation was assigned a unique land use in the SWAT so that a HRU would be created for that particular rotation and a specific management scenario could be defined using the ArcSWAT interface. Most commonly, a rotation of corn,
soybeans, and wheat was applied. Conventional tillage was assumed for corn and conservation tillage/zero tillage for soybeans and winter wheat. Fertilizer application rates were estimated for each crop based on average application rates in the study area. At the start of the season, 180 kg/ha of nitrogen and 38 kg/ha of phosphorus were applied for corn and 110 kg/ha of nitrogen and 12 kg/ha of phosphorus were applied for winter wheat.

<table>
<thead>
<tr>
<th>Cropping System</th>
<th>HRU</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Area (km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous Row</td>
<td>AGRL</td>
<td>Corn</td>
<td>Corn</td>
<td>Bean</td>
<td>22.7</td>
</tr>
<tr>
<td></td>
<td>AGRR</td>
<td>Corn</td>
<td>Bean</td>
<td>Corn</td>
<td>23.0</td>
</tr>
<tr>
<td></td>
<td>AGRC</td>
<td>Bean</td>
<td>Corn</td>
<td>Corn</td>
<td>22.9</td>
</tr>
<tr>
<td>Mixed</td>
<td>CORN</td>
<td>Corn</td>
<td>Bean</td>
<td>Grain</td>
<td>92.1</td>
</tr>
<tr>
<td></td>
<td>SOYB</td>
<td>Bean</td>
<td>Grain</td>
<td>Corn</td>
<td>95.3</td>
</tr>
<tr>
<td></td>
<td>WWHT</td>
<td>Grain</td>
<td>Corn</td>
<td>Bean</td>
<td>91.6</td>
</tr>
<tr>
<td>Grain System</td>
<td>BARL</td>
<td>Barley</td>
<td>Barley</td>
<td>Barley</td>
<td>15.9</td>
</tr>
<tr>
<td>Hay System</td>
<td>HAY</td>
<td>Hay</td>
<td>Hay</td>
<td>Hay</td>
<td>12.5</td>
</tr>
<tr>
<td>Pasture/Grazing</td>
<td>PAST</td>
<td>Pasture</td>
<td>Pasture</td>
<td>Pasture</td>
<td>4.12</td>
</tr>
</tbody>
</table>

In the SWAT, the SCS curve number is an important parameter for predicting runoff. The default curve number from the SWAT database was assigned to each crop during the seeding operation. When an operation was performed (i.e., harvest or tillage), literature values were used to estimate the modified curve number for croplands (Rawls et al., 1980).

Ten existing water and sediment control basins in the Bayfield River watershed were included in the final model set-up. The location and stage-area-storage relationship for three of the control basins in the study area were determined by staff at OMAFRA using a 1 m x 1 m DEM, derived from 2011 LiDAR data. Discharge was then estimated using equations provided by OMAFRA (2008). LiDAR data was not available for the remaining control basins, so stage-area-storage relationships could not be determined directly. Rating curves were available for a number of water and sediment control basins in the nearby Gully Creek watershed, so curves were assigned based on drainage area size. During model set-up, routing was manually changed to use a custom
algorithm that partitions flow from basins into over berm flow or tile drain flow and
directs it to the appropriate outlet. Other SWAT simulation options used in the
model set-up were the selection of the skewed normal setting for rainfall
distribution, the Hargreaves method to estimate potential evapotranspiration, the
Muskingum channel routing method, and the SCS runoff curve number method
to predict direct runoff.

After model set-up, the SWAT model was run on a daily time step from 2001 to
2011. The first year, 2001, was a one-year initialization period. The five most
recent years of data, 2007 to 2011, were used for calibration. The remaining
years, 2002 to 2006, were used for validation. The most recent years of data
were selected for calibration because the land management data and wastewater
treatment plant discharge data was collected during this period, so fewer
assumptions were required for this period than for earlier years modelled.

Sensitivity analysis was first conducted for flow parameters using the SWAT
imbedded tool developed by Van Griensven (2006). Based on the results of the
sensitivity analysis, 18 parameters were selected for auto-calibration. The
variables selected for flow calibration along with range and final values used for
calibration are summarized in Table 3.2. The calibration was performed using
daily stream flow data collected from Parr Line, north of Varna (43°33'04" N,
81°35'22" W) located approximately 15 km from the watershed outlet. The
coefficient of determination $r^2$ and the Nash-Sutcliff efficiency $E$ (Nash and
Sutcliffe, 1970) were selected to evaluate model efficiency at both the daily and
monthly scales. The value of $r^2$ can range from 0 to 1, where a value of zero
means that there is no correlation, and a value of 1 means that the dispersion of
the observed and predicted values is the same (Krause et al., 2005). The
gradient $b$ and the intercept $a$ of the regression were also considered to check for
systematic over- or under-prediction. For the Nash-Sutcliffe efficiency, the range of
values is between $-\infty$ to 1. A value of one means that the predicted data is a
perfect fit; whereas, a negative value indicates that the mean of the observed
data would have been a better fit than the predicted time series (Krause et al.,
2005).
Table 3-2 Flow parameter, range and final values used for calibration

