Reporting History

<table>
<thead>
<tr>
<th>Version No</th>
<th>Date</th>
<th>Status</th>
<th>Comments</th>
<th>Reviewed by</th>
<th>Approved by</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>30-01-06</td>
<td>Draft</td>
<td>To LSRCA for review.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>31-05-06</td>
<td>FINAL</td>
<td>To LSRCA</td>
<td>F.J.L.D.</td>
<td>R.B.N.</td>
</tr>
</tbody>
</table>

For further information please contact

Rob Nairn, Ph.D. or Fiona Duckett, M.Sc., P.Eng.
905-845-5385

This report was prepared by W.F. Baird & Associates Coastal Engineers Ltd. for Lake Simcoe Region Conservation Authority. The material in it reflects the judgment of Baird & Associates in light of the information available to them at the time of preparation. Any use which a Third Party makes of this report, or any reliance on decisions to be made based on it, are the responsibility of such Third Parties. Baird & Associates accepts no responsibility for damages, if any, suffered by any Third Party as a result of decisions made or actions based on this report.
# TABLE OF CONTENTS

1 INTRODUCTION ................................................................................................................................. 1
  1.1 Scope of Work................................................................................................................................ 1
  1.2 Project Objectives .......................................................................................................................... 1

2 BACKGROUND ...................................................................................................................................... 3
  2.1 In-Lake Processes .......................................................................................................................... 3
  2.2 Watershed Processes ..................................................................................................................... 4
  2.3 New Growth and Implications to Water Quality ........................................................................ 4

3 DATA COLLECTION ............................................................................................................................... 6
  3.1 Bathymetry ...................................................................................................................................... 6
  3.2 Climate .......................................................................................................................................... 6
  3.3 River Hydrology ............................................................................................................................ 8
  3.4 Lake Levels and Temperature ....................................................................................................... 9
  3.5 Water Quality ................................................................................................................................ 10
    3.5.1 Load Data............................................................................................................................. 10
    3.5.2 Monitoring Data .................................................................................................................... 11
  3.6 Vertical Profile of Current Velocity .............................................................................................. 12

4 MODEL SELECTION AND OVERVIEW .............................................................................................. 23
  4.1 Model Selection............................................................................................................................ 23
  4.2 Model Overview............................................................................................................................ 23

5 MODEL SETUP ................................................................................................................................... 27
  5.1 Model Domain and Grids .............................................................................................................. 27
  5.2 Boundary Conditions ................................................................................................................... 27
    5.2.1 Water Surface ......................................................................................................................... 27
      5.2.1.1 Wind............................................................................................................................... 27
      5.2.1.2 Air Temperature and Evaporation .................................................................................. 28
      5.2.1.4 Precipitation and Rain Droplet Temperature ................................................................. 29
      5.2.1.4 Cloud Cover .................................................................................................................... 29
    5.2.2 Lake Bottom ............................................................................................................................. 29
    5.2.3 Inflows and Outflows ............................................................................................................. 29
      5.2.3.1 Discharge ......................................................................................................................... 29
      5.2.3.2 Water Temperature in Rivers ......................................................................................... 30
      5.2.3.2 Lake Outflow .................................................................................................................. 30
  5.3 Nutrient Loading ............................................................................................................................ 31
# Table of Contents

5.4 Initial Conditions.................................................................35

6 MODEL CALIBRATION..............................................................44

6.1 Hydrodynamic Model ..............................................................44

6.1.1 Lake Level.............................................................................44

6.1.2 Currents .................................................................................44

6.1.3 Temperature............................................................................45

6.2 Water Quality Calibration .........................................................46

6.2.1 Phosphorus at MOE Stations ..................................................47

6.2.2 Nitrogen (at MOE Stations) ....................................................48

6.2.3 Chlorophyll “a” (at MOE Stations) ..........................................49

6.2.4 P,N and Chlorophyll “a” (at Intakes) .......................................50

6.2.5 Secchi Depth ...........................................................................50

6.2.6 Dissolved Oxygen.................................................................51

7 MODEL SIMULATIONS OF PRESENT AND FUTURE CONDITIONS ..........96

7.1 Present Conditions Scenario......................................................96

7.2 Future Scenario .........................................................................98

8 MONITORING RECOMMENDATIONS...........................................137

8.1 Water and Sediment Quality Monitoring ..................................137

8.2 Sampling for Extension to Entire Year Model ............................139

8.3 Meteorological Data Inputs......................................................140

8.4 Ecological Surveys....................................................................140

8.4.1 Zebra mussels .................................................................140

8.4.2 Aquatic Vegetation.............................................................141

9.1 Summary and Conclusions.....................................................142

9.2 Recommendations for Numerical Model Input and Process Refinements........144

REFERENCES .....................................................................................147

APPENDIX A - Temperature Calibration Results At MOE Stations

APPENDIX B - DO Calibration Results At MOE Stations

APPENDIX C – Model Animations
# TABLE OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Estimated Phosphorus Loadings to Lake Simcoe for 1998</td>
<td>5</td>
</tr>
<tr>
<td>3.1</td>
<td>Bathymetry and Shoreline Digitized from 1957 Field Sheet</td>
<td>13</td>
</tr>
<tr>
<td>3.2</td>
<td>Map showing Climate Stations in Project Area</td>
<td>14</td>
</tr>
<tr>
<td>3.3</td>
<td>Lake Simcoe Watershed and Subwatersheds</td>
<td>15</td>
</tr>
<tr>
<td>3.4</td>
<td>Daily Flow in the Holland River (1990 to present)</td>
<td>16</td>
</tr>
<tr>
<td>3.5</td>
<td>Daily Mean Water Level on Lake Simcoe</td>
<td>17</td>
</tr>
<tr>
<td>3.6</td>
<td>Daily Temperature at Innisfil Intake</td>
<td>18</td>
</tr>
<tr>
<td>3.7</td>
<td>Seasonal Variation in Temperature Profile at MOE Station K42</td>
<td>19</td>
</tr>
<tr>
<td>3.8</td>
<td>Map showing Locations of MOE Monitoring Stations and Water Treatment Intakes</td>
<td>20</td>
</tr>
<tr>
<td>3.9</td>
<td>Map showing Location of ADCP</td>
<td>21</td>
</tr>
<tr>
<td>3.10</td>
<td>ADCP before Deployment</td>
<td>22</td>
</tr>
<tr>
<td>4.1</td>
<td>Conceptual Model of Ecological Processes in Lake Simcoe</td>
<td>25</td>
</tr>
<tr>
<td>4.2</td>
<td>Process Model of Ecological Processes in Lake Simcoe</td>
<td>26</td>
</tr>
<tr>
<td>5.1</td>
<td>Model Bathymetry Grid</td>
<td>37</td>
</tr>
<tr>
<td>5.2</td>
<td>Impact of Constant and Spatially Varied Wind Data on Temperature Profile</td>
<td>38</td>
</tr>
<tr>
<td>5.3</td>
<td>Comparison of Wind Speed at Lagoon City, Barrie, and the EC Buoy</td>
<td>39</td>
</tr>
<tr>
<td>5.4</td>
<td>Air Temperature Comparison between Lagoon City Station, Barrie (Auto)</td>
<td>40</td>
</tr>
<tr>
<td>5.5</td>
<td>Map showing Locations of Rivers and Streams in the Watershed</td>
<td>41</td>
</tr>
<tr>
<td>5.6</td>
<td>Comparison of Air and Stream Temperature for the Holland River</td>
<td>42</td>
</tr>
<tr>
<td>5.7</td>
<td>Relationship used to Define Stream Temperature</td>
<td>43</td>
</tr>
<tr>
<td>6.1</td>
<td>Comparison of Measured and Modeled Lake Levels at Jacksons Point Gauge</td>
<td>55</td>
</tr>
<tr>
<td>6.2</td>
<td>Current Comparison between 2005 Measured ADCP data and 2002 Model Predictions at the Surface</td>
<td>56</td>
</tr>
<tr>
<td>6.3</td>
<td>Current Comparison between 2005 Measured ADCP data and 2002 Model Predictions at 10 m below the Surface</td>
<td>57</td>
</tr>
<tr>
<td>6.4a</td>
<td>Temperature Profile Comparison at C6</td>
<td>58</td>
</tr>
<tr>
<td>6.4b</td>
<td>Temperature Profile Comparison at C6</td>
<td>59</td>
</tr>
<tr>
<td>6.4c</td>
<td>Temperature Profile Comparison at C6</td>
<td>60</td>
</tr>
<tr>
<td>6.5a</td>
<td>Temperature Profile Comparison at K42</td>
<td>61</td>
</tr>
<tr>
<td>6.5b</td>
<td>Temperature Profile Comparison at K42</td>
<td>62</td>
</tr>
<tr>
<td>6.5c</td>
<td>Temperature Profile Comparison at K42</td>
<td>63</td>
</tr>
<tr>
<td>6.6</td>
<td>Modeled and Measured Temperature Data at Sutton Intake</td>
<td>64</td>
</tr>
<tr>
<td>6.7</td>
<td>Modeled and Measured Temperature Data at Beaverton Intake</td>
<td>64</td>
</tr>
<tr>
<td>6.8</td>
<td>Modeled and Measured Temperature Data at Ramara Intake</td>
<td>65</td>
</tr>
<tr>
<td>6.9</td>
<td>Modeled and Measured Temperature Data at Innisfil Intake</td>
<td>65</td>
</tr>
<tr>
<td>6.10</td>
<td>Modeled and Measured Temperature Data at Keswick Intake</td>
<td>66</td>
</tr>
<tr>
<td>6.11</td>
<td>Modeled and Measured Temperature Data at Lagoon City Intake</td>
<td>66</td>
</tr>
<tr>
<td>6.12</td>
<td>Modeled and Measured Temperature Data at EC Buoy e45151</td>
<td>67</td>
</tr>
<tr>
<td>6.13</td>
<td>Modeled and Measured Temperature Data at Keswick Intake</td>
<td>68</td>
</tr>
<tr>
<td></td>
<td>Phosphorus Concentrations at MOE Stations in 2001</td>
<td></td>
</tr>
</tbody>
</table>
Figure 6.14  Model Calibration showing Predicted and Measured TP ........................................ 69
Figure 6.15a Model Calibration showing Predicted and Measured TP ......................................... 70
Figure 6.15b Model Calibration showing Predicted and Measured TP ......................................... 71
Figure 6.16  Total Nitrogen Concentrations at MOE Stations in 2001 ........................................... 72
Figure 6.17a Model Calibration showing Predicted and Measured TN ........................................... 73
Figure 6.17b Model Calibration showing Predicted and Measured TN ........................................... 74
Figure 6.17c Model Calibration showing Predicted and Measured TN ........................................... 75
Figure 6.18  Chlorophyll “a” Concentrations at MOE Stations in 2001 ........................................... 76
Figure 6.19  Chlorophyll “a” comparison between modeled and measured results at MOE Stations E51, K46, S15 and K42 ............................................................ 77
Figure 6.20a Chlorophyll “a” comparison between modeled and measured results at MOE Stations K39, C9, C6 and C1 .............................................................................. 78
Figure 6.20b Chlorophyll “a” comparison between modeled and measured results at MOE Stations K39, C9, C6 and C1 .............................................................................. 79
Figure 6.21  Solar Radiation (PAR) Variation over the Spring, Summer and Fall of 2001 ................. 80
Figure 6.22  Temperature variation at Lagoon City for 2001 ............................................................ 81
Figure 6.23  Modeled and Measured Chlorophyll “a”, TP & TN at Intakes ....................................... 82
Figure 6.24  Modeled and Measured Chlorophyll “a”, TP & TN at Intakes ....................................... 83
Figure 6.25  Modeled and Measured Chlorophyll “a”, TP & TN at Intakes ....................................... 84
Figure 6.26a  Secchi Depth Calibration ............................................................................................ 85
Figure 6.26b  Secchi Depth Calibration ............................................................................................ 86
Figure 6.26c  Secchi Depth Calibration ............................................................................................ 87
Figure 6.27  Measured Temperature and DO at MOE Station C6 (Cook Bay) ................................. 88
Figure 6.28a Dissolved Oxygen Level Profile Comparison at C6 .................................................... 89
Figure 6.28b Dissolved Oxygen Level Profile Comparison at C6 .................................................... 90
Figure 6.28c Dissolved Oxygen Level Profile Comparison at C6 .................................................... 91
Figure 6.29  Measured Temperature and DO at MOE Station K42 (Kempenfelt Bay) ......................... 92
Figure 6.30a Dissolved Oxygen Level Profile Comparison at K42 .................................................. 93
Figure 6.30b Dissolved Oxygen Level Profile Comparison at K42 .................................................. 94
Figure 6.30c Dissolved Oxygen Level Profile Comparison at K42 .................................................. 95
Figure 7.1a  Total Loading Data for all tributaries (April to November) from MOE, Present Scenario and Future Scenario ................................................................. 99
Figure 7.1b  Phosphorus Loads by Source (April to November) from MOE, Present Scenario and Future Scenario ......................................................................................... 100
Figure 7.1c  Nitrogen Loads by Source (April to November) from MOE, Present Scenario and Future Scenario ......................................................................................... 100
Figure 7.1c  Nitrogen Loads by Source (April to November) from MOE, Present Scenario and Future Scenario ......................................................................................... 100
Figure 7.2a  TP Comparison for MOE and CanWet Present Scenario Input ..................................... 101
Figure 7.2b  TP Comparison for MOE and CanWet Present Scenario Input ..................................... 102
Figure 7.2c  TP Comparison for MOE and CanWet Present Scenario Input ..................................... 103
Figure 7.3  TP Comparison for MOE and CanWet Present Scenario Input ..................................... 104
Figure 7.4a  TN Comparison for MOE and CanWet Present Scenario Input ..................................... 105
Figure 7.4b  TN Comparison for MOE and CanWet Present Scenario Input ..................................... 106
Figure 7.4b  TN Comparison for MOE and CanWet Present Scenario Input ..................................... 107
Figure 7.4c  TN Comparison for MOE and CanWet Present Scenario Input ..................................... 108
Figure 7.5  TN Comparison for MOE and CanWet Present Scenario Input ....................... 109
Figure 7.6a Chlorophyll “a” Comparison for MOE and CanWet Present Scenario Input 110
Figure 7.6b Chlorophyll “a” Comparison for MOE and CanWet Present Scenario Input 111
Figure 7.6c Chlorophyll “a” Comparison for MOE and CanWet Present Scenario Input 112
Figure 7.7  Chlorophyll “a” Comparison for MOE and CanWet Present Scenario Input 113
Figure 7.8a  TP Comparison for CanWet Present and Future Scenario Input ..................... 114
Figure 7.8b  TP Comparison for CanWet Present and Future Scenario Input ..................... 115
Figure 7.8c  TP Comparison for CanWet Present and Future Scenario Input ..................... 116
Figure 7.9  TP Comparison for CanWet Present and Future Scenario Input ..................... 117
Figure 7.10a TN Comparison for CanWet Present and Future Scenario Input .................... 118
Figure 7.10b TN Comparison for CanWet Present and Future Scenario Input .................... 119
Figure 7.10c TN Comparison for CanWet Present and Future Scenario Input .................... 120
Figure 7.11 TN Comparison for CanWet Present and Future Scenario Input .................... 121
Figure 7.12a Chlorophyll “a” Comparison for CanWet Present and Future Scenario Input .......................................................................................................................... 122
Figure 7.12b Chlorophyll “a” Comparison for CanWet Present and Future Scenario Input .......................................................................................................................... 123
Figure 7.12c Chlorophyll “a” Comparison for CanWet Present and Future Scenario Input .......................................................................................................................... 124
Figure 7.13 Chlorophyll “a” Comparison for CanWet Present and Future Scenario Input .......................................................................................................................... 125
Figure 7.14a DO Comparison for MOE Data, CanWet Present and Future Scenario Input .......................................................................................................................... 126
Figure 7.14b DO Comparison for MOE Data, CanWet Present and Future Scenario Input .......................................................................................................................... 127
Figure 7.14c DO Comparison for MOE Data, CanWet Present and Future Scenario Input .......................................................................................................................... 128
Figure 7.14d DO Comparison for MOE Data, CanWet Present and Future Scenario Input .......................................................................................................................... 129
Figure 7.14e DO Comparison for MOE Data, CanWet Present and Future Scenario Input .......................................................................................................................... 130
Figure 7.14f DO Comparison for MOE Data, CanWet Present and Future Scenario Input .......................................................................................................................... 131
Figure 7.14g DO Comparison for MOE Data, CanWet Present and Future Scenario Input .......................................................................................................................... 132
Figure 7.14h DO Comparison for MOE Data, CanWet Present and Future Scenario Input .......................................................................................................................... 133
Figure 7.15a MOE Secchi Calibration 2001 Comparison .................................................... 134
Figure 7.15b MOE Secchi Calibration 2001 Comparison .................................................... 135
Figure 7.15c MOE Secchi Calibration 2001 Comparison .................................................... 136