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Ref. Value</th>
<th>Range</th>
<th>Cal.Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha_Bf</td>
<td>Base flow alpha factor (days)</td>
<td>0.1 to 1</td>
<td>0.637</td>
<td></td>
</tr>
<tr>
<td>Biomix</td>
<td>Biological mixing efficiency</td>
<td>0.20</td>
<td>1 to 0.3</td>
<td>0.18</td>
</tr>
<tr>
<td>Blai</td>
<td>Maximum potential leaf area index</td>
<td>Database</td>
<td>± 10%</td>
<td>-9.9%</td>
</tr>
<tr>
<td>Canmx</td>
<td>Maximum canopy storage (mm H₂O)</td>
<td>2 to 5</td>
<td>2.50</td>
<td></td>
</tr>
<tr>
<td>Ch_K2</td>
<td>Effective hydraulic conductivity in main channel alluvium (mm/hr)</td>
<td>0 to 15</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Ch_N2</td>
<td>Manning’s “n” value for the main channel</td>
<td>0.003 to 0.140</td>
<td>0.085</td>
<td></td>
</tr>
<tr>
<td>CN2</td>
<td>SCS runoff curve number</td>
<td>Standard list</td>
<td>± 10%</td>
<td>+8.8%</td>
</tr>
<tr>
<td>EpcO</td>
<td>Plant uptake compensation factor</td>
<td>1.0</td>
<td>0.01 to 1</td>
<td>0.981</td>
</tr>
<tr>
<td>Esco</td>
<td>Soil evaporation compensation factor</td>
<td>0.95</td>
<td>0.01 to 1</td>
<td>0.033</td>
</tr>
<tr>
<td>Gw_Delay</td>
<td>Groundwater delay time (days)</td>
<td>31</td>
<td>0 to 50 days</td>
<td>18</td>
</tr>
<tr>
<td>Gw_Revap</td>
<td>Groundwater “revap” coefficient</td>
<td>0.02</td>
<td>0.02 to 0.20</td>
<td>0.12</td>
</tr>
<tr>
<td>Gwqmn</td>
<td>Water in the shallow aquifer required for return flow to occur (mm H₂O)</td>
<td>10 to 1000</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Revapmn</td>
<td>Water in the shallow aquifer for percolation to the deep aquifer to occur (mm H₂O)</td>
<td>1.0</td>
<td>0.0 to 500</td>
<td>288</td>
</tr>
<tr>
<td>Sftmp</td>
<td>Snowfall temperature (°C)</td>
<td>1.0</td>
<td>-3.0 to 3.0</td>
<td>1.1</td>
</tr>
<tr>
<td>Slope</td>
<td>Mean slope within the HRU</td>
<td>DEM</td>
<td>± 10%</td>
<td>-10%</td>
</tr>
<tr>
<td>Slsubbasin</td>
<td>Average slope length (m)</td>
<td>DEM</td>
<td>± 10%</td>
<td>-4.7%</td>
</tr>
<tr>
<td>Sol_Alb</td>
<td>Moist soil albedo</td>
<td>Database</td>
<td>± 10%</td>
<td>+7.2%</td>
</tr>
<tr>
<td>Sol_Awc</td>
<td>Available water cap. of soil (mm H₂O/mm)</td>
<td>Database</td>
<td>± 10%</td>
<td>-5.7%</td>
</tr>
<tr>
<td>Sol_K</td>
<td>Saturated hydraulic conductivity (mm/hr)</td>
<td>Database</td>
<td>± 10%</td>
<td>-8.1%</td>
</tr>
<tr>
<td>Surlag</td>
<td>Surface runoff lag coefficient</td>
<td>4</td>
<td>0.1 – 6.0</td>
<td>4.4</td>
</tr>
</tbody>
</table>

The sediment and phosphorous calibration was performed using an interface iSWAT developed by Yang (2006). Based on sensitivity analysis and the SWAT user manuals (Arnold et al., 2011), the parameters shown in Table 3.3 and Table 3.4 were manually adjusted over the ranges listed. Water-quality grab samples collected approximately bi-weekly at the station located at Parr Line north of Varna (43°33′04″ N, 81°35′22″ W) were used. Daily loads were estimated using the measured concentration and flow data so that comparisons could be made with the SWAT model output for water-quality parameters. Model performance was evaluated qualitatively using time series plots and quantitatively using three statistical measures: root mean square error RMSE, root mean squared deviation CV, and the correlation coefficient CORR.

Table 3-3 Sediment parameter, range and final values used for calibration

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Ref. Value</th>
<th>Range</th>
<th>Cal.Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filterw</td>
<td>Width of edge-of-field filter strip (m)</td>
<td>0 to 2.5</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>PRF</td>
<td>Peak rate adjustment for routing in channel</td>
<td>1.0</td>
<td>0.5 to 1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Spcon</td>
<td>Max sediment that can be reentrained (linear)</td>
<td>0.0001</td>
<td>0.0001 to 0.01</td>
<td>0.002</td>
</tr>
<tr>
<td>Spexp</td>
<td>Max sediment that can be reentrained (exp)</td>
<td>1.0</td>
<td>1 to 2</td>
<td>1.0</td>
</tr>
<tr>
<td>Usle_P</td>
<td>USLE equation support practice factor</td>
<td>0.5 to 0.9</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Usle_K</td>
<td>USLE soil erodibility factor</td>
<td>± 25%</td>
<td>-25%</td>
<td></td>
</tr>
<tr>
<td>Usle_C</td>
<td>Min value of USLE C factor for land cover</td>
<td>± 25%</td>
<td>-25%</td>
<td></td>
</tr>
</tbody>
</table>
### Table 3-4 TP Parameter, Range and Final Values Used for Calibration

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Ref. Value</th>
<th>Range</th>
<th>Cal. Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phoskd</td>
<td>Phosphorous soil partitioning coeff. (m³/Mg)</td>
<td>175</td>
<td>150 to 200</td>
<td>175</td>
</tr>
<tr>
<td>Pperco</td>
<td>Phosphorous percolation coeff. (10 m³/Mg)</td>
<td>10</td>
<td>10 to 17.5</td>
<td>10</td>
</tr>
<tr>
<td>Sol_minP</td>
<td>Initial soluble P in the soil (mg P/kg soil)</td>
<td>5</td>
<td>5 to 25</td>
<td>5</td>
</tr>
<tr>
<td>Sol_orgP</td>
<td>Initial organic P in the soil (mg P/kg soil)</td>
<td>Calculated</td>
<td>± 10%</td>
<td>0%</td>
</tr>
</tbody>
</table>

### 3.3 Results and Discussion

#### 3.3.1 Calibration and Validation

The results of the SWAT simulation for the Bayfield River watershed found that, on average, 44% precipitation (467 mm) reaches the stream as surface runoff, lateral flow, and groundwater flow. Evapotranspiration comprises 55% (589 mm) of the remaining precipitation, and the last 1% (6.50 mm) contributes to deep aquifer recharge. In a previous study, modelled actual evapotranspiration was found to range between 464 mm and 425 mm/year (Ausable Bayfield Maitland Valley, 2007) and Tan et al., (2002) found that during the growing season, actual evapotranspiration on agricultural sites in this southwestern Ontario study area ranged from 420 mm to 450 mm. This suggests that the simulation water balance for the study area is in a reasonable magnitude. A monthly comparison of the observed and SWAT simulated stream flow at the monitoring station was made for the calibration (Fig. 3.2) and validation (Fig. 3.3) periods.
Figure 3-2 Comparison of monthly precipitation and average stream flow at the monitoring station for the calibration period (2007 to 2011).

Figure 3-3 Comparison of monthly precipitation and average stream flow at the monitoring station for the validation period (2002 to 2006).
The graphical comparison shows that with the exception of a few months there is generally good agreement between the observed stream flow data and the results of the SWAT simulation. The highest magnitude flows occur during the spring snowmelt, which is typically between February and April each year. During the summer months, flows are quite low and are often reduced to less than 1 m$^3$/s. Evaluation of two commonly used efficiency criteria $r^2$ and $E$ (Table 3.3) resulted in monthly values of 0.87 and 0.86 for the calibration period (2007 to 2011) and 0.70 and 0.70 for the validation period (2001 to 2006). The snowmelt period from February to April is generally well simulated; however, there is poor response from the model between July and September of 2005. Four of the largest daily rainfall events occurring in the 10-year period studied dominates precipitation in these months. During these events, almost 50% of the monthly precipitation falls on one day. It is possible that this precipitation was the result of localized thunderstorms and measurements at the rain gauge did not represent the precipitation over the entire watershed area. This mismatch may also be caused by modelling limitations if only a small portion of the drainage areas is generating flow. If these months are removed from the comparison, the model efficiency improved substantially, and the resulting $r^2$ and $E$ for monthly values rose to 0.78 and 0.77. This is within the acceptable range reported by Moriasi et al., (2007).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Time step</th>
<th>$r^2$</th>
<th>$E$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stream flow</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calibration (2006 to 2011)</td>
<td>Daily</td>
<td>0.65</td>
<td>0.65</td>
</tr>
<tr>
<td></td>
<td>Monthly</td>
<td>0.87</td>
<td>0.86</td>
</tr>
<tr>
<td>Validation (2002 to 2005)</td>
<td>Daily</td>
<td>0.29</td>
<td>0.16</td>
</tr>
<tr>
<td></td>
<td>Monthly</td>
<td>0.70</td>
<td>0.70</td>
</tr>
</tbody>
</table>

Observed sediment data was not available after 2006 so the entire period was used for model calibration. The sediment loading typically follows the same seasonal pattern as stream flows with high loading during the spring snowmelt and low loading rates during the drier summer months. When measured
sediment data is plotted with the simulated load, the simulated data falls within an acceptable range (Fig. 3.4). However, during periods of high flow during the snowmelt period from February to April, measured data is generally not available. This makes it difficult to assess the model’s performance during these critical times. The results of statistical model performance RMSE, CV, and CORR (Table 3.6) were computed for the calibration period (2006 to 2011) and the validation period (2002 to 2005). The results for the calibration period are 7.82, 0.03, and 0.29 respectively. The calculation of sediment load is dependent on both simulated discharge and sediment concentration; as a result, the sediment efficiency criteria are poorer than for flow calibration. Model efficiency may be improved with further calibration; however, there is a risk of over fitting model parameters. To improve the quality of model simulation, land management (e.g., tillage practices) and point discharge data and assumptions were verified during model calibration.

The average sediment loading is 1.1 ton/ha/yr. Van Vliet et al., (1978) completed a study investigating potential sheet erosion losses from cropland in Ontario. They found that sediment losses ranged from 0.9 - 6.9 ton/ha/yr. for corn in rotation. The sediment losses over the study area are in this range and suggest that the results of the modelling exercise are reasonable. It is important to note that SWAT simulates both sediment loading to streams from upland fields using the Modified Universal Soil Loss Equation (MUSLE) and channel bed sediment erosion and deposition. Therefore, the model estimates of sediment loading at the watershed outlet comprise the total sediment loading including both overland and channel sources. Based on literature values, the loading of 1.1 ton/ha/yr. may be an underestimate of the load when channel deposition is considered. Additional monitoring stations inside the watershed would be helpful in determining the partition of the two sources of the sediment loading.
TABLE 3-6 STATISTICAL EVALUATION OF OBSERVED AND SIMULATED SEDIMENT AND NUTRIENT CONCENTRATION IN THE BAYFIELD RIVER WATERSHED.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Time step</th>
<th>RMSE</th>
<th>CV</th>
<th>CORR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sediment Load</td>
<td>Calibration (2002 to 2006)</td>
<td>Sample Days</td>
<td>7.82</td>
<td>0.04</td>
</tr>
<tr>
<td>Phosphorous Load</td>
<td>Calibration (2002 to 2011)</td>
<td>Sample Days</td>
<td>7.97</td>
<td>0.09</td>
</tr>
</tbody>
</table>

Due to the limited number of measured data samples, phosphorous calibration was conducted using data from 2002 to 2011. The measured and observed phosphorous loads are compared in Figure 3.5. Phosphorous loading follows much the same pattern as stream flow and sediment loading. The highest loads occur in the spring during snowmelt and drop to almost zero during the summer months. The model appears to predict the phosphorous loading reasonably well; however, measured samples were not taken during the spring snowmelt when loading is highest. Phosphorous loading is partially dependent on
the flow rate and sediment loading, so the predicted daily discharge and sediment loading have an impact on predicted phosphorous loads (Arnold et al., 2011). The tendency for compounding simulation errors accounts for some of the difficulty achieving good agreement between measured and simulated phosphorous loads. This is evidenced by poor results of statistical model performance RMSE, CV, and CORR (Table 3.6). For the calibration period, these values are 7.97, 0.09, and 0.29 respectively. As with sediment loading, model performance was poorer for phosphorus than for flow calibration. These types of errors are apparent in the summer of 2005 when there is poor agreement between modelled and measured loading (see previous sections for discussion). Input data affecting phosphorous loading such as fertilizer applications and tillage operations were carefully verified to improve model performance.