APPENDIX A - TEMPERATURE CALIBRATION RESULTS AT MOE STATIONS....... 1
Figure A.1a Temperature Profile Comparison at E51 ....................................................... 2
Figure A.1b Temperature Profile Comparison at E51 ....................................................... 3
Figure A.1c Temperature Profile Comparison at E51 ....................................................... 4
<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.2a</td>
<td>Temperature Profile Comparison at K45</td>
<td>5</td>
</tr>
<tr>
<td>A.2b</td>
<td>Temperature Profile Comparison at K45</td>
<td>6</td>
</tr>
<tr>
<td>A.2c</td>
<td>Temperature Profile Comparison at K45</td>
<td>7</td>
</tr>
<tr>
<td>A.3a</td>
<td>Temperature Profile Comparison at S15</td>
<td>8</td>
</tr>
<tr>
<td>A.3b</td>
<td>Temperature Profile Comparison at S15</td>
<td>9</td>
</tr>
<tr>
<td>A.3c</td>
<td>Temperature Profile Comparison at S15</td>
<td>10</td>
</tr>
<tr>
<td>A.4a</td>
<td>Temperature Profile Comparison at K42</td>
<td>11</td>
</tr>
<tr>
<td>A.4b</td>
<td>Temperature Profile Comparison at K42</td>
<td>12</td>
</tr>
<tr>
<td>A.4c</td>
<td>Temperature Profile Comparison at K42</td>
<td>13</td>
</tr>
<tr>
<td>A.5a</td>
<td>Temperature Profile Comparison at K39</td>
<td>14</td>
</tr>
<tr>
<td>A.5b</td>
<td>Temperature Profile Comparison at K39</td>
<td>15</td>
</tr>
<tr>
<td>A.5c</td>
<td>Temperature Profile Comparison at K39</td>
<td>16</td>
</tr>
<tr>
<td>A.6a</td>
<td>Temperature Profile Comparison at C9</td>
<td>17</td>
</tr>
<tr>
<td>A.6b</td>
<td>Temperature Profile Comparison at C9</td>
<td>18</td>
</tr>
<tr>
<td>A.6c</td>
<td>Temperature Profile Comparison at C9</td>
<td>19</td>
</tr>
<tr>
<td>A.7a</td>
<td>Temperature Profile Comparison at C6</td>
<td>20</td>
</tr>
<tr>
<td>A.7b</td>
<td>Temperature Profile Comparison at C6</td>
<td>21</td>
</tr>
<tr>
<td>A.7c</td>
<td>Temperature Profile Comparison at C6</td>
<td>22</td>
</tr>
<tr>
<td>A.8a</td>
<td>Temperature Profile Comparison at C1</td>
<td>23</td>
</tr>
<tr>
<td>A.8b</td>
<td>Temperature Profile Comparison at C1</td>
<td>24</td>
</tr>
<tr>
<td>A.8c</td>
<td>Temperature Profile Comparison at C1</td>
<td>25</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>APPENDIX B</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>B.1a</td>
<td>Dissolved Oxygen Level Profile Comparison at E51</td>
<td>2</td>
</tr>
<tr>
<td>B.1b</td>
<td>Dissolved Oxygen Level Profile Comparison at E51</td>
<td>3</td>
</tr>
<tr>
<td>B.1c</td>
<td>Dissolved Oxygen Level Profile Comparison at E51</td>
<td>4</td>
</tr>
<tr>
<td>B.2a</td>
<td>Dissolved Oxygen Level Profile Comparison at K45</td>
<td>5</td>
</tr>
<tr>
<td>B.2b</td>
<td>Dissolved Oxygen Level Profile Comparison at K45</td>
<td>6</td>
</tr>
<tr>
<td>B.2c</td>
<td>Dissolved Oxygen Level Profile Comparison at K45</td>
<td>7</td>
</tr>
<tr>
<td>B.3a</td>
<td>Dissolved Oxygen Level Profile Comparison at S15</td>
<td>8</td>
</tr>
<tr>
<td>B.3b</td>
<td>Dissolved Oxygen Level Profile Comparison at S15</td>
<td>9</td>
</tr>
<tr>
<td>B.3c</td>
<td>Dissolved Oxygen Level Profile Comparison at S15</td>
<td>10</td>
</tr>
<tr>
<td>B.4a</td>
<td>Dissolved Oxygen Level Profile Comparison at K42</td>
<td>11</td>
</tr>
<tr>
<td>B.4b</td>
<td>Dissolved Oxygen Level Profile Comparison at K42</td>
<td>12</td>
</tr>
<tr>
<td>B.4c</td>
<td>Dissolved Oxygen Level Profile Comparison at K42</td>
<td>13</td>
</tr>
<tr>
<td>B.5a</td>
<td>Dissolved Oxygen Level Profile Comparison at K39</td>
<td>14</td>
</tr>
<tr>
<td>B.5b</td>
<td>Dissolved Oxygen Level Profile Comparison at K39</td>
<td>15</td>
</tr>
<tr>
<td>B.5c</td>
<td>Dissolved Oxygen Level Profile Comparison at K39</td>
<td>16</td>
</tr>
<tr>
<td>B.6a</td>
<td>Dissolved Oxygen Level Profile Comparison at C9</td>
<td>17</td>
</tr>
<tr>
<td>B.6b</td>
<td>Dissolved Oxygen Level Profile Comparison at C9</td>
<td>18</td>
</tr>
<tr>
<td>B.6c</td>
<td>Dissolved Oxygen Level Profile Comparison at C9</td>
<td>19</td>
</tr>
<tr>
<td>B.7a</td>
<td>Dissolved Oxygen Level Profile Comparison at C6</td>
<td>20</td>
</tr>
<tr>
<td>B.7b</td>
<td>Dissolved Oxygen Level Profile Comparison at C6</td>
<td>21</td>
</tr>
<tr>
<td>B.7c</td>
<td>Dissolved Oxygen Level Profile Comparison at C6</td>
<td>22</td>
</tr>
<tr>
<td>B.8a</td>
<td>Dissolved Oxygen Level Profile Comparison at C1</td>
<td>23</td>
</tr>
</tbody>
</table>
Figure B.8b  Dissolved Oxygen Level Profile Comparison at C1 ........................................... 24
Figure B.8c  Dissolved Oxygen Level Profile Comparison at C1 ........................................... 25

APPENDIX C – MODEL ANIMATIONS .................................................................................. 1
Glossary

Anoxia – Absence of oxygen.

Benthic Zone – The lowest level of a body of water, near the lakebed, inhabited by benthic organisms.

Epilimnion – The topmost layer of a thermally stratified lake, occurring above the deeper hypolimnnion. The epilimnion is warmer and typically has higher DO concentrations than the hypolimnion. There is typically a free exchange of dissolved gases with the atmosphere.

Euphotic – The uppermost layer of water that is capable of receiving sunlight in order for green plants to undergo photosynthesis.

Eutrophic – Having waters rich in organic and mineral content that promote the growth of aquatic plant life, such as algae, thus reducing the dissolved oxygen (DO) content.

Hydrodynamic – Anything pertaining to the forces of fluid in motion.

Hypolimnion – The bottom and most dense layer of water in a thermally stratified lake. is the layer that lies below the thermocline. Typically, it is non-circulatory and remains cold throughout the year. Being at depth, it is isolated from surface wind-mixing and is does not receive enough incoming irradiance (light) for photosynthesis to occur.

Seiching – The process of sloshing of water within the lake following an initial storm surge or setup on one part of the lake.

Senescence – The process of aging, growing old.

Sloughing – The process by which something is shed or separated from living tissue.
1 INTRODUCTION

1.1 Scope of Work

The Lake Simcoe Conservation Authority, and the Province of Ontario are undertaking a series of studies to help manage the pressures for population growth in the Lake Simcoe watershed, through an assessment of the Lake Simcoe’s capacity to assimilate this existing approved growth and future new growth.

The studies will proceed from a series of models that:

- Link changes in land use in the watershed and implementation of Best Management Practices to phosphorus loading to Lake Simcoe;
- Link changes in land use in the watershed and implementation of Best Management Practices to loading targets to maintain aquatic system health in watershed and tributaries to the lake; and
- Link the phosphorus loading from the watershed to a hydrodynamic and water quality model to evaluate the lake response to these phosphorus loadings.

Taken together, these studies will help the LSRCA and the Province to determine how much development can be accommodated in the Lake Simcoe Watershed and the management practices necessary to minimize future phosphorus loading from the watershed or to reduce current loadings, to meet the Lake Simcoe Environmental Management Strategy (LSEMS) remedial target for Lake Simcoe.

This report forms part of the Lake Simcoe Assimilative Capacity Studies and specifically describes the development of a hydrodynamic and water quality model of Lake Simcoe using the Danish Hydraulic Institute’s MIKE3 and ECO Lab modules.

1.2 Project Objectives

The objectives of the Lake Simcoe Assimilative Capacity Studies project are:

- To develop a better understanding of the complex hydrodynamic nature of Lake Simcoe in respect to water cycling/flushing, phosphorus retention, relationship of hydrodynamic characteristics with dissolved oxygen, water movement patterns within the lake and the role of the lake’s two large bays (Cook Bay and Kempenfelt Bay) in hydrodynamic processes;
• To undertake a complete 3-D hydrodynamic and water quality model for Lake Simcoe with an emphasis on total phosphorus and the prediction of dissolved oxygen concentrations, including the prediction of end of summer hypolimnetic dissolved oxygen concentrations based on annual phosphorus loads;

• To integrate the findings with the other core undertakings of the Assimilative Capacity Study to develop assimilative capacity targets for Lake Simcoe and TMDL/TMML (Total Maximum Daily Loads/Total Maximum Monthly Loads) targets for its watersheds; and

• To provide recommendations on future monitoring to better improve the understanding of the hydrodynamic and water quality processes in Lake Simcoe.

Specifically, this has been based on the setup, testing and application of DHI’s MIKE3 hydrodynamic model linked to DHI’s ECO Lab water quality/eutrophication model.

The water quality model was developed on the basis of nutrient and hydraulic loadings to Lake Simcoe. The scope of the project was development of the model and not generation of, or validation of, the model inputs such as hydraulic and nutrient loads. These loadings were provided by the Ontario Ministry of the Environment for the initial model development, and by Greenlands Engineering, for the model runs for present and future conditions in the watershed, respectively. The methods used by these groups to develop their loading estimates were not documented at the time of model formulation and validation of these loads was not part of the scope of our study. Although we did compare the loading estimates provided for recent conditions by MOE and Greenlands, the scope of the project did not include validation or reconciliation of figures provided by other sources, and did not include documentation of their methods. In all cases, the reader is referred to the MOE and Greenlands Engineering reports prepared as part of the Lake Simcoe Assimilative Capacity Studies for details on how loads were calculated, how they were validated, and how well they compared.
2 BACKGROUND

Lake Simcoe and its watershed represent the convergence of two classic lake management issues. The lake is presently suffering from the symptoms of existing agricultural practices, decades of land use changes in its watershed, and at the same time is at the centre of one of the fastest growing populations in the country, with attendant pressures for further land use change in its watershed.