![Figure 3-5 Comparing simulated and measured phosphorous loading at the monitoring station for the calibration period (2002 to 2011).](image)
On average, the organic phosphorous loading was 0.63 kg/ha. In a study conducted by Spires and Miller (1978a), it was found that sediment-associated phosphorous loading from agricultural watersheds in southern Ontario ranged from 0.14 to 1.09 kg/ha. Studies tend to focus on sediment phosphorous loading so there is less information about dissolved phosphorus available for comparison. However, another study conducted by Miller and Spires (1978b) found that, on average, dissolved phosphorus was 25% - 60% of total phosphorus. After calibration, dissolved phosphorous loading modelled was 0.96 kg/ha or 61% of total phosphorus. This is in the high end of the expected range, but the higher than average concentrations may be the result of extensive tile drainage, which is suspected of increasing the amount of soluble phosphorus from agricultural watersheds (Gentry et al., 2007). Overall, the organic and dissolved phosphorous loading seems reasonable when compared to other studies in the region.

3.3.2 Derivation of Effluent Requirements

Stream-water quality near the Bayfield wastewater treatment plant on the Bayfield River exceeds the Provincial Water Quality Objectives for phosphorus in 2007 (ABCA, 2007). Between 2007 and 2013, the phosphorous concentration improved and dropped below the Objectives (ABCA, 2013). However, the concentration is near the Objective and excesses could be experienced in the future. This is significant because the MOE policy for surface water quality states that “where water quality does not meet the Objectives, it shall not be degraded further and all practical measures must be taken to upgrade the water quality to the Objectives” (MOE, 1994). Unfortunately, further water quality degradation of the Bayfield River may occur if the capacity of the wastewater treatment plant is increased without adopting an integrated watershed-wide wastewater management approach. Consequently, this watershed is an opportune location for exploring the challenges associated with innovative means of achieving the provincial Objectives.
Effect of water and sediment control basins. To evaluate the strengths and limitations of the watershed-level approach for deriving effluent requirements, the SWAT was used to examine the effects of water and sediment control basins on phosphorous loading near the outlet of the Bayfield Wastewater Treatment Plant. Ten existing water and sediment control basins in the lower part of the watershed were included in the final model set-up. This represents the present-day conditions in the watershed. These control basins were then removed to observe the possible effects on water quality.

When all 10 sediment control basins are removed from the watershed, the phosphorous loading directly downstream of the basins increased by 98 kg (7.3%) in total (Table 3.7). The greatest increase, 38 kg (>400%), occurred where two control basins were built in series. There was, however, only a slight change in the monthly average phosphorous loading near the watershed outlet. This suggests that the existing water and sediment control basins in the watershed may be having an effect on stream water quality with respect to phosphorous loading, but the impact is marginal at the watershed scale.

| TABLE 3-7 DOWNSTREAM EFFECT OF CONTROL BASINS ON PHOSPHOROUS CONCENTRATION IN THE BAYFIELD RIVER WATERSHED, ABSOLUTE AND % CHANGE FROM PRESENT-DAY SCENARIO |
|---------------------------------|-----------------|-----------------|
| Absolute Change (kg)            | Percent Change (%) |
| All basins combined             | 98.2            | 7.33            |
| Maximum (downstream of 2 basins)| 38.4            | 462             |
| Average                         | 14.0            | 7.33            |

The area draining to the modelled sediment control basins is 178 ha, which is less than 1% of the total watershed area. These effects may be more pronounced if more control basins, or additional agricultural conservation practices, were included in the scenario. Nonetheless, these results show that the impact of water and sediment control basins may be quantified using the control basin module developed to extend the capabilities of the SWAT. Simulated water quality information could improve the estimation of non-point
source effects on surface water quality for integrated wastewater management programs.

**Effect of climate change.** A number of climate change scenarios were explored. Climate change predictions, provided for southern Ontario by the Ministry of Natural Resources (2007b), were then used to assess the impact of climate change on phosphorous loading. The predictions show a 10% decrease in summer and winter precipitation. This was simulated by reducing the historical summer and winter precipitation by the projected 10%. This change had a noticeable effect on monthly ten-year average stream flow and phosphorous loading (Fig. 3.6).

The phosphorous load decreased by almost 15% annually with the largest decreases occurring during the spring. However, the decline in stream flow has the overall effect of increasing phosphorous concentration downstream of the wastewater treatment plant (Table 3.8). These changes, which may affect aquatic life and other water users, emphasize the importance of considering climate change effects when deriving effluent requirements. Note that changes in the intensity and timing of events were not considered when adjusting precipitation inputs for investigating climate change and this could have significant implications on the model results. It is also important to note that a number of datasets for regional climate change are available from Environment Canada (2013), but care must be taken when selecting, as recent studies have shown that Canadian Regional Climate Model simulated precipitation and temperature data is considerably different from the observation (Rahaman et al., 2012).