2.1 In-Lake Processes

Water quality problems in Lake Simcoe first became apparent in the late 1960s, as nuisance growths of algae and rooted aquatic plants, decreased water clarity and contributed to a declining catches of cold water fish. In the mid 1980’s, the Lake Simcoe Environmental Management Strategy (LSEMS) documented the loss of dissolved oxygen from the hypolimnetic waters of the lake and resultant losses of habitat for lake trout (*Salvelinus namaycush*) and lake whitefish (*Coregonus clupeaformis*). Depressed oxygen levels were linked to enrichment of the lake with the algal nutrient, phosphorus, the resultant stimulation of algal growth in the sunlit upper waters of the lake and its subsequent senescence and settling into the hypolimnion where bacterial decomposition consumed oxygen from the stratified waters. Cold-water fish prefer the deep, cold water habitat of the lake and so loss of oxygen represents a loss in the volume of available habitat. Oxygen is replenished into the bottom waters when the lake destratifies and turns over in spring and fall. Once the summer stratification is set up, however, ongoing oxygen demand from bacterial decomposition in the lake sediments depresses the oxygen content. This becomes limiting for coldwater fish by late summer and the oxygen conditions continue declining until fall turnover. In the worst case, oxygen levels decline to anoxia, and reduction reactions dominate, reducing nitrate to ammonia, ferric to ferrous iron and stimulating the release of phosphorus from the bottom sediments further exacerbating the problem.

The effects of nutrient enrichment are not confined, however, to the hypolimnetic waters of the lake. Recent years have also seen a proliferation of rooted aquatic plants around the littoral margin of Lake Simcoe. These aquatic macrophytes take their nutrients from lake sediments and the water column and so respond to nutrient loading from the watershed. Their response to nutrient loading is difficult to separate, however, from the effects of the zebra mussel (*Dreissena polymorpha*), which invaded the lake in the mid 1990s. The zebra mussels have proliferated to the point where their filter feeding of algae and other particulate matter has increased the clarity of the water column of the lake. As a result, the compensation depth, at which light penetration limits plant growth, has increased such that aquatic plants can now take root at far greater depths than they could historically. This has increased the volume of plant growth in the lake. Aquatic macrophytes, like algae, also die at the end of each year and substantial amounts of their
biomass end up settling into hypolimnetic waters. Their decomposition adds to the oxygen demand and further reduces end of summer hypolimnetic dissolved oxygen.

2.2 Watershed Processes

Nutrient enrichment in Lake Simcoe is a direct result of human development in the watershed. In the past century, forests have been cleared and wetlands drained for agriculture and forests have also been cleared for urban development. Runoff of stormwater containing sediments and nutrients, agricultural drainage (including fertilizers, animal waste and soils), direct discharge of treated sewage from Waste Water Treatment Plants and runoff from failing septic systems have all contributed to nutrient enrichment of the lake. In 1998 the LSEMS Program estimated a total annual phosphorus load to Lake Simcoe of approximately 102 tonnes per year, partitioned as shown in Figure 2.1 below.

The most obvious direct human sources of phosphorus are discharge from Sewage Treatment Plants (5.7 tonnes/yr), urban runoff (21.9 tonnes/yr) and runoff from polder agriculture at Holland Marsh and elsewhere (5.6 tonnes/yr). Loadings from tributaries, however, are also elevated by land use changes and agriculture, and atmospheric loading is also enriched by erosion-generated dust.

The LSEMS set a target to reduce the annual phosphorus loading to the lake by 25%, or approximately 25 tonnes, from levels estimated in the mid 1990s. The target setting exercise recognized that such a reduction was not sufficient to rehabilitate the lake, but that it was not feasible to reduce phosphorus loadings to pre-development levels. The target reduction was estimated to be sufficient to the restore hypolimnetic dissolved oxygen annual minimum from present-day levels of 3 – 3.5 mg/L, to approximately 5 mg/L (Nicholls, 1997).

2.3 New Growth and Implications to Water Quality

The recognition that Lake Simcoe required an approximate 25% reduction in phosphorus loading came several years before it became apparent that substantial urban development was occurring, and planned, for its watershed. Overall population growth in Ontario, coupled with development restrictions on the Oak Ridges Moraine and other Green Belt areas focused population growth and urban expansion in the watershed of Lake Simcoe. With urban growth will come additional land clearing, greater application of chemical fertilizer, storm water runoff and the discharge of treated sewage, all of which are sources of additional phosphorus to Lake Simcoe. On the other hand, conversion of poorly managed agricultural lands to urban development that meets modern standards for storm water management and fertilization practices can stabilize or even reduce phosphorus loadings to the lake. The problems in Lake Simcoe represent a near century of
development and land use change. Although it is possible that new development will not create additional problems, or can be used to help remediate historic problems, the pressure to accommodate new growth requires a comprehensive analysis of its implication to water quality in Lake Simcoe. The proposed numerical modeling (coupled with ongoing monitoring) approach, including the hydrodynamic and water quality model component that is the topic of this report, represents the best available approach to complete this comprehensive analysis.

Figure 2.1   Estimated Phosphorus Loadings to Lake Simcoe for 1998
3 DATA COLLECTION

The setup, testing and application of a lakewide model of hydrodynamics and water quality requires a variety of different data sets to specify boundary or input conditions and for model calibration and verification. This section provides a summary of the available data that was used in addition to initial comments on shortcomings of the available data.

3.1 Bathymetry

Bathymetry and shoreline data were extracted from the 1957 field sheet, obtained from the Canadian Hydrographic Service (CHS). The scale of the field sheet is 1:3,000. Both the soundings and the shoreline data were digitized from the field sheet. It was assumed that this data had a horizontal projection of UTM 17N NAD 1927. This was confirmed by comparing the shoreline data with other data of a similar spatial reference. The digitized data was later re-projected to UTM 17N NAD 1983.

Almost 50 years have passed since the water depths on a lakewide basis were determined. There will have been changes in water depths throughout the lake over this period. Changes in shallow nearshore regions would definitely have an influence on model predictions, particularly for nearshore processes. Providing the focus of this investigation is the hypolimnetic waters and not the nearshore regions, the 1957 hydrographic data set should be sufficient for the purpose of this initial setup and testing. It is however recommended that the hydrographic data be updated in the future.

Lake Simcoe Region Conservation Authority provided Baird with additional hydrographic data and high-resolution orthophotos. The hydrographic data was in ESRI shapefile format and included lakewide shoreline layers and a stream/river network layer. The orthophotos were dated 2002 and had 20 cm resolution, with the exception of two photos with 30 cm resolution. The imagery covered the entire shoreline of Lake Simcoe. Figure 3.1 shows the bathymetry and the shoreline digitized from the field sheet.

3.2 Climate

Climate data, required as input to the hydrodynamic model, were obtained from Environment Canada (EC). The locations of the climate stations surrounding Lake Simcoe are shown in Figure 3.2 and listed in Table 3.1. Data were obtained for 1999, 2001, and 2002 for calibration and testing of the model. The climate data used in the model included air temperature, wind speed and direction, precipitation, relative humidity, Photosynthetically Active Radiation (PAR) and specifically:
- Hourly wind and air temperature data at the stations of Lagoon City, Barrie (Auto), and Egbert CS;

- Daily wind and air temperature data at the stations which are close to the main rivers in the watershed of Lake Simcoe as shown in Figure 3.2;

- Hourly relative humidity data at the stations of Lagoon City, Barrie (Auto), and Egbert CS;

- Daily precipitation data at the stations of Lagoon City and Barrie (WPCC). The data were extracted from the climate data CDROM released by Environment Canada (http://www.climate.weatheroffice.ec.gc.ca/prods_servs/cdcd_iso_e.html);

- Cloud coverage data in percentage at Pearson International Airport (the data is not available at the selected climate stations around the lake, and this is the closest station at which data is collected);

- Daily measurements of Photosynthetically Active Radiation (PAR) to estimate phytoplankton growth in the ECO Lab module. These light measurements are not made at meteorological stations in the Lake Simcoe watershed. They were therefore obtained from the Dorset Environmental Science Centre of the Ontario Ministry of the Environment, 100 km NNE of the center of Lake Simcoe, the closest available point of measurement.
### Table 3.1 Summary of Climate Station Data

<table>
<thead>
<tr>
<th>Name</th>
<th>Data Frequency</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Elevation (m)</th>
<th>Climate_ID</th>
<th>WMO_ID</th>
<th>TC_ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALLISTON NELSON</td>
<td>Daily</td>
<td>44° 09' N</td>
<td>79° 52' W</td>
<td>221</td>
<td>6110218</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>BARRIE (AUT)</td>
<td>Hourly/Daily</td>
<td>44° 22' N</td>
<td>79° 46' W</td>
<td>295</td>
<td>6110552</td>
<td>71436</td>
<td>WCU</td>
</tr>
<tr>
<td>BARRIE WPCC</td>
<td>Daily</td>
<td>44° 22' N</td>
<td>79° 41' W</td>
<td>221</td>
<td>6110557</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>BORDEN</td>
<td>Hourly</td>
<td>44° 16' N</td>
<td>79° 55' W</td>
<td>222.5</td>
<td>611B001</td>
<td>na</td>
<td>YBN</td>
</tr>
<tr>
<td>BORDEN AWOS</td>
<td>Daily</td>
<td>44° 16' N</td>
<td>79° 54' W</td>
<td>222.5</td>
<td>611B002</td>
<td>71534</td>
<td>YBN</td>
</tr>
<tr>
<td>COLDWATER WARMINSTER</td>
<td>Daily</td>
<td>44° 37' N</td>
<td>79° 31' W</td>
<td>285</td>
<td>6111769</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>COOKSTOWN</td>
<td>Daily</td>
<td>44° 12' N</td>
<td>79° 41' W</td>
<td>243.8</td>
<td>6111859</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>EGBERT CARE</td>
<td>Daily</td>
<td>44° 13' N</td>
<td>79° 46' W</td>
<td>252</td>
<td>611KBE0</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>EGBERT CS</td>
<td>Hourly/Daily</td>
<td>44° 13' N</td>
<td>79° 46' W</td>
<td>251</td>
<td>611E001</td>
<td>71296</td>
<td>XET</td>
</tr>
<tr>
<td>HARTLEY</td>
<td>Daily</td>
<td>44° 25' N</td>
<td>78° 54' W</td>
<td>290</td>
<td>6163360</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>KING SMOKES TREE</td>
<td>Daily</td>
<td>44° 01' N</td>
<td>79° 31' W</td>
<td>352</td>
<td>6154142</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>LAGOON CITY</td>
<td>Hourly/Daily</td>
<td>44° 33' N</td>
<td>79° 13' W</td>
<td>220.7</td>
<td>6114295</td>
<td>71282</td>
<td>WGL</td>
</tr>
<tr>
<td>MARSH HILL</td>
<td>Daily</td>
<td>44° 09' N</td>
<td>79° 04' W</td>
<td>285</td>
<td>6155000</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>MIDLAND HURONIA A</td>
<td>Daily</td>
<td>44° 40' N</td>
<td>79° 55' W</td>
<td>234.7</td>
<td>6115130</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>MUSKOKA AIRPORT</td>
<td>Hourly/Daily</td>
<td>44° 58' N</td>
<td>79° 18' W</td>
<td>281.9</td>
<td>6115525</td>
<td>71630</td>
<td>YQA</td>
</tr>
<tr>
<td>NEWMARKET 3</td>
<td>Daily</td>
<td>44° 03' N</td>
<td>79° 25' W</td>
<td>240</td>
<td>615N002</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>ORILLIA BRAIN</td>
<td>Daily</td>
<td>44° 36' N</td>
<td>79° 26' W</td>
<td>250</td>
<td>6115811</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>PORT PERRY NONQUON</td>
<td>Daily</td>
<td>44° 09' N</td>
<td>79° 58' W</td>
<td>253</td>
<td>6156682</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>SANDFORD SOLETUDE</td>
<td>Daily</td>
<td>44° 09' N</td>
<td>79° 13' W</td>
<td>247</td>
<td>6157875</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>SHANTY BAY</td>
<td>Daily</td>
<td>44° 24' N</td>
<td>79° 37' W</td>
<td>251.5</td>
<td>6117684</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>SONYA SUNDANCE MEADOWS</td>
<td>Daily</td>
<td>44° 13' N</td>
<td>78° 57' W</td>
<td>275</td>
<td>6168100</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>UDORA</td>
<td>Daily</td>
<td>44° 15' N</td>
<td>79° 09' W</td>
<td>262</td>
<td>6119055</td>
<td>na</td>
<td>na</td>
</tr>
</tbody>
</table>

Further discussion on climate data and its application in the model is provided in Section 5.2.

### 3.3 River Hydrology

The numerical model of hydrodynamics and water quality was set up to calculate daily hydrodynamic and nutrient load based on specified daily flow rate and nutrient concentrations in respective source streams. Thus, the model required as input the daily stream flow and its water quality parameters for each source stream to the lake. The watersheds and sub-watersheds for Lake Simcoe are shown in Figure 3.3. The flow data used in the model is described in this section and water quality or nutrient loading is described in Section 3.5.

The hydrology data included:

- River flow at the gauges shown in Figure 3.2;
- Water temperature in the Holland River (Burnside, 2005); Environment Canada HYDAT for stream data at the gauges (http://www.wsc.ec.gc.ca/products/hydat/main_e.cfm?cname=hydat_iso_e.cfm)

The river flow at the EC gauges in the watershed of Lake Simcoe were collected from the EC HYDAT CD. The river flows for the local gauges were collected from MOE. The locations of the EC gauges which are published on HYDAT are shown in Figure 3.2 and are listed in Table 3.2. Note that there are five gauges located on the Holland River and its tributaries including: the EC gauge at the east branch of the Holland River (02EC009), the local gauges at the Upper Schomberg River, North Schomberg River, and Kettleby Creek which drain to the west branch of the Holland River, and the gauge at Holland Marsh, Bradford.

Table 3.2 Listing of HYDAT Gauged Rivers

<table>
<thead>
<tr>
<th>Station</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>02EC009</td>
<td>44.09500</td>
<td>-79.48944</td>
<td>HOLLAND RIVER AT HOLLAND LANDING</td>
</tr>
<tr>
<td>02EC010</td>
<td>44.01222</td>
<td>-79.68556</td>
<td>SCHOMBERG RIVER NEAR SCHOMBERG</td>
</tr>
<tr>
<td>02EC011</td>
<td>44.39694</td>
<td>-79.07111</td>
<td>BEAVERTON RIVER NEAR BEAVERTON</td>
</tr>
<tr>
<td>02EC012</td>
<td>44.30500</td>
<td>-79.36028</td>
<td>BLACK RIVER AT SUTTON</td>
</tr>
<tr>
<td>02EC018</td>
<td>44.26750</td>
<td>-79.19472</td>
<td>PEFFERLAW BROOK NEAR UDORA</td>
</tr>
</tbody>
</table>

Since the gauged flows do not cover the entire catchment of any given river, the total flow from a river to the lake was calculated by using the following linear relationship, i.e.

\[ Q_{\text{total}} = Q_{\text{gaged}} \left( 1 + \frac{A_{\text{ungaged}}}{A_{\text{gaged}}} \right) \]

where Q represents the flow and A represents the area of the watershed. The daily total flows at the Holland River are shown in Figure 3.4. Additional comments on the application of flow data in the model are provided in Section 5.2.

3.4 Lake Levels and Temperature

The lake levels were collected from the EC HYDAT CD and also from MOE stations. There are two lake level gauges operated by MOE at Jacksons Point on Lake Simcoe and Atherley Narrows. The original levels were referenced to a datum 200 m above Canadian Geodetic Datum (CGD). The levels were transferred to Chart Datum (218.7 m above CGD) for use in the model. The lakewide-mean lake levels on Lake Simcoe from 1999 to 2002 are shown in Figure 3.5. The annual variation of lake level is about 0.5 m with higher lake levels occurring in summer and lower levels in the winter months.
There are three sets of water temperature data collected in the lake. The profiles of water temperature were obtained from measurements made by MOE at their routine water quality monitoring sites at approximate three-week intervals during the ice free season from 1999 to 2004. The time series water temperature at the existing intakes was collected from the local water treatment plants in 2002. Surface water temperature is also collected at the EC Buoy station. The MOE and intake data were used to calibrate the model. Table 3.3 shows the locations and depth of the existing intakes in the lake.

Table 3.3 Locations and Depths of Intakes

<table>
<thead>
<tr>
<th>Intake</th>
<th>UTM (m)</th>
<th>Intake Depth (m)</th>
<th>Bed Elevation (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Easting</td>
<td>Northing</td>
<td></td>
</tr>
<tr>
<td>Sutton</td>
<td>629546</td>
<td>4909292</td>
<td>4.0</td>
</tr>
<tr>
<td>Beaverton</td>
<td>645100</td>
<td>4920720</td>
<td>4.6</td>
</tr>
<tr>
<td>South Ramara</td>
<td>643300</td>
<td>4927180</td>
<td></td>
</tr>
<tr>
<td>Innisfil</td>
<td>617300</td>
<td>4908350</td>
<td>11.0</td>
</tr>
<tr>
<td>Keswick</td>
<td>620235</td>
<td>4901296</td>
<td>8.5</td>
</tr>
<tr>
<td>Lagoon City</td>
<td>641720</td>
<td>4931550</td>
<td>5.2</td>
</tr>
<tr>
<td>Buoy Station</td>
<td>629582</td>
<td>4928701</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Figure 3.6 shows the water temperature at the Innisfil intake. The water temperature varies from 4 °C in the winter to 24 °C in the summer. Figure 3.7 shows the water temperature profile at station K42. The development of the hypolimnion in the summer months and the turn over in the fall are clearly depicted in Figure 3.7.

3.5 Water Quality

Water quality data used in the project fall into two main categories: nutrient load data, and monitoring data.

3.5.1 Load Data

Nutrient load data were required as input to the model. The data included Total Phosphorus (TP), Total Nitrogen (TN = Total Kjeldahl+nitrate nitrogen, Dr. J. Winter, MOE, pers. comm.. July 21, 2005), Chlorophyll “a” and Dissolved Oxygen (DO). The load data were obtained from two sources. The model was calibrated with load data provided by the Environmental Monitoring and Reporting Branch of the Ontario Ministry of the Environment (MOE). These data were obtained through a variety of sources by MOE and will be described in MOE’s reporting for the ACS study. The data and
assumptions made in developing the input files for the model are described in further
detail in Section 5.3.

Nutrient loading data for the present and future scenarios were provided from watershed
models applied by Greenland International Consulting Ltd and used in the convention
provided. This data was developed for the Assimilative Capacity Studies and included
monthly average flow rates, dissolved and total nitrogen, dissolved and total phosphorus,
and suspended solids for all major tributaries and rivers within the Lake Simcoe
watershed. The watershed model study did not estimate atmospheric loading and so the
MOE estimates of atmospheric load were used for both the current and “future land use”
scenarios. Point and non point source inputs such as sewage treatment plant discharges,
septic contributions and urban runoff are accounted for within the watershed model and
loaded to Lake Simcoe as loads from each tributary and river. Although this method does
not, strictly speaking, provide spatially explicit spatial loads at the smallest scale, all
major and minor tributaries of the lake were modelled, and so the resolution of the model
was considered acceptable at the intermediate scale. We note that the hydrodynamics of
wind driven water would also incorporate small local loadings into the greater lake
volume.

3.5.2 Monitoring Data

Monitoring data were obtained from two sources: the MOE monitoring stations on Lake
Simcoe, and the water treatment plant intakes. There are twelve MOE monitoring
stations (N31, N32, E50, E51, S15, K45, K42, K38, K39, C1, C6 AND C9). The
locations of the MOE stations are shown in Figure 3.8. Data have been collected at
these stations since 1980 and were provided for the years 1980 to 2004. The data were
collected at intervals ranging from biweekly to monthly over that period for the ice-free
season on Lake Simcoe (generally April to November, with exceptions in some years).
The MOE program measures profiles of temperature and dissolved oxygen at each site,
Secchi depth and a series of water chemistry parameters taken as a composite sample of
the euphotic zone (approximately two times the Secchi depth), including total
phosphorus, chlorophyll ‘a’, nitrate, ammonia and Kjeldahl Nitrogen, conductivity, iron,
 pH, major ions (Na, Ca, Mg, Cl, sulphate), silica, dissolved inorganic and organic carbon,
conductivity and alkalinity. The MOE program also provides measurements of the
phytoplankton community composition and phytoplankton bio-volume.

Water quality monitoring data were also obtained from the eight Water Treatment Plants
located on Lake Simcoe: Keswick, Innisfil, Georgina, Sutton, Beaverton, South Ramara,
Brechin and Lagoon City. The locations of the intakes are shown in Figure 3.8. Intake
data provides weekly samples year round for nutrients (total phosphorus, reactive
phosphorus, ammonia, nitrate and Kjeldahl nitrogen, organic and inorganic carbon, silica
and chlorophyll ‘a’).
3.6 Vertical Profile of Current Velocity

As will be demonstrated in later sections of this report, the hydrodynamics of the lake are very complex with significant temporal and spatial variability, the latter in both horizontal and vertical planes. Therefore, vertical profile measurements of currents are best for comparison to predicted currents. No historic data on vertical profiles of current velocity were available. An Acoustic Doppler Current Profiler (ADCP) was therefore deployed from June 23, 2005 to July 20, 2005 to collect current data for comparison with and future validation of the MIKE 3 hydrodynamic model. The instrument was deployed for approximately one month to capture data during a significant wind event (i.e. storm conditions). The ADCP, which is mounted on the lakebed, provides a profile of the currents through the water column above the instrument. The location at which the ADCP was deployed (depth = 23 m) was chosen because the lake circulation (3D profiles) at this point is sensitive to the winds from a wide range of directions, based on the initial model results of MIKE3. The location of the instrument and a photograph taken during the deployment are provided in Figures 3.9 and 3.10 respectively. A detailed comparison of the measured and modeled data was not possible during this study due to funding and scheduling constraints and a qualitative comparison was therefore undertaken as described in Section 6.1.2. Although the MIKE3 model has been widely used including numerous applications by Baird at other sites, validation of the hydrodynamic model with site specific measured data would provide added confidence in the model and is recommended.
Figure 3.1  Bathymetry and Shoreline Digitized from 1957 Field Sheet
Figure 3.2  Map showing Climate Stations in Project Area
Figure 3.3  Lake Simcoe Watershed and Subwatersheds
Figure 3.4  Daily Flow in the Holland River (1990 to present)
Figure 3.5 Daily Mean Water Level on Lake Simcoe
Figure 3.6  Daily Temperature at Innisfill Intake
Figure 3.7  Seasonal Variation in Temperature Profile at MOE Station K42
Figure 3.8  Map showing Locations of MOE Monitoring Stations and Water Treatment Intakes
Figure 3.9  Map showing Location of ADCP
Figure 3.10  ADCP before Deployment
4 MODEL SELECTION AND OVERVIEW

4.1 Model Selection

Model selection is an important step in any project involving complex numerical modeling, particularly when the model will be used in the future by the client. Each model has its specific strengths and weaknesses and there is usually a uniquely appropriate model for each project. Important considerations in model selection are:

- Technical strengths and limitations compared to the site conditions;
- Data requirements and availability;
- Model grid approach (curvilinear, rectilinear, finite difference, finite element, horizontal layers or sigma layers);
- License and future upgrade fees;
- Likelihood of future support in the form of upgrades;
- User friendliness;
- Computation time;
- Hardware and platform requirements;
- End user capabilities; and
- Future “what-if” scenario requirements (i.e. which inputs will change).

Models considered for this project included: the U.S. EPA Environmental Fluid Dynamics Code (EFDC)/WASP combination, The Danish Hydraulics Institute (DHI) MIKE3 model, Delft 3D from Delft Hydraulics in the Netherlands, or Baird’s in-house model MISED. Based on an initial review of these models and our experience working with them, two leading candidates were identified: U.S. EPA’s EFDC; and DHI’s MIKE3. Following consultation with the Conservation Authority, a consensus decision was reached to implement DHI’s MIKE3, three-dimensional hydrodynamic model, linked with the DHI’s ECO Lab water quality/eutrophication model. The model was selected for its ability to model the physical and biological processes and for the support provided by DHI. Another consideration in the selection was the limited amount of time to perform the model application, which favoured the selection of an off the shelf commercial product that would require a minimum level of customization and testing. The trade-off is the user license fee for the commercial software package.

4.2 Model Overview

The MIKE3 hydrodynamic model includes thermal stratification, oxygen profiles, wind-driven currents and hydraulic forcing from inflowing tributaries. The model describes the dynamics of the lake with sufficient resolution to link it to models of phosphorus loading and describe the distributions of phosphorus throughout the lake, as well as temperature and oxygen stratification.
The model is also able to describe and accommodate specific geographic phosphorus sources including point source loadings such as the Holland River and Barrie Waste Water Treatment Plant, as well as non-point source loadings from smaller tributaries, atmospheric deposition and urban runoff.

The MIKE3 3-dimensional hydrodynamic model was coupled with the ECO Lab water quality/eutrophication model to quantify the responses of the lake to loadings of phosphorus and, ultimately, other pollutants of interest. The water quality/eutrophication model links phosphorus loading to algal growth, the growth of aquatic plants, death and decomposition of this organic matter and subsequent oxygen consumption. The model tracks the influence of both physical (mixing and thermocline development) and biological processes on dissolved oxygen throughout the model domain. This model output can ultimately be used to estimate fish habitat volumes. Fish habitat volumes are a function of the volume of water present in the hypolimnion that is < 12°C (the temperature optimum for lake trout) and containing > 6 mg/L of dissolved oxygen at the end of the summer period. Alternatively, habitat requirements can be stated and modeled in terms of the LSEMS target of 5 mg/L of dissolved oxygen, or any other targets developed by the user.

The ECO Lab model links the factors that modify the expression of the phosphorus load as water quality (water clarity, algal biomass or dissolved oxygen). The linkages are complex. Algal growth, for example is linked to the nutrient regime of the lake (phosphorus and nitrogen concentrations), the light regime (the volume of water containing sufficient light to allow algal growth), and water temperature. Algal growth, in turn, limits light penetration, but this is offset by grazing on algae from the water by zooplankton and, in recent years (although not currently coded in the model), zebra mussels. Resultant changes in water clarity increase the nearshore habitat available for colonization by rooted aquatic plants. The growth and senescence of algae and rooted aquatic plants then contribute to the hypolimnetic oxygen demand in the lake. Figure 4.1 provides a schematic of the conceptual water quality model for Lake Simcoe.

The ecological processes described above are captured in the MIKE3 ECO Lab model as shown in Figure 4.2. The ECO Lab model distinguishes between inorganic and particulate carbon, nitrogen and phosphorus and, like the conceptual model, partitions these nutrients into the water column, phytoplankton, zooplankton, benthic vegetation (aquatic macrophytes), detritus and sediment. The model provides specific functions of nutrient uptake, production, transfer, settling, death, respiration, detritus formation (“sloughing”) and mineralization.

The major disadvantage of the MIKE3 model is the finite difference (FD) grid that the model utilizes. The FD grid does not accurately define the complicated lake shorelines. Ideally, a finer grid size would be used in the narrow channels such as Cook Bay to avoid inaccurate reproduction due to the grid resolution. However, the computational time then becomes an issue for long-term simulations.
Figure 4.1  Conceptual Model of Ecological Processes in Lake Simcoe
Figure 4.2 Process Model of Ecological Processes in Lake Simcoe

PN – Phytoplankton Nitrogen
PP - Phytoplankton Phosphorus,
ZC - Zooplankton Carbon
DN - Detritus Nitrogen
DP - Detritus Phosphorus,
IN - Inorganic Nitrogen
IP - Inorganic Phosphorus (IP)
HD – Hydrodynamic exchange to external
PAR, UVA, UVB – solar radiation
5 MODEL SETUP

5.1 Model Domain and Grids

The model domain encompasses the entire lake. Square grids with 900 m grid spacing were generated using Baird’s in-house software X-Vision. The water depth at the grid points was interpolated using the 1957 bathymetry data. The datum used in the model is 218.7 m above Geodetic Survey of Canada Datum (GSCD) and is close to the mean lake level.

The possibility of using nested grids with a finer mesh (300 m) in Cook Bay and Kempenfelt Bay was considered. The model was tested with the nested grids, however the computational time made this option impracticable for long-term simulations, considering the short timeline for the project work. In addition, satisfactory results in the bays were obtained with the 900 m mesh. The model grid is shown in Figure 5.1.

5.2 Boundary Conditions

There are a number of boundaries in the model domain on which the external forces must be specified, including the water surface, the lake bottom, inflows from all tributaries, and outflow at Atherley Narrows. The boundary conditions specified in the model are described below.