<table>
<thead>
<tr>
<th>TABLE 3-8 EFFECT OF CLIMATE CHANGE ON PHOSPHOROUS CONCENTRATION DOWNSTREAM OF THE BAYFIELD WASTEWATER TREATMENT PLANT, ABSOLUTE AND % CHANGE FROM PRESENT DAY SCENARIO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Summer (May 1 to Oct. 31)</td>
</tr>
<tr>
<td>Winter (Nov. 1 to April 30)</td>
</tr>
<tr>
<td>Annual Average</td>
</tr>
</tbody>
</table>
Implementation challenges. This study shows that watershed-level models can be a valuable tool for deriving effluent requirements. This is supported by several studies where continuous simulation models like the SWAT have been found useful for analyzing long-term effects of watershed management practices (examples can be found in Gassman et al., 2007). However, some challenges arose while setting up the model. The first issues pertain to data from wastewater treatment plants. Effluent quality and flow data can be easily obtained from plant owners and operators, but the data must often be extracted from hard-copy reports that often contain errors or omissions. Identifying errors and transcribing data many years after the reports are produced is time consuming. As suggested by McDonald and DiLabio (2013), implementing data storage and verification standards would alleviate some of these issues. Additionally, not all parameters required for modelling were collected at wastewater treatment plants in the study.
area. For example, total phosphorus was measured in the treated effluent, but
the relative amounts of organic and mineral phosphorus was estimated. For
integrated wastewater management programs, it will be important to ensure that
data required for modelling is collected and reported at the plants.

The second set of issues relates to land use and land management data. There are a number of land use datasets available that provide different levels of
detail and focus on different types of land cover (e.g., forest, agriculture). The
ability to quickly merge these datasets and use standardized look-up tables to
link provincial datasets to land cover databases in modelling programs would
save time and provide a greater level of consistency when watershed-modelling
efforts are undertaken throughout the province. As well, datasets such as the
Agricultural Resources Inventory (OMAFRA, 1983) provide valuable information
on cropping systems that could be used to develop built-in management rotations
(e.g., corn-soybeans-wheat) in modelling programs such as the SWAT, which
only have default management practices for single crop types (Arnold, 2011).

Another area requiring improvement is the water and sediment control basin
module. Prior to the creation of this module, the SWAT was not capable of
modelling water and sediment control basins. This is a new module, so there is
potential to make it easier to use by integrating it into the model interface. It
would also be beneficial to conduct studies to validate the modelled results with
measurements in the field.

Lastly, but perhaps most importantly, sediment and phosphorous monitoring
data was only available during the non-winter months. This presents a significant
challenge for model calibration and validation as high-predicted loads during
spring snowmelt could not be compared to measured data. Implementing long-
term monitoring programs with year-round data collection at outlet and inside
stations may be necessary to address this issue.

3.4 Conclusion

Presently, integrated wastewater management programs use site-specific
calculations or pre-determined nutrient reductions for practices to estimate
reductions in nutrient losses from non-point sources to determine exchangeable reduction credits (Selman et al., 2009). While useful for determining financial compensation for land users, this approach provides limited insight into the watershed level effects of conservation practices and into the impact of short- and long-term weather variability on water quality. Understanding these effects is important for satisfactorily deriving effluent requirements. It has been suggested that watershed-level models may address these issues; this modelling case study, testing the watershed-level approach, provides insight into the opportunities and challenges that come from using watershed-level models for deriving requirements.

Watershed modelling allows consideration of the effects of various conservation practice and climate scenarios; however, confidence in the modelled results is limited because of inadequate sediment and phosphorus data for informing the model calibration. This means that to use watershed-level models for decision-making, water quantity and quality data must be collected at the outlet and inside stations for storm events and throughout the winter months, particularly during the snowmelt period. There are also a number of other challenges related to wastewater treatment plant data, land use and cropping system mapping, and the development of modules for specific conservation practice that must be addressed. Overall, however, it appears advantageous to use a tool, such as watershed-level models, to evaluate the effects of water and sediment control basins and the impact of climate change for the purposes of deriving effluent requirements in Ontario.
References


CHAPTER 4

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 Overview

The landscape of wastewater management is changing. New integrated approaches for improving surface water quality throughout Ontario require practitioners and regulators to think beyond the wastewater treatment plant. Innovation in water quality improvement calls for a watershed-level approach to determine effluent requirements for wastewater treatment plants.

This study examines the appropriateness and feasibility of three approaches for deriving effluent requirements in Ontario. It was found that when there is a need to consider complex interaction and ecological processes, watershed-level modelling is the best available approach for deriving effluent requirements, despite the additional cost and expertise required. However, the survey and modelling case study conducted for the project reveal a number of opportunities to improve this approach. This section summarizes the findings of this research as well as the recommendations for policy makers and practitioners in this field.

4.2 Summary of Findings

The major findings of this critical evaluation of three approaches for deriving effluent requirements for wastewater treatment plants in Ontario are as follows.

- Watershed-level modelling is the best available approach in situations where there is a need to extend the model to obtain information about the effects of pollution abatement strategies or climate change.
- When cost is a major consideration and limited modelling expertise is available, the mass balance method may be the most appropriate approach available for deriving effluent requirements.
- There is general agreement among practitioners that further testing and validation of approaches is needed as are modelling and monitoring enhancements and tools to make data more accessible.
- There appears to be a need to develop or incorporate tools that consider cumulative loadings and ecological effects into the approach for deriving effluent requirements for wastewater treatment plants.
- It may be advantageous to evaluate the effects of water and sediment control basins and other agricultural conservation practices as well as the impact of climate change for the purposes of deriving effluent requirements.
- To use watershed-level models for decision-making, water quality data must be collected at the outlet and inside stations more frequently and throughout the winter months, particularly during the snowmelt period.
- The level of effort and expertise required to set up and run the model presents a significant challenge.