5.2.1 Water Surface

Water surface is the interface between air and water, where heat exchange and air and water mixing occurs. The boundary conditions for the surface include wind speeds 10 m above the water surface, air temperature, relative humidity, precipitation, rain droplet temperature, and cloud coverage, which will be described below in detail.

5.2.1.1 Wind

The wind at the water surface is the major force that creates drag on the water and generates the circulation in the lake. The wind generates three-dimensional flow in the lake, which is the primary dynamic for temperature mixing and nutrient advection. In addition, wind has a significant effect on the heat exchange between air and water through evaporation and molecular mixing, and vice-versa (i.e. wind speeds are influenced by the temperature difference between the air and water). This is particularly important in the spring and fall seasons when there are significant differences between
water and air temperature. The speed and direction of wind measured 10 m above the water surface must be specified.

Theoretically, wind conditions over the lake may be slightly different from wind measurements at an onshore station, as wind varies spatially and there is reduced roughness over the lake. In order to understand the impact of spatially varied wind on the temperature patterns in the lake, sensitivity tests were carried out using spatially varied wind data. The spatially varied wind data were calculated by using an in-house program that reduced the winds along the windward shores. The simulations showed that using spatially varied wind data has no significant impact on the water temperature predictions but may cause a slight difference in the predicted lake circulation temporally (see Figure 5.2). Figure 5.3 shows the comparison of wind speeds measured at the EC buoy station, Lagoon City station, and the Barrie station. The wind speed measured at the buoy station is closer to the data measured at Lagoon City. The data measured at the buoy station should more accurately represent the wind conditions on the lake. However, there is a lot of missing data from the buoy. Since the model focuses on the long-term simulation in the lake, it is not necessary to use the spatial wind data for the simulation. The wind data measured at the Lagoon City station were therefore selected for model input. In future, it may be worthwhile to revisit the development of wind input data for the lake to improve the definition of spatially and temporally varying wind fields.

5.2.1.2 Air Temperature and Evaporation

Air temperature at the water surface was used to calculate the heat exchange between air and water. Water in the lake loses heat through molecular mixing and evaporation if the air temperature is less than the water temperature. Air temperature as well as wind has a significant impact on the cooling period of water in the fall. The air temperature measured at the Lagoon City station is not significantly different from that measured at the Barrie station (see Figure 3.2 for locations) and at the Environment Canada Buoy e45151 as shown in Figure 5.4. The data from Lagoon City station was used as input air temperature data for the entire lake.

5.2.1.3 Relative Humidity

Relative humidity is used to calculate the evaporation and heat exchange at the water surface of the lake. The recorded precipitation at the Lagoon City station was used. Data gaps were filled using the relative humidity data measured at the Barrie station, i.e. the relative humidity measured at the Barrie Station is used if the data is missing in Lagoon City Station.
5.2.1.4 Precipitation and Rain Droplet Temperature

Rainfall with its associated rain droplet temperature must be specified for the model. The recorded precipitation at the Lagoon City station was used. Since there is no measurement for rain droplet temperature, it was assumed that it is equal to air temperature. The water temperature in the lake is not highly sensitive to rain droplet temperature as the input to the lake directly from rainfall is very small compared with the contribution from streams, and the water volume in the lake.

5.2.1.4 Cloud Cover

The cloud coverage data was used to calculate the absorption of the solar radiation from the atmosphere to the water surface. There is no cloud coverage data available at the Lagoon City station. The data measured at the Toronto Peterson International Airport (nearest station for which there are measurements) were therefore used in the modeling setup.

5.2.2 Lake Bottom

Theoretically, the boundary conditions at the lake bottom include the bottom friction, heat exchange between water and bed sediment, and the release of nutrients from the bed. Based on our experience during previous applications of the model, a constant value for bed roughness (=0.20) was initially assumed and then refined during calibration of the hydrodynamic model. Since the model components applied for this study did not include sediment transport algorithms, no heat exchange between bed sediment and water was considered. The release of nutrients from the bed sediment is described below.

5.2.3 Inflows and Outflows

There are five main rivers, sixteen small creeks, and one outlet surrounding Lake Simcoe. The rivers and creeks are the main point sources of nutrients to the lake. All rivers and creeks are processed as the sources in the model. The discharge, water temperature, and nutrient loads must be specified at these inlets and for the outlet for those times when there is reverse flow into Lake Simcoe from Lake Couchiching through Atherley Narrows.

5.2.3.1 Discharge

The model includes 21 rivers and streams and the outlet at Atherley Narrows flowing into Lake Simcoe as follows: (1) Holland River; (2) Black River; (3) Pefferlaw Creeks; (4) Beaver River; (5) Talbot River; Creeks; (6) back water from Atherley Narrows; (7)
Hawkestone; (8) Lovers; (9) Whites; (10) Keswick; (11) Maskononge; (12) Georgina; (13) Jacksons Point; (14) Beaverton; (15) Talbot; (16) Ramara; (17) Oro North; (18) Cathew Bay; (19) Oro South; (20) Barrie (small creeks in Barrie); (21) Hewitts; and (22) Innisfil Creeks. The location of each of these streams was modeled based on their UTM coordinates to accurately simulate local environmental and ecological response to their loading within the lake. The locations of the rivers and streams are shown in Figure 5.5.

There are Environment Canada gauges on all of the main rivers flowing into Lake Simcoe as shown in Figure 3.2. Only the five main rivers were included in the hydrodynamic simulation since the discharge from the small creeks is generally small and has no significant contribution to the circulation in the lake. However, the nutrient loading from all twenty-two rivers, creeks and inlets was included in the eutrophication model.

### 5.2.3.2 Water Temperature in Rivers

Water temperature in the rivers is required for model input. The water temperature in the river may have significant impact on the local temperature pattern near the river mouth but solar radiation has the most significant impact on the lake temperature. Generally, water temperature in a river correlates with air temperature as shown in Figure 5.6. The non-linear correlation described in Morrill (2005) was used to define water temperature in the rivers based on the measured water temperature at the Holland River as provided in Burnside (2005).

\[
T_s = \mu + \frac{\alpha - \mu}{1 + \gamma(\beta - T_a)}
\]

where \( T_s \) is estimated stream temperature and \( T_a \) is measured air temperature for the period of interest. There are four parameters: \( \mu \) is minimum stream temperature (=0.5); \( \alpha \) is maximum stream temperature (29°C); \( \gamma \) is function of the steepest slope (inflection point) of the \( T_s \) function (when plotted against \( T_a \)) (0.18); and \( \beta \) is air temperature at this inflection point (12°C). This correlation is shown in Figure 5.7. This equation was used for all other streams since there was no water temperature data in the streams. Air temperature was defined based on the nearest climate station.

### 5.2.3.2 Lake Outflow

The only outflow from Lake Simcoe is through Atherley Narrows to Lake Couchiching. Based on the discharge data provided by Environment Canada and the modeling results, reverse flow at Atherley Narrows occurs when there is lake level set-down near the outlet to Lake Couchiching. The hydrodynamic boundary condition at the outlet was set as the measured lake water level. The water temperature and water quality boundary condition
for the reverse flow conditions (where water flows into Lake Simcoe from Lake Couchiching) were set by assuming the water temperature and water quality conditions near the outlet in Lake Simcoe would be similar to those in Lake Couchiching (in the absence of measured data for Lake Couchiching). This was achieved by first running the Lake Simcoe model using a constant water temperature and water quality for reverse flow from Atherley Narrows, and then extracting the results from that model run to set the boundary condition as noted above.

5.3 Nutrient Loading

As described in Section 5.2, the model is set up to calculate daily hydrodynamic and nutrient load based on specified daily flow rate and nutrient concentrations in respective source streams. Thus, the model requires as input the daily stream flow and its water quality parameters for each source stream to the lake.

Non-point source loadings such as urban runoff and septic load were included in the loading for the major subwatershed in which they were located. The model added these non-point sources by means of the stream draining that catchment to the lake. Similarly, water and nutrient loads from the wastewater treatment plant (WWTPs) effluents were combined with appropriate nearby stream flow to reduce the total number of source files for easy manipulation of the model. A time series model input file was prepared for each of the streams listed in Section 5.2.3.1. The file included stream flow, urban runoff sources, relevant septic load, and effluents from wastewater treatment plants (WWTPs) within its watershed.


As described in Section 5.2.3.1, MOE gauged stations recording the daily stream flows are located on the five main rivers. Measured daily stream flows, as provided by MOE, were used where available. For the streams that are not gauged, the daily flow rates were estimated by MOE assuming the same unit flow (m³/sec/km²) of a gauged stream with similar watershed characteristics when compared with the watershed of the ungauged stream. The unit flow for a gauged stream was calculated as

[2] Unit Flow (m³/s/km²) = \frac{\text{Daily Measured Flow (m}^3/\text{s})}{\text{Watershed Drainage Area (km}^2\text{)}}

Thus, the flow rate for an ungauged stream was calculated by MOE as:
Flow Rate Ungauged Stream \( (m^3/s) = \text{Unit Flow of a Similar Watershed (m}^3/s/km^2) \times \text{Total Drainage Area of the Ungauged Stream (Km}^2) \)

Equally distributed daily water flow rates were assumed, when the monthly averages of stream flow were the only available data. Urban runoff was calculated by MOE as water surplus based on the water balance using the daily precipitation data and average infiltration coefficient of 150 mm/yr for the entire Lake Simcoe watershed. These calculations were provided by MOE but details of all methods were not provided. The following is a simplified calculation to estimate urban runoff for Lake Simcoe:

\[
\text{Water Surplus (as runoff)} = \text{Precipitation} - \text{Evapotranspiration} - \text{Infiltration}
\]

It was assumed that in reality, septic systems within a 100 m distance of Lake Simcoe discharge effluent directly into the lake (although this load was modeled by adding it by means of the stream draining the subwatershed in which they were located, see above). The Ministry of Environment (MOE) estimated that there are 3,279 septic systems within 100 m of the Lake Simcoe shoreline and that these represent an additional nutrient load from 2087 ha. The total figures include 1,924 systems servicing permanent homes and 1,355 systems servicing seasonal homes. The MOE data assumes a per-capita phosphorus contribution based on usage of 2.56 capita years/year for permanent homes and 0.68 capita years/year for seasonal usage. The seasonal usage figure was increased to the MOE’s “extended seasonal” usage figure of 1.23 capita years/year, to reflect a) the proximity of Lake Simcoe to large urban centres, b) the popularity of Lake Simcoe for winter use such as ice fishing and snowmobiling and c) the easy access to Lake Simcoe provided by the large number of all weather roads in the watershed. All of these factors would increase the seasonal usage factor, and hence potential phosphorus loading, from lakeside residences. The septic contribution was based on MOE’s assumption of 66% total phosphorus mobility for the septic load, (i.e. only 66% of the total phosphorus in septic effluent reached the lake), although it is acknowledged that there is considerable scientific debate regarding the mobility of septic system-derived phosphorus. Total annual loading from septic systems was therefore estimated as 3,251 kg/yr from permanent homes and 1,100 kg/yr from seasonal homes for a total of 4,351 kg/yr.

The septic system data provided by the MOE was given as a total lake load. In reality, septic systems are dispersed around the lake perimeter and should be modeled as non-point source input. Locational data for individual septs was not provided, however, and it would neither be practical, nor would it improve model resolution, to assign individual point sources to 3279 septic systems that collectively accounted for a small fraction of the total lake load.

The total septic load was therefore distributed to each of the 15 major sub-watersheds of the lake as a function of the proportion of the lake’s perimeter represented by that sub-watershed based on LSRCA (2003) as listed in Table 5.1 below. The actual shoreline length was not required to do this, as the septic systems were assigned by proportion. The
septic load was then included in the loading from the major tributary that drained that basin. Annual average flow was estimated from the loading estimate by assuming a septic phosphorus concentration of 10 mg/L. This estimate was an average of published averages of 13.2 mg/L (Dillon et al., 1986), 8.2 mg/L (Hutchinson, 2002) and 9 mg/L (Paterson et. al, 2006).

Table 5.1: Septic Phosphorus Contribution to Lake Simcoe

<table>
<thead>
<tr>
<th>Subwatershed Area</th>
<th>Proportion of Lake Perimeter</th>
<th>No. Septics - Permanent</th>
<th>No. Septics - Seasonal</th>
<th>Conc (mg/L)</th>
<th>Permanent Load (kg/yr)</th>
<th>Average Flow Permanent (L/sec)</th>
<th>Seasonal Load (kg)</th>
<th>Average Flow Seasonal (L/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Innisfil Creeks</td>
<td>0.22</td>
<td>426.97</td>
<td>300.70</td>
<td>10.00</td>
<td>721.41</td>
<td>2.29</td>
<td>244.11</td>
<td>0.77</td>
</tr>
<tr>
<td>Hewitts Creek</td>
<td>0.01</td>
<td>15.81</td>
<td>11.14</td>
<td>10.00</td>
<td>26.72</td>
<td>0.08</td>
<td>9.04</td>
<td>0.03</td>
</tr>
<tr>
<td>Oro Creek South</td>
<td>0.08</td>
<td>163.41</td>
<td>115.08</td>
<td>10.00</td>
<td>276.09</td>
<td>0.88</td>
<td>93.42</td>
<td>0.30</td>
</tr>
<tr>
<td>Oro Creeks North</td>
<td>0.08</td>
<td>147.59</td>
<td>103.95</td>
<td>10.00</td>
<td>249.38</td>
<td>0.79</td>
<td>84.38</td>
<td>0.27</td>
</tr>
<tr>
<td>Hawkestone Creek</td>
<td>0.01</td>
<td>21.08</td>
<td>14.85</td>
<td>10.00</td>
<td>35.63</td>
<td>0.11</td>
<td>12.05</td>
<td>0.04</td>
</tr>
<tr>
<td>Orillia</td>
<td>0.03</td>
<td>57.98</td>
<td>40.84</td>
<td>10.00</td>
<td>97.97</td>
<td>0.31</td>
<td>33.15</td>
<td>0.11</td>
</tr>
<tr>
<td>Ramara Creeks</td>
<td>0.21</td>
<td>405.88</td>
<td>285.85</td>
<td>10.00</td>
<td>685.78</td>
<td>2.17</td>
<td>232.05</td>
<td>0.74</td>
</tr>
<tr>
<td>Talbot River</td>
<td>0.01</td>
<td>28.36</td>
<td>18.56</td>
<td>10.00</td>
<td>44.53</td>
<td>0.14</td>
<td>15.07</td>
<td>0.05</td>
</tr>
<tr>
<td>Whites Creek</td>
<td>0.03</td>
<td>52.71</td>
<td>37.12</td>
<td>10.00</td>
<td>89.06</td>
<td>0.28</td>
<td>30.14</td>
<td>0.10</td>
</tr>
<tr>
<td>Beaver River</td>
<td>0.01</td>
<td>15.81</td>
<td>11.14</td>
<td>10.00</td>
<td>26.72</td>
<td>0.08</td>
<td>9.04</td>
<td>0.03</td>
</tr>
<tr>
<td>Pefferlaw brook</td>
<td>0.05</td>
<td>105.42</td>
<td>74.25</td>
<td>10.00</td>
<td>178.13</td>
<td>0.56</td>
<td>60.27</td>
<td>0.19</td>
</tr>
<tr>
<td>Black River</td>
<td>0.08</td>
<td>158.14</td>
<td>111.37</td>
<td>10.00</td>
<td>267.19</td>
<td>0.85</td>
<td>90.41</td>
<td>0.29</td>
</tr>
<tr>
<td>Georgina Creeks</td>
<td>0.13</td>
<td>250.29</td>
<td>181.90</td>
<td>10.00</td>
<td>436.41</td>
<td>1.38</td>
<td>147.67</td>
<td>0.47</td>
</tr>
<tr>
<td>East Holland</td>
<td>0.02</td>
<td>36.90</td>
<td>25.99</td>
<td>10.00</td>
<td>62.34</td>
<td>0.20</td>
<td>21.10</td>
<td>0.07</td>
</tr>
<tr>
<td>Maskinonge</td>
<td>0.02</td>
<td>31.63</td>
<td>22.27</td>
<td>10.00</td>
<td>53.44</td>
<td>0.17</td>
<td>18.08</td>
<td>0.06</td>
</tr>
<tr>
<td>Total</td>
<td>1.00</td>
<td>1924</td>
<td>1355</td>
<td></td>
<td>3251</td>
<td>3251</td>
<td></td>
<td>1100</td>
</tr>
</tbody>
</table>