4.3 Recommendations and Research Opportunities

As the number of integrated wastewater management programs in Ontario increases, there is a need to address challenges related to water quality and effluent data, land use and cropping system mapping, the development of modules for specific conservation practice, and the overall level of collaboration among stakeholders. Table 4.1 presents recommendations and future research areas for policy makers, researchers, and practitioners in this field.
<table>
<thead>
<tr>
<th>Recommendation</th>
<th>Rationale</th>
<th>Stakeholders</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collect stream water quality data at outlet and at inside stations during</td>
<td>This data is infrequently collected at provincial water quality monitoring stations; however, this data is needed to confidently set up watershed-level models.</td>
<td>Gov’t agencies</td>
</tr>
<tr>
<td>storm events and throughout the winter months, particularly during spring</td>
<td></td>
<td></td>
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<tr>
<td>snowmelt.</td>
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<td></td>
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<tr>
<td>Ensure that sampling requirements at wastewater treatment plants provide the</td>
<td>Total phosphorus is typically measured, but relative amounts of organic and mineral phosphorus are not measured. These are required inputs into watershed-level models and better results may be obtained with measurements rather than estimates.</td>
<td>Regulators Consultants</td>
</tr>
<tr>
<td>information required for setting up the watershed-level model selected.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Implement data verification standards for annual wastewater treatment plant</td>
<td>Transcription errors and missing data were found in data provided by two of three plant owners. This can negatively affect model output, if not found and corrected.</td>
<td>Plant operators</td>
</tr>
<tr>
<td>reports to ensure that data is complete and accurate.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Link provincial and regional GIS mapping of land use and cropping systems to</td>
<td>Having standard look-up tables will save practitioners time and help to ensure consistency when provincial mapping products are used.</td>
<td>Gov’t agencies Researchers</td>
</tr>
<tr>
<td>crop databases in watershed-level models.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop land management scenarios that represent the common cropping systems</td>
<td>The SWAT model includes default management practices for single crops, but the user must define specific crop rotations and corresponding management practices.</td>
<td>Researchers</td>
</tr>
<tr>
<td>in Ontario (e.g., corn – soybeans – wheat) and integrate these into</td>
<td></td>
<td></td>
</tr>
<tr>
<td>watershed-level models.</td>
<td></td>
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</tbody>
</table>
Further develop and validate water and sediment control basin module and other conservation practices modules for watershed-level modelling applications. Integrating control basin and other conservation practice modules in model interfaces would make it easier to include a larger number of control basins and other conservation practices in model set-up. As well, validating model results with measured data would improve confidence in model.

Develop a decision-making tool that could help practitioners select the most appropriate approach or approaches for deriving effluent requirements on a case-specific basis. There are unique advantages to using the various tools available. Providing practitioners with the information needed to make informed selections when deriving effluent requirements is important for regulation.

Increase collaboration between watershed managers and municipal wastewater treatment plant owners. Managing wastewater at the watershed scale requires sharing of information and knowledge from a variety of sources. Increased collaboration will aid in this process.

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4.4 Common Themes and Concluding Remarks

Understanding the effects of various conservation practices and climate scenarios is important for satisfactorily deriving effluent requirements. It has been suggested that watershed-level models may address these issues; this survey and modelling case study, testing the watershed-level approach, provide insight into the opportunities and challenges that come with using watershed-level models for deriving requirements. This study shows that until advancements are made, compromise is necessary when selecting an approach for deriving effluent requirements, as no one approach meets all the evaluation criteria. However, the necessary steps toward improvement are relatively clear and require multi-disciplinary input.
There are three key themes emerging in both the survey and the modelling case study: the need for further testing and validation of approaches for deriving effluent requirements, modelling and monitoring enhancements to improve the characterization of receiving bodies, and implementation of tools that make data easy to access and use. These are the three most important ranked next steps in the survey and they underpin the recommendations emerging from the modelling case study. Overall, in spite of the need for advancements, it appears advantageous to use a tool, such as watershed-level models, to evaluate the effects of water and sediment control basins and the impact of climate change for the purposes of deriving effluent requirements in Ontario.

As we broaden our definition of wastewater treatment, we open the door to innovation and new opportunities to improve the water quality in our lakes and streams. However, confidently regulating these innovations is paramount to safeguarding human health and the environment. This study presents a path to overcoming some of these regulatory challenges so that surface water quality improvements can be realized throughout the province of Ontario.
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to be presented at the WEAO conference.

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b. Audio or video tape recordings of the oral presentation for sale during and after the conference;

c. Copies of the paper for inclusion in any proceedings of the conference that might be printed and sold or included within the WEAO web site; and,

d. Individual copies of the paper for sale during and after the conference

I understand that the paper may also be accepted for subsequent publication in the magazine of the Association. Journal of Environmental Engineering and Science and/or Environmental Science and Engineering Magazine.

Signature Jane Simmons Date Feb. 6, 2013

(Adapted from the WEF Copyright Release Form)

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APPENDIX B: SURVEY DOCUMENTS
PART #1: CRITERIA WEIGHTING QUESTIONNAIRE

Deriving Effluent Requirements Using a Watershed-Level Model

Researchers at the University of Guelph are conducting a study to gain a better understanding of how watershed-level modelling could be used for determining effluent requirements for wastewater treatment plants. In order to evaluate the merits of the 7Q20 approach\(^2\) and the proposed watershed-level modelling approach\(^3\), both types of models will be evaluated using a set of criteria. The criteria focus on technical, environmental, and regulatory issues. To emphasize the significance of certain criterion in the evaluation, a weighting between 1 and 3 will be assigned to each criterion. The weighting exercise will ensure that factors having a higher value to stakeholders will have a greater influence on the ranking of the two models.

Below is a description of the criteria that are being considered. We would appreciate your input to help determine the significance of the proposed evaluation criteria. Please complete the survey and return it to our research group by October 25, 2012 via email or mail.