For seasonal residences, annual septic flow was distributed to each month based on the annual loading figures provided by MOE and the following assumptions of residential use: 100% usage in summer (June to September), 50% usage in winter (January to March), 25% usage in shoulder seasons (May and October), 10% usage in December and no usage in April or November.

The recorded total monthly discharge for each WWTP was provided by MOE. The monthly discharge was divided into equivalent daily flows and loads for the model input.

The model also includes the nutrient loading via direct atmospheric deposition on the lake surface. This is calculated as a product of daily precipitation rates (mm/day) and measured nutrient concentrations (g/m³) in the precipitation. Daily precipitation from the Lagoon City meteorological station was used. Total nutrient loading via atmospheric deposition was provided by MOE. In order to calculate the nutrient concentration in the precipitation we considered two aspects: (1) periodically measured concentrations were used for the days they were available, and (2) values were interpolated for the days when the measured concentrations were not available and a check was carried out to ensure that the total loading for that month did not exceed the estimated total monthly loading provided by MOE.

For most of the point and non-point sources, only the measured or estimated concentrations of total phosphorus (TP) and nitrogen (TN) were available. The model, however, requires input of other water quality parameters for the complete loading data.
The following is a list of water quality parameters (in g/m³) required for each source stream as input to the model:

1. Phytoplankton Carbon (PC),
2. Phytoplankton Nitrogen (PN),
3. Phytoplankton Phosphorus (PN),
4. Chlorophyll a (Chl-a),
5. Zooplankton Carbon (ZC),
6. Detritus Carbon (DC),
7. Detritus Nitrogen (DN),
8. Detritus Phosphorus (DP),
9. Inorganic Nitrogen (IN),
10. Inorganic Phosphorus (IP), and
11. Dissolved Oxygen (DO).

Since nearly all of these data are not measured in Lake Simcoe or its tributaries, it was necessary to make several assumptions to complete the input files and to adjust these to assess model sensitivity over the course of calibration. This was done to converge the model on the final output but we recommend that a) measured data be obtained and b) further sensitivity analysis on the model be undertaken to assess the importance of these assumptions.

1. The total phosphorus and nitrogen load was divided into inorganic and organic load using a fixed partition coefficients of 0.8 and 0.7. Thus, it was assumed that 80% of the total nitrogen and 70% of the total phosphorus load is in the form of Inorganic Nitrogen (IN) and Inorganic Phosphorus (IP), respectively. The organic fraction of phosphorus and nitrogen was then divided into phytoplankton, zooplankton and detritus forms using the literature available\(^1\) on cell compositions of these groups to provide the following: phytoplankton composition is 70 gPC/m³ : 150 mgPN/m³ : 20 mgPP/m³; zooplankton composition is 100 gZC/m³ : 7 gZN/m³ : 0.2 gZP/m³; detritus composition is 36 gDC/m³ : 7.2 gDN/m³ : 1 gDP/m³.

2. The phytoplankton biomass contains an average of 1.5% of chlorophyll “a” (Chl a). In order to divide the organic load into phytoplankton, zooplankton and detritus fractions, it was further assumed that all streams have Chlor A and zooplankton concentrations of 0.65 mg/L and 50 mg/L respectively.

In the absence of measured dissolved oxygen concentrations, it was assumed that all streams remain oxic throughout the year with a dissolved oxygen level of 9 mg/L.

\(^1\) the author of the literature review of these coefficients has been contacted to provide the rationale and summaries and these will be forwarded at a later date
5.4 Initial Conditions

The model was set up to model water quality during the ice-free period, from April 1 to November 30. This was done to coincide with availability of MOE data for the open water stations for calibration and because the MIKE3 Hydrodynamic Model does not simulate ice formation, ice loss or under-ice conditions in a lake. In future, it is possible that ice formation could be simulated using the ECO Lab module. The selection of the ice-free period for modeling allows water quality to be modeled during the key period of interest – the summer growth season and the end of summer period of minimum dissolved oxygen saturation in the hypolimnion. Development of a continuous model of lake response is recommended as a next stage, as described in Section 9.

The initial conditions, that is, the values of the variables at the beginning of the simulation, must be specified in the model. It is not critical to accurately define the initial hydrodynamic conditions, as any error in the initial condition will quickly disappear with the correct boundary conditions. Average lake level and zero velocity were therefore used as initial conditions. Based on the model testing, the initial setup for the hydrodynamic simulation impacts the model results only for the first few days and does not impact the modeling results for the remainder of the simulation period.

The initial condition for temperature has no significant impact on the long-term thermal simulation. If there is error introduced in the initial condition, it adjusts to the correct temperature within a few days. A constant temperature of 4 °C was specified for the initial temperature.

The initial conditions for eutrophication simulation have some impact on the phytoplankton production at the beginning of the simulation. There are twelve state variables in the eutrophication model, i.e. Phytoplankton Carbon, Phytoplankton Nitrogen, Phytoplankton Phosphorus, Chlorophyll “a”, Zooplankton Carbon, Detritus Carbon, Detritus Nitrogen, Detritus Phosphorus, Inorganic Nitrogen, Inorganic Phosphorus, Dissolved Oxygen, and Benthic Vegetation Carbon. The initial values of all state variables at the beginning of the simulation are required.

The earliest measured data for 2001 were for June 3. The model had to be run for earlier in the season, however, in order to capture the correct conditions for the spring diatom bloom in the lake and to achieve stable realistic conditions for modeling the summer transition to green algal growth. Therefore, April 1 was chosen as the model start up to capture the spring freshet to the lake, and, in the absence of data, the initial condition for April 1 became one of the calibration parameters. Fortunately, the impacts of the initial condition on the model results are limited to the first half-month of simulation based on the results of model sensitivity tests. The initial condition for the twelve state variables was set as the lake average values calculated from the earliest available measurements. The initial conditions were then adjusted during the model calibration, as described in Section 6.
The MOE measurements for model loading input only provide total nitrogen and phosphorus. However, as noted above, the model requires inputs for four components, i.e. phytoplankton, zooplankton, detritus, and inorganics (or dissolved). The proportions of these components to the total values were unknown and will vary with time due to temperature change and nutrient dynamics in the tributaries and the lake. Nutrient partitioning therefore became another calibration parameter in the model, which will be described in the calibration section below. The model was initially set up assuming proportions of 80% inorganics and 20% organic.
Figure 5.1  Model Bathymetry Grid
Figure 5.2  Impact of Constant and Spatially Varied Wind Data on Temperature Profile

Profile Change with Wind Data
(at MOE Station K39)

Temperature (°C)

Water Depth (m)

- Constant
- Spatial
- Measured

Figure 5.2  Impact of Constant and Spatially Varied Wind Data on Temperature Profile
Wind Speed at Lagoon City Station, Barrie (Auto) Station and from the Buoy

Figure 5.3  Comparison of Wind Speed at Lagoon City, Barrie and the EC Buoy
Figure 5.4 Air Temperature Comparison between Lagoon City Station, Barrie (Auto) Station and EC Buoy e45151
Figure 5.5  Map showing Locations of Rivers and Streams in the Watershed (dimensions indicate river mouth width)
Temperature Comparison of Holland River and atmosphere Temperature (Amplified)

Figure 5.6 Comparison of Air and Stream Temperature for the Holland River

Date

Air Temperature at Cooks Town Weather Station
Water Temperature at the Holland River
Weekly moving mean air temperature

Temp (°C)

1/01/87 7/20/87 2/05/88 8/23/88 3/11/89 9/27/89
Figure 5.7  Relationship used to Define Stream Temperature
6 MODEL CALIBRATION

There are two purposes of model calibration: a) selecting appropriate parameters which are generally site specific and b) checking and refining the ability of the model to reproduce measured monitoring data. Since the calibration process is very time consuming, the model was decoupled for calibration, that is, the hydrodynamic model was calibrated first and the water quality was then calibrated using the calibrated hydrodynamics. A detailed description of the model calibration is provided in this section.

6.1 Hydrodynamic Model

6.1.1 Lake Level

The water levels in Lake Simcoe vary seasonally. The lake levels are higher in summer and lower in winter. The rise and fall of the lake level is a function of runoff, over-lake precipitation and evaporation (the latter process influenced by many factors including but not limited to air-water temperature difference and wind speed). Figure 6.1 shows a comparison between the modeled hourly lake levels and the measured daily lake levels. Note that the large variation of the modeled lake levels is caused by storm surges and seiching during storm events. Seiching is the process of sloshing of water within the lake following an initial storm surge or setup on one part of the lake. The impact of seiching on the measured daily average water level data would not be discernable due to the small seiche period (generally less than 3 hours). Clearly, the model results agree well with the measured values.

6.1.2 Currents

The wind drag factor and bottom friction are the two primary variables used for calibration of the hydrodynamics. The wind drag factor is a function of wind speed. The default values were initially used for both the drag factor and bottom friction. All input parameters are provided in the digital copy of the model.

No direct current calibration was carried out in the model since we are not aware of any current data that were available prior to this study. As part of this study, ADCP data were collected as described in Section 3.5. Although there was insufficient time and budget to re-calibrate the model with the ADCP data, a qualitative comparison was undertaken.
The modeled current data for 2002 was compared with the ADCP data collected by Baird in 2005. Figures 6.2 and 6.3 show predicted (2002) and measured data (2005) at the surface and at 10 m below the surface, respectively. The comparison of the currents measured in 2005 and the modeled currents for 2002 indicates that the overall flow generated by the model is in the same order of magnitude as flow measured in the field. Although this does not represent calibration of the model, it does confirm that the modeled currents are reasonable for the lake.

Although it is recommended that the model be calibrated with the ADCP data, we are confident that the hydrodynamic model generally reproduces flow patterns based on the comparison of predicted and measured temperature. The advection and diffusion of these variables depends on the hydrodynamic modeling results, and if the model were not hydrodynamically well calibrated, the predicted temperature and water quality data would not agree with measured values. It is therefore our opinion that the model generally reproduces the flow patterns in the lake.

### 6.1.3 Temperature

Temperature is one of the key factors for algal production. The water temperatures predicted by the model were calibrated with: a) temperature profiles at the MOE stations in the lake (see Figure 3.2 for locations); and b) the time series temperature data from the water treatment plant intakes. The temperature profiles from the MOE stations were used to verify whether the model could accurately reproduce the temperature stratification in the summer (as input to model predictions of DO reduction in the hypolimnion). The time series data from the intakes were used to check whether the model could correctly generate the seasonal and continuous temperature variation that is important for the algae development through the year.

Figures 6.4 and 6.5 show the comparison between the model predicted temperature profiles and those measured at MOE stations C6 and K42. Data for the remaining stations is provided in Appendix A. The model successfully simulated the thermocline development in the early summer and the thermocline disappearance in the fall. The discrepancy between model predicted and measured temperature profiles at some stations during isolated time frames, for example July 13 at K45 and K39 and Sept. 3 at K45, may be due to the use of constant wind data as opposed to spatially varied data. As discussed in Section 5.2.1.1, wind data measured at Lagoon City was applied to the entire lake on the basis that it would not cause significant impacts on the prediction of temperature profiles over the period of weeks. However, for individual storm events the spatial variation of winds over the lake may be significant and may be responsible for errors in these individual profiles. While use of a spatially constant wind speed for the entire lake is likely the primary explanation for these differences, other factors influencing the internal dynamics of the thermocline fluctuations, such as bottom friction, may play a secondary role in observed differences between measured and predicted temperature profiles.
Figures 6.6 to 6.12 show the comparison of the model predicted temperature with the measured data at the six intakes and one EC buoy station. The model successfully reproduced most water temperature peaks and lows observed at various time scales through the year. In the lake cooling period after the end of August, the model slightly over-predicted the temperature at the intakes at South Ramara and Lagoon City. This may be caused by local hydrodynamic conditions such as waves that are not currently considered in the model. The waves could increase evaporation and contribute to faster cooling of the lake water. It is possible that waves may be consistently higher at the north-east side of the lake than the south-west side in the fall season, as the seasonal wind is mostly from the south-west.