Personal Information (Optional)

Name and affiliation: ________________________________

\(^2\) The low flow statistic 7Q20 (the minimum 7-day average flow with a recurrence period of 20 years) is typically used as the design basis for the receiving stream in the development of effluent requirements for continuous point source discharges. It is described in Procedure B-1-5 Deriving receiving-water based, point-source effluent requirements for Ontario waters (MOEE, 1994)

\(^3\) Watershed models, such as the Soil and Water Assessment Tool (SWAT) and the Generalized Watershed Loading Function (GWLF), are computer-based simulation models. These models simulate the long-term effects of watershed practices and processes.
Evaluation Criteria Weighting

Please weight the importance of these criteria to you (see description of ratings below):

<table>
<thead>
<tr>
<th>Weight</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Criterion is critical</td>
</tr>
<tr>
<td>2</td>
<td>Criterion is very important</td>
</tr>
<tr>
<td>1</td>
<td>Criterion is important</td>
</tr>
<tr>
<td>0</td>
<td>Criterion is unimportant</td>
</tr>
</tbody>
</table>

PART #1: Technical Feasibility

*Technical Risk and Acceptance:* Evaluates the degree to which a model has been tested and proven. This criterion will be measured in terms of each model's performance history.

*Availability of data:* Evaluates the ease at which the required data can be obtained. This criterion will be measured in terms of the type, format, and amount of data required for modelling.

*Expertise required:* Evaluates the level of training and experience required to use a model. This criterion will be measured in terms of the level of model complexity and by the amount of new technology introduced.

PART #2: Environmental Protection

*System Integrity:* Evaluates how well the model enables stakeholders to understand the complex interactions between activities. This criterion will be measured in terms of the model's ability to incorporate consideration of human-ecological relations.

*Precaution and Adaptation:* Evaluates how well the model enables stakeholders to avoid risks and manage for adaptation. This criterion will be measured in terms of the model's ability to use incomplete information, design for uncertainty, ensure the practicality of back-up alternatives, and establish mechanisms for effective monitoring.

PART #3: Regulatory Issues

*Current Regulatory Constraints:* Evaluates how well the model complies with current regulations. This criterion will be measured in terms of the model's compliance with current regulations.

*Anticipated Regulatory Constraints:* Evaluates how well the model complies with proposed or anticipated regulations. This criterion will be measured in terms of the model's compliance with anticipated regulations.
Additional Comments or Input

If there are any criterion that you think are missing, please describe them below (include weighting) or attach an additional document.

If there is any additional information that you think would be useful to this study or additional comments you wish to make, please provide your comments below or attach an additional document.

Thank you for your time and consideration. If you have any questions regarding this questionnaire, please contact the researchers: University of Guelph Watershed Evaluation Group, Department of Geography, 50 Stone Road East, Guelph, Ontario, N1G 2W1. Telephone (519) 824-4120 x58563. Attention: Jane Simmons, simmonse@uoguelph.ca

Comments and information collected by the University of Guelph Watershed Evaluation Group will assist in decision making pertaining to the model evaluation criteria. Personal information and comments provided to the University of Guelph Watershed Evaluation Group will remain confidential unless prior consent has been obtained.
PART #2: DETAILED EVALUATION

Comparison of Approaches for Deriving Effluent Requirements

Thank you for participating in the first part of this survey. Based on the responses, three different approaches to set discharge limits for wastewater treatment plants have been defined and the criteria used to compare these approaches have been finalized. Once this evaluation is complete, the results could be used on a case-by-case basis to support the selection of an appropriate approach for determining discharge limits. This information could also direct the development of tools to set wastewater limits.

Below is a description of the approaches and the criteria. We would appreciate you indicating your rating of the approaches in the categories provided. Please complete the survey and return it to our research group by January 7, 2012 via email or mail.

Personal Information (Optional)

Name and affiliation: __________________________________________
Phone Number: ________________________________________________
Street Address: _______________________________________________
Approaches for deriving effluent requirements

The assessment for discharge approvals has typically been conducted using simple mass balance modelling. Increasingly, however, more complex modelling approaches are being implemented. Based on survey comments three general approaches have been defined for this study:

**Mass Balance Modelling** – In this approach background concentrations and flow are determined as well as the effluent concentration and flow. A low flow statistic (i.e. 7Q20 flow) is then used to evaluate the effect of discharge on surface water quality and/or quantity.

**Watershed Modelling** – In this approach a dynamic simulation model is set up which includes the effects of multiple point and non-point sources. This model is then applied to predict stream flow and water quality which can be used to evaluate the effect of discharge on surface water quality and/or quantity. Although many watershed level models exist [e.g. Water Quality Simulation Program (WASP7), Environmental Fluid Dynamics Code (EFDC), Soil Water and Assessment Tool (SWAT), ArcView Generalized Water Loading Function (AVGWLF)], for this survey you are asked to consider watershed level modelling generally.

**Combined Approach** – In this approach watershed modelling can be applied to predict stream flow and water quality, then the watershed modelling outputs can be used in conjunction with the mass balance modelling approach (i.e. 7Q20) to evaluate the effect of discharge on surface water quality and/or quantity.

**Description of criteria**

The detailed evaluation will compare each of the approaches using a set of criteria. The criteria focus on the characteristics of the approach and how the approach can be applied. The significance of certain criteria in the evaluation will be application specific so a weighting has not been assigned. In the future, weights could be used to ensure that factors having a higher value to stakeholders have a greater influence on the selection of an approach. Table 3.1 lists the evaluation categories and selection criteria.
Table 3.1
Evaluation Categories and Criteria

<table>
<thead>
<tr>
<th>Category</th>
<th>Selection Criteria</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characteristics</td>
<td>Technical risk and acceptance</td>
<td>Has been tested and proven</td>
</tr>
<tr>
<td></td>
<td>Receiver characterization</td>
<td>Performs well when it is difficult to characterize the receiver</td>
</tr>
<tr>
<td></td>
<td>Availability of data</td>
<td>Requires readily available or easy to obtain data</td>
</tr>
<tr>
<td></td>
<td>Transferability of the approach</td>
<td>Transferable to different types of watersheds (e.g. small/large)</td>
</tr>
<tr>
<td></td>
<td>Expertise required</td>
<td>Easy to use and does not require highly specialized experience</td>
</tr>
<tr>
<td></td>
<td>Capital and operational costs</td>
<td>Low cost to set-up and use</td>
</tr>
<tr>
<td>Applications</td>
<td>Climate change assessment</td>
<td>Can be used to assess the impact of climate change</td>
</tr>
<tr>
<td></td>
<td>Cumulative loading evaluation</td>
<td>Can be used to evaluate the effect of cumulative loadings</td>
</tr>
<tr>
<td></td>
<td>Impacts on ecological processes</td>
<td>Can consider impacts on ecological processes</td>
</tr>
<tr>
<td></td>
<td>Effects of abatement strategies</td>
<td>Can simulate the effects of pollution abatement strategies</td>
</tr>
</tbody>
</table>

**CHARACTERISTICS:**

*Technical risk and acceptance*
This criterion will be used to evaluate the degree to which an approach has been tested and proven. This criterion will be measured in terms of each approach’s performance history.