Recommendations for future temperature measurements are to: 1) collect data at locations susceptible to upwellings and downwellings; and 2) to collect more continuous measurements of temperature profile to confirm the very dynamic nature of the thermocline predicted by the numerical model.

### 6.2 Water Quality Calibration

Calibration of the ECO Lab water quality module was a long and involved process. This reflected several factors, most notably the complexity of the processes and the related model representation, and the detailed data requirements for the model and resultant need to make estimates and assess model sensitivity in the absence of measured data.

ECO Lab provides a template for eutrophication modeling which has 71 parameters to be adjusted during the model calibration. Though default values are provided for a number of these parameters based on their physical meaning, there are still 22 parameters that are site specific and must be adjusted through the calibration. These parameters are inter-related and adjustments to one parameter may affect others. Therefore, a large number of runs were required during the calibration phase.

The calibration phase proceeded with two goals:

- First, to produce reasonable estimates of the temporal average water quality conditions in Lake Simcoe for the ice free period of 2001,
- And second to duplicate seasonal trends in water quality parameters over the ice-free period for 2001.

Calibration of the ECO Lab module proceeded in two steps. Firstly, the nutrient indicators (i.e. total phosphorus and total nitrogen) and chlorophyll “a” were modeled and model parameters adjusted to achieve reasonable correspondence with the measured data. Once the nutrient indicators were satisfactory then the model parameters were adjusted to model dissolved oxygen.
Trends and average response were considered more important than point-to-point correspondence between measured data and modeled estimates for the same day. Measurements of phosphorus and chlorophyll “a” in particular, are influenced by the presence of particulate matter in the water and anomalous values in the data record are not uncommon. These cannot be captured in a modeling exercise. As such, the calibration focused on capturing seasonal trends and average responses.

Although phosphorus and chlorophyll “a” data were provided for several water intakes around the lake, the calibration exercise was focused on MOE’s in-lake stations. This was done for several reasons. First, the intake sites are all in shallow, nearshore areas. As such, they are not suitable for modeling dissolved oxygen, because oxygen consumption processes are offset by turbulent mixing with the atmosphere. Secondly, all of the dynamics associated with nearshore regions were not captured in this application of the model (e.g. overland runoff, greater number of tributary inputs, wind driven and waves, and re-suspension of sediments by wind driven waves and currents). Finally, the management objective of the modeling project is focused on the response of dissolved oxygen in the hypolimnetic habitat of cold-water fish in Lake Simcoe. It was therefore prudent to focus the dissolved oxygen calibration on the deep water sites.

Under the timeline and budget constraints of the project, it was not possible to apply the calibrated model from 2001 to another year to provide an independent validation of the model. Nevertheless, model verification for an additional ice-free season is recommended, preferably with improved information on initial and input conditions. Also, it is recommended, the representation of nearshore dynamic processes in the model are improved in the future.

### 6.2.1 Phosphorus at MOE Stations

Table 6.1 shows the total annual loadings of phosphorus (including atmospheric, tributaries and direct loading) to Lake Simcoe for 1998-2004 based on data provided by MOE. The model was calibrated to the 2001-2002 data (53-67 tonnes per year), which is a mid range year for phosphorus loading.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>65</td>
<td>76</td>
<td>71</td>
<td>53</td>
<td>67</td>
<td>72</td>
<td></td>
</tr>
</tbody>
</table>

Phosphorus modeling proceeded with the intent of successfully capturing average conditions and seasonality of phosphorus concentrations in the lake. Table 6.2 shows the average, minimum and maximum concentrations of total phosphorus measured at the
8 MOE stations in Lake Simcoe between June 3 and November 2, 2001. Figure 6.13 shows the seasonal trend for 2001 at each of the stations.

Table 6.2  Average, Maximum and Minimum Phosphorus Concentrations at MOE Monitoring Stations in 2001

<table>
<thead>
<tr>
<th>MOE Station</th>
<th>E51</th>
<th>K45</th>
<th>S15</th>
<th>K42</th>
<th>K39</th>
<th>C9</th>
<th>C6</th>
<th>C1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>0.014</td>
<td>0.013</td>
<td>0.016</td>
<td>0.015</td>
<td>0.015</td>
<td>0.016</td>
<td>0.017</td>
<td>0.0184</td>
</tr>
<tr>
<td>Minimum</td>
<td>0.006</td>
<td>0.008</td>
<td>0.006</td>
<td>0.008</td>
<td>0.01</td>
<td>0.012</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Maximum</td>
<td>0.016</td>
<td>0.024</td>
<td>0.032</td>
<td>0.022</td>
<td>0.02</td>
<td>0.036</td>
<td>0.022</td>
<td>0.05</td>
</tr>
<tr>
<td>n</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>10</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>10</td>
</tr>
</tbody>
</table>

Figures 6.14 and 6.15 show the comparison of the modeled total phosphorus (TP) to the measurements at the MOE stations. The model reproduced the TP well in deep water. Values were over-predicted at some of the shallow water stations such as C1 (Cook Bay). This over-prediction likely resulted from the inappropriate specification of nutrient loading from the Holland River. Over-prediction was most pronounced in the spring, and in shallow sites, suggesting that future calibration or monitoring efforts should focus on settling of phosphorus in shallow areas, uptake by rooted aquatic plants or refinement of the amount of particulate phosphorus in major inflows. The latter point is particularly important. If total phosphorus is input to the model as inorganic, it remains in the water column until assimilated by plant growth and settling. If it is input as particulate, it settles from the water column into the sediments quickly, without being taken up into the plant growth.

6.2.2  Nitrogen (at MOE Stations)

Calibration of the model for nitrogen proceeded with the intent of successfully capturing average conditions and seasonality of total nitrogen concentrations in the lake. Table 6.3 shows the average, minimum and maximum concentrations of total nitrogen measured at the 8 MOE stations in Lake Simcoe between June 3 and November 2, 2001. Figure 6.16 shows the seasonal trend for 2001.

Table 6.3  Average, Maximum and Minimum Nitrogen Concentrations at MOE Monitoring Stations in 2001

<table>
<thead>
<tr>
<th>MOE Station</th>
<th>E51</th>
<th>K45</th>
<th>S15</th>
<th>K42</th>
<th>K39</th>
<th>C9</th>
<th>C6</th>
<th>C1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>0.426</td>
<td>0.415</td>
<td>0.427</td>
<td>0.499</td>
<td>0.451</td>
<td>0.425</td>
<td>0.461</td>
<td>0.478</td>
</tr>
<tr>
<td>Minimum</td>
<td>0.376</td>
<td>0.377</td>
<td>0.360</td>
<td>0.382</td>
<td>0.400</td>
<td>0.364</td>
<td>0.394</td>
<td>0.344</td>
</tr>
<tr>
<td>Maximum</td>
<td>0.496</td>
<td>0.500</td>
<td>0.552</td>
<td>0.918</td>
<td>0.568</td>
<td>0.526</td>
<td>0.710</td>
<td>0.680</td>
</tr>
<tr>
<td>n</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>11</td>
</tr>
</tbody>
</table>
Figure 6.17 shows the comparison of the modeled total nitrogen (TN) to the measurement at the MOE stations. The model predicted TN at the MOE stations generally agrees well with the measurements. One exception is the exaggerated decay in N at Station E51 and a tendency to under-prediction in the shallow Cook Bay sites.

### 6.2.3 Chlorophyll “a” (at MOE Stations)

Table 6.4 shows the average, minimum and maximum concentrations of chlorophyll “a” measured at the 8 MOE stations in Lake Simcoe between June 3 and November 2, 2001. Figure 6.18 shows the seasonal trend for 2001.

**Table 6.4  Average, Maximum and Minimum Chlorophyll “a” Concentrations at MOE Monitoring Stations in 2001**

<table>
<thead>
<tr>
<th>Chlorophyll &quot;a&quot;</th>
<th>MOE Station</th>
<th>E51</th>
<th>K45</th>
<th>S15</th>
<th>K42</th>
<th>K39</th>
<th>C9</th>
<th>C6</th>
<th>C1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td></td>
<td>0.0021</td>
<td>0.0027</td>
<td>0.0026</td>
<td>0.0032</td>
<td>0.0031</td>
<td>0.0028</td>
<td>0.0024</td>
<td>0.0036</td>
</tr>
<tr>
<td>Minimum</td>
<td></td>
<td>0.0010</td>
<td>0.0012</td>
<td>0.0012</td>
<td>0.0010</td>
<td>0.0010</td>
<td>0.0010</td>
<td>0.0010</td>
<td>0.0006</td>
</tr>
<tr>
<td>Maximum</td>
<td></td>
<td>0.0048</td>
<td>0.0046</td>
<td>0.0042</td>
<td>0.0052</td>
<td>0.0048</td>
<td>0.0040</td>
<td>0.0036</td>
<td>0.0026</td>
</tr>
<tr>
<td>n =</td>
<td></td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>11</td>
</tr>
</tbody>
</table>

Figures 6.19 and 6.20 show the comparison of the model predicted chlorophyll “a” (Chl “a”) to measured data at the MOE stations. Generally, the predicted results agree well with the measurements. The algal increases in early spring, the beginning of summer, the end of summer, and the end of fall were successfully simulated. The algal production relies on three factors: photosynthetically active solar radiation (PAR), temperature, and nutrients. In the early spring, the diatoms grow quickly due to rising temperatures and intensifying PAR. The growth reaches a peak in early May, which corresponds to the peak found in the PAR data (see Figure 6.21). The green algae becomes dominant from the beginning of summer. The peak in the quantity of algae in the early summer is likely caused by the quick growth of green algae due to high temperatures as shown in Figure 6.22, while the peak at the end of summer is likely caused by high temperatures and the second peak of PAR (see Figure 6.21). At the end of the fall, the peak of algal growth may be related to increased nutrient levels, which may result from the sloughing of benthic vegetation.

The model over-predicted the quantity of algae in shallow water areas. This over-prediction is likely caused by an incorrect partitioning of inorganic and organic nutrients, and possibly due to the limitations in the representation of nearshore dynamics. MOE provides total nitrogen and phosphorus data from the streams and atmosphere. However, the model requires independent inputs for phytoplankton, zooplankton, detritus, and inorganic forms. Therefore, the partitioning of these four components to the total must be specified. These data are not provided by MOE and the proportions
must therefore be assumed and either confirmed by monitoring or refined in the future by a sensitivity analysis.

Through the model sensitivity tests, it was determined that the production of phytoplankton carbon is sensitive to the partitioning of the inorganic and organic forms of nutrients. It was found that the input of a large proportion of inorganic material could result in rapid algal blooms over a short period. The in-lake proportion of inorganic material to the total nutrient varies with time. The proportion of inorganic material is reduced with algal growth. Therefore, the in-lake proportion of inorganic material is high in the spring and fall season but low in the summer season. This is likely also the case for the proportion in the streams. However, since there is no time series partitioning data for the nutrient components, a constant nutrient partitioning was used through the entire simulation period. The inability to specify variation in the nutrient partitioning may have induced higher algal growth at the nearshore stations and particularly in areas close to river mouths. Other factors to consider include partitioning of nutrients into aquatic macrophytes as well as into phytoplankton.

6.2.4 \textit{P,N and Chlorophyll “a” (at Intakes)}

Figures 6.23 to 6.25 show the comparison of the modeled TP, TN, and Chl-a at the three intakes. It is seen that the model reproduces TP and TN well but over-predicts the Chl-a. This may reflect the inappropriate specification of the partitioning of nutrients in the stream loading as mentioned above and highlights the differences in model response between deep water and shallow water sites. It may also, however, reflect the influence of zebra mussels, which would be highest in the shallow water sites at the intakes, but which has not been considered in the current model.

6.2.5 \textit{Secchi Depth}

The model was calibrated for Secchi depth. Secchi depth readings provide a measurement of water clarity and, as a general rule, Secchi depth multiplied by 2.5 provides an approximation of the depth of light penetration in the water column.\textsuperscript{2}.

The depth to which light penetrates defines the euphotic zone, where photosynthesis can occur. Secchi depth readings vary seasonally and are an indication of algal growth, filtering by zebra mussels and resuspension of particulates in shallow areas. Figure 6.26 shows that the model provided a reasonable estimate of Secchi depth in the early summer response to algal growth, but that it underestimated Secchi depth in the late summer. The late summer estimates likely reflect the influence of zebra mussels, which are not included in this model formulation. We note that, although zebra mussel filtration is confined to shallow water because of their habitat preference and stratification of the

\textsuperscript{2} Bench sheets provided by the MOE for their water quality surveys of Lake Simcoe as part of this project, for example, used 2.5 x Secchi depth to estimate this depth, termed the compensation depth
lakes, that their influence is lake-wide. They produce a net removal of particulate matter from the entire epilimnneite water mass, and this water is moved about the lake by wind-driven currents.

6.2.6 **Dissolved Oxygen**

The objective of the modeling was to reproduce dissolved oxygen distribution with depth in the lake, during the ice-free period. Dissolved oxygen dynamics in epilimnetic waters were of less interest for the calibration exercise, as photosynthesis plus exposure to wind and wave action maintain oxygen saturation, such that epilimnetic concentrations are not limiting to aquatic life. Therefore, although oxygen concentrations were modeled throughout the lake, at all depths, the calibration exercise was focused on deeper, stratified sites.

The management focus for the Lake Simcoe remedial efforts is restoration of dissolved oxygen in the hypolimnion at the end of summer. MOE field survey data were therefore reviewed to establish the average time of year when hypolimnetic dissolved oxygen concentrations were lowest in the hypolimnion of Lake Simcoe, and therefore of most concern to cold water fish. Lowest values were reached towards the end of the summer.

The calibration exercise was then focused on the prediction of minimum dissolved oxygen concentrations in Lake Simcoe at the end of summer. The calibration was tested by comparing the profiles of dissolved oxygen that were measured by MOE at the deep (stratified) sites of the lake with the profiles predicted by the model for the same site. Correspondence between measured and predicted profiles would therefore provide confidence that the model was predicting oxygen levels accurately in the lake.

Two examples of the seasonal stratification of Lake Simcoe are presented here as examples of the calibration exercise. Shallow lake dynamics are represented by the calibration for MOE Station C6, the mid point of Cook Bay. The deepest monitoring station in Lake Simcoe is MOE Station K42, near the mouth of Kempenfelt Bay.

**Cook Bay (C6)**

The Cook Bay site showed weak temperature stratification in 2001. The greatest temperature gradient was observed on June 3, when a thermocline was present at 7 to 10 m depth. The entire water column warmed over the summer, reaching 16 to 22°C on July 29, and began cooling between August 18 and September 5. The water column was isothermal from September 28 (~16°C) to November 2 (~11°C) as shown in Figure 6.27.

Dissolved oxygen concentrations were a uniform 10 mg/L from surface to 12 m on June 3, 2001. Dissolved oxygen concentrations were not stratified, but showed a steady decline with depth as the summer progressed. Oxygen concentrations declined below the 6 m depth starting on June 15 and began to recover in mid-October as the water
column cooled. Minimum dissolved oxygen concentrations of 1 mg/L or less were recorded at 11 m and deeper on July 1 but did not persist; a likely response to increasing water temperature, and reduced density gradient, which allowed wind to mix the water column.

Figure 6.28 provides a comparison of model predictions with measured dissolved oxygen profiles in Cook Bay. The predicted DO variation is shown in the figures for the period spanning the week before the measurement and the week after the measurement. The model successfully captured the dynamics of decreased oxygen with depth and gradual decrease in dissolved oxygen between June and early September. The modeled DO levels at the surface and bottom agree with the measured data. The model showed a general trend to overestimation of dissolved oxygen at all depths in early to mid summer, and to underestimation of dissolved oxygen in the late summer and early autumn. Modeled estimates were generally within 1 to 2 mg/L of measured values, with the exception of July 1, 2001, when very low concentrations were measured in the bottom 2m of Cook Bay, but the model predicted concentrations in excess of 6mg/L. Modelled dissolved oxygen profiles were not sufficiently accurate for management purposes and further refinement is warranted.

**Kempenfelt Bay (K42)**

The measured data at Kempenfelt Bay (K42) site also showed weak temperature stratification in 2001. Surface water warmed to ~14 °C by June 3 and temperature stratification was apparent at approximately 10m below the surface. Surface waters warmed to ~20 °C by June 15 but cooled back to 14 °C by July 1. A persistent thermocline had formed by July 17 and was maintained at the 15m depth until September 17, with epilimnetic temperatures above 20 °C. The lake was mixed to a depth of 25m and temperature of 17.5 °C by September 28, maintained that pattern until October 12 and was isothermal at ~12 °C by November 2 (see Figure 6.29).

Measured dissolved oxygen concentrations were a uniform 10 mg/L from surface to 30 m on June 3, 2001, and decreased to 6 mg/L at the maximum depth of 38 m. Dissolved oxygen concentrations did not show strong stratification, but showed a steady decline with depth as the summer progressed. Oxygen concentrations declined from the surface down in response to warmer temperatures and reduced saturation between June 3 and August 29, but did not show a classic pattern of oxygen stratification until September. At that time, the dissolved oxygen concentration was ~ 8 mg/L in the epilimnion (0 to 11 m) and then declined to ~ 4 mg/L at 12 to 14 m and declined gradually to ~ 3 mg/L at bottom (38 m) by September 28 and 2 mg/L by October 12. Fall turnover restored dissolved oxygen to ~ 8 mg/L by November 2 except for the bottom 1 m of the water column, where sediment oxygen demand reduced oxygen to 6 mg/L.

The modeled and measured results for MOE Station K42 are shown in Figure 6.30. The predicted DO variation for the week before the measurement and a week after the
measurement is shown as the error bars in the figures. The model showed a reasonably good relationship with measured data in the early summer and in autumn, when the lake was isothermal and physical hydrodynamic processes (temperature and wind mixing) were the dominant influence on dissolved oxygen. The model also successfully captured the dynamics of decreased oxygen with depth and gradual decrease in dissolved oxygen between June and September.

The comparison of the model predicted and measured DO profiles indicated that generally the model was unable to simulate the conditions of strong stratification in DO. The predicted DO profiles generally showed a steady and monotonic decline with water depth which matches the measured data relatively well through the spring and at the shallower stations. The predicted DO profile even shows some inflection with a reduction in the rate of DO decrease slightly above the thermocline, again matching the data relatively well (see August 18 and September 5, 2001 for K42 in Figure 6.30). However, the strong stratification in DO that is evident in the measurements from September 17 to October 12, 2001 at K42 (again in Figure 6.30) is not reproduced by the model.

The explanation of the deficiency of the model in predicting the strong stratification of DO later in the year first requires a discussion of the physical processes that influence the variation in DO through the depth. The reduction in DO with depth is a result of a combination of the following factors: 1) DO is introduced at the water surface through mixing with the atmosphere; 2) DO production is related to phytoplankton production in the euphotic zone of the lake and this, in turn, is a function of light (among other factors) and therefore is limited to the euphotic zone (equal to about half the epilimnion thickness on Lake Simcoe) and decreases with depth; 3) decomposition of detritus and oxygen depletion takes over from production of DO below the euphotic zone and increases with depth to a maximum near the lake bed where detritus is deposited. Local minima of decomposition may also occur within the water column, for example where the settling of detritus is slowed by the higher density of the thermocline.

On their own, these three processes would result in a relatively monotonic decrease in DO with depth (as occurs before late summer for deeper stations and at all times for shallow stations). The strong stratification of DO is explained by two additional processes: 1) the lack of vertical mixing between the epilimnion and the hypolimnion due to a physical process called Richardson Damping that accounts for the buoyancy impact on the vertical mixing as the epilimnion warms; and 2) the settling velocity of algae or detritus is influenced by water density since the density of algae and detritus are only slightly greater than the density of water. Settling velocity will increase as water density decreases (i.e. as water temperature increases). The difference between a faster settling velocity within the warmer waters of the epilimnion and the slower settling velocity in the hypolimnion creates a bottleneck for settling above the thermocline and results in a buildup of suspended detritus below the euphotic zone, but above the thermocline. This explains why in Figure 6.29, comparing the development of the temperature and DO
profiles using measured data at K42, the stratification of DO occurs at a depth of 10 m below the surface which is approximately 5 m above the thermocline.

The DO stratification sets up approximately one month after the temperature stratification has set up, presumably this delay is related to the time to build up and begin decomposition of the suspended detritus at the bottleneck above the thermocline. A review of the temperature profile data in Figure 6.29 and the animation of the model results, reveals that turnover begins sometime between 17 September and 28 September 2001, initiated by a strong southeasterly wind event on September 19. This explains the drop in the depth of stratification for both temperature and DO later in September and in early October (in addition to the temperature reduction and DO increase in the upper 25 to 30 m of the water column).

The model simulated the density difference effect that dampens vertical diffusion across the thermocline (i.e. Richardson Damping). On the other hand, the ECO Lab model, as it is currently formulated, is unable to account for the different settling rates in water of different temperatures and resulting densities. In other words, the model is incapable of reproducing the bottleneck, buildup and decomposition of detritus just above the thermocline but below the euphotic zone. Therefore, it is likely that this is the primary reason for the inability of the model to reproduce strong stratification in the DO towards the end of summer. The sharp gradient in dominance between oxygen production and oxygen depletion, that is initiated by the bottleneck in settling of detritus just above the thermocline (and then continued through the water column to the lake bed) is not simulated. Instead, the model produced monotonically decreasing D.O. concentrations with depth. It is recommended that a revised algorithm for settling that has density (or water temperature) as a variable be developed and implemented within ECO Lab. The advantage of the ECO Lab model is that these changes can be made directly within the model code.
Figure 6.1  Comparison of Measured and Modeled Lake Levels at Jacksons Point Gauge
Figure 6.2  Current Comparison between 2005 Measured ADCP data and 2002 Model Predictions at the Surface
Figure 6.3  Current Comparison between 2005 Measured ADCP data and 2002 Model Predictions at 10 m below the Surface
Figure 6.4a  Temperature Profile Comparison at C6
Figure 6.4b  Temperature Profile Comparison at C6
Figure 6.4c  Temperature Profile Comparison at C6
Figure 6.5a  Temperature Profile Comparison at K42
Figure 6.5b  Temperature Profile Comparison at K42
Figure 6.5c  Temperature Profile Comparison at K42
Figure 6.6 Modeled and Measured Temperature Data at Sutton Intake

Figure 6.7 Modeled and Measured Temperature Data at Beaverton Intake
Figure 6.8  Modeled and Measured Temperature Data at Ramara Intake

Figure 6.9  Modeled and Measured Temperature Data at Innisfil Intake
Figure 6.10  Modeled and Measured Temperature Data at Keswick Intake

Figure 6.11  Modeled and Measured Temperature Data at Lagoon City Intake
Figure 6.12  Modeled and Measured Temperature Data at EC Buoy e45151
Figure 6.13  Phosphorus Concentrations at MOE Stations in 2001

Measured Total Phosphorus in Lake Simcoe
2001 Model Year

TP in mg/L

0.000  0.010  0.020  0.030  0.040  0.050  0.060

Jun-01 Jul-01 Aug-01 Sep-01 Oct-01 Nov-01
Figure 6.14   Model Calibration showing Predicted and Measured TP
Figure 6.15a  Model Calibration showing Predicted and Measured TP
Figure 6.15b  Model Calibration showing Predicted and Measured TP
Figure 6.16  Total Nitrogen Concentrations at MOE Stations in 2001
Figure 6.17a  Model Calibration showing Predicted and Measured TN
Figure 6.17b  Model Calibration showing Predicted and Measured TN
Figure 6.17c  Model Calibration showing Predicted and Measured TN
Figure 6.18  Chlorophyll “a” Concentrations at MOE Stations in 2001
Figure 6.19 Chlorophyll “a” comparison between modeled and measured results at MOE Stations E51, K46, S15 and K42
Figure 6.20a  Chlorophyll “a” comparison between modeled and measured results at MOE Stations K39, C9, C6 and C1
Figure 6.20b  Chlorophyll “a” comparison between modeled and measured results at MOE Stations K39, C9, C6 and C1
Figure 6.21  Solar Radiation (PAR) Variation over the Spring, Summer and Fall of 2001
Figure 6.22  Temperature variation at Lagoon City for 2001
Figure 6.23  Modeled and Measured Chlorophyll “a”, TP & TN at Intakes
Figure 6.24    Modeled and Measured Chlorophyll “a”, TP & TN at Intakes
**Figure 6.25** Modeled and Measured Chlorophyll “a”, TP & TN at Intakes
Figure 6.26a  Secchi Depth Calibration
Figure 6.26b  Secchi Depth Calibration
Figure 6.26c  Secchi Depth Calibration
Figure 6.27  Measured Temperature and DO at MOE Station C6 (Cook Bay)
Figure 6.28a  Dissolved Oxygen Level Profile Comparison at C6
Figure 6.28b  Dissolved Oxygen Level Profile Comparison at C6
Figure 6.28c  Dissolved Oxygen Level Profile Comparison at C6
Figure 6.29  Measured Temperature and DO at MOE Station K42 (Kempenfelt Bay)
Figure 6.30a  Dissolved Oxygen Level Profile Comparison at K42
Figure 6.30b  Dissolved Oxygen Level Profile Comparison at K42
Figure 6.30c  Dissolved Oxygen Level Profile Comparison at K42
7 MODEL SIMULATIONS OF PRESENT AND FUTURE CONDITIONS

The model was applied to simulate conditions representative of Present and Future loading, based on output from CanWet, a watershed/nutrient model setup for the Lake Simcoe watershed by Greenland International Consulting as part of the Assimilative Capacity Studies. The “Present Conditions” represent the present land use, which was digitized on the basis of 2002 satellite images. The “Future Conditions” represents a future land use in which all existing official plan conditions in the watershed are built out and sewage treatment plants are operating at their presently permitted capacity. Details of loading derivations and validation are provided in reports submitted by Greenland Engineering as part of the Lake Simcoe Assimilation Study. This section describes the scenario simulation by using the flow and loading provided by the CanWet model to assess the lake responses to the land use change.

7.1 Present Conditions Scenario

The MIKE3/ECOLab simulation of the Present Conditions consisted of a combination of the MIKE 3 hydrodynamic model results for 2001 with the CanWet flow and loading data for 2001. Output from the CanWet model was provided for the years 1997 to 2004. The CanWet output for 2001 was selected for the Present Scenario for the following reasons:

- The ECO Lab model of water quality was calibrated with MOE flow and loading data from 2001. Therefore, simulation with the 2001 conditions provides the ability to evaluate the impact of any differences between the MOE loading data and loading data predicted with the CanWet model;
- There is no meteorological data available after 2003; and
- Hydrodynamic simulations with MIKE3 were completed for 1999, 2001, and 2002.

With the CanWet model output, all nutrient loadings and flow to the lake are provided through tributaries. The tributary stream flow consists of groundwater, runoff, withdrawal, tile drain discharges, and all point sources which make up the flow at the river mouth of each tributary. The nutrient concentrations required for the MIKE3/ECO Lab input data were calculated by dividing the total nutrient load by the stream flow. MIKE3/ECO Lab also requires definition of partitioning of nutrient sources and in-lake nutrient concentrations into inorganic, organic and particulate forms of carbon, nitrogen and phosphorus and the values determined in the model calibration as described in Section 6.2 were used. The 2001 hydrodynamic conditions in the lake are the same as those used in the calibration and described in Section 6.1.

The total loading data used for the Present Scenario simulation are shown in Figure 7.1a, along with the total loadings for the Future Scenario and the MOE (calibration) run.
Figure 7.1b compares the loadings for individual tributaries. We note that the “CanWet” model values in Figure 7.1a are lower than the MOE total loads used in Section 6 of this report. The major difference in the two is that the “total” loads presented in Section 6 include atmospheric deposition to the lake surface and this is not included in the “CanWet” tributary loads shown in Figure 7.1. The atmospheric loads to the model were entered separately. Figure 7.1b therefore compares the tributary loads from the MOE estimates with those from the “CanWet” estimates. These show differences between the two methods for different tributaries although, the overall load to the lake was very close (Figure 7.1a).

Figures 7.2 to 7.7 compare the MOE and intake monitoring in-lake measurements with: 1) the model output results using MOE input nutrient loads; and 2) the model output using CanWet Present Scenario input nutrient loads. The results show that there is generally no significant difference in total phosphorus (TP) at the stations in the lake between the results of the MOE and CanWet Present Scenario