*Receiver characterization*
This criterion will be used to evaluate how well the approach performs in the absence of long-term historical records for flow and water quality or in cases where it is difficult to characterize conditions in the receiving body (e.g. systems regulated by large reservoirs).

*Availability of data*
This criterion will be used to evaluate the ease with which the required data can be obtained. This criterion will be measured in terms of the type, format, and amount of data required as well as how easily it can be acquired.

*Transferability of the approach*
This criterion will be used to evaluate how well the approach can be applied to watersheds of varying size (i.e. small/large) and in different regions of Ontario (i.e. southern/northern).

*Expertise required*
This criterion will be used to evaluate the level of training and experience required to use an approach. This criterion will be measured in terms of the level of complexity and by the amount of new technology introduced.
Capital and operational costs
The capital investment cost and operational costs of each approach will be compared. Potential revenue streams may be included in the cost evaluation.

APPLICATIONS:
Climate change assessment
This criterion will be used to evaluate how well the approach enables stakeholders to examine climate change impacts.

Cumulative loading assessment
This criterion will be used to evaluate how well each approach can be used to assess cumulative loads.

Impacts on ecological processes
This criterion will be used to evaluate the approach’s ability to incorporate ecological processes and life histories.

Effects of abatement strategies
This criterion will be used to evaluate the degree to which abatement strategies (e.g. best management practices) can be simulated.

Detailed Evaluation
On a scale from 1 (very poorly) to a scale of 5 (very well), rate how well each approach meets the selection criteria.

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>5</td>
<td>Very well</td>
</tr>
<tr>
<td>4</td>
<td>Well</td>
</tr>
<tr>
<td>3</td>
<td>Neither well or poorly</td>
</tr>
<tr>
<td>2</td>
<td>Poorly</td>
</tr>
<tr>
<td>1</td>
<td>Very poorly</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PART #1: Characteristics</th>
<th>Mass Balance</th>
<th>Watershed Model</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>The approach has been highly tested and is proven.</td>
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<tr>
<td>The approach performs well when it is difficult to characterize the receiver.</td>
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<td></td>
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<tr>
<td>The approach requires readily available or easy to obtain data.</td>
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<tr>
<td>The approach is transferable to different types of watersheds.</td>
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<tr>
<td>The approach is easy to use and does not require specialized experience</td>
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<td></td>
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<tr>
<td>The approach has a low cost to set-up and use</td>
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</table>

<table>
<thead>
<tr>
<th>PART #2: Applications</th>
<th>Mass Balance</th>
<th>Watershed Model</th>
<th>Combined</th>
</tr>
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<tbody>
<tr>
<td>The approach can be used to assess the impacts of climate change</td>
<td></td>
<td></td>
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<tr>
<td>The approach can be used to evaluate the effect of cumulative loadings</td>
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<td></td>
</tr>
<tr>
<td>The approach can consider impacts on ecological processes</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>The approach can simulate the effects of pollution abatement strategies</td>
<td></td>
<td></td>
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</tbody>
</table>
Follow-up Questions

Rate from 1 (not important) to 5 (very important) how important each of these steps that could be taken to improve approaches for the derivation of effluent requirements for Ontario waters are.

Place an ‘x’ next to the three most important.

<table>
<thead>
<tr>
<th>Steps</th>
<th>Rating</th>
<th>Top 3</th>
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</thead>
<tbody>
<tr>
<td>Further testing and validation of approaches for deriving effluent requirements</td>
<td></td>
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<tr>
<td>Modelling and monitoring enhancements to improve characterization of receiving bodies</td>
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<tr>
<td>Implementation of tools that makes data easy to access</td>
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<tr>
<td>Development of approaches for deriving requirements in small or northern watersheds</td>
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<tr>
<td>Specialized training for practitioners</td>
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<tr>
<td>Establishment of programs to offset the cost of expensive approaches</td>
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<td>Other (specify):</td>
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</tbody>
</table>

Rate from 1 (not important) to 5 (very important) how important each of these additional considerations are when deriving effluent requirements for Ontario waters.

<table>
<thead>
<tr>
<th>Additional Considerations</th>
<th>Rating</th>
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</thead>
<tbody>
<tr>
<td>The approach can be used to assess the impacts of climate change</td>
<td></td>
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<tr>
<td>The approach can be used to evaluate the effects of cumulative loadings</td>
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<tr>
<td>The approach can consider impacts on ecological processes</td>
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<tr>
<td>The approach can simulate the effects of pollution abatement strategies</td>
<td></td>
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<tr>
<td>Other (specify):</td>
<td></td>
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</tbody>
</table>

Additional Comments or Input

If there is any additional information that you think would be useful to this study or additional comments you wish to make, please provide your comments below or attach an additional document.
Thank you for your time and consideration. If you have any questions regarding this questionnaire, please contact the researchers: University of Guelph Watershed Evaluation Group, Department of Geography, 50 Stone Road East, Guelph, Ontario, N1G 2W1. Telephone (519) 824-4120 x 58563. Attention: Jane Simmons, simmonse@uoguelph.ca.

Comments and information collected by the University of Guelph Watershed Evaluation Group will assist in decision making pertaining to the research study. Personal information and comments provided to the University of Guelph Watershed Evaluation Group will remain confidential unless prior consent has been obtained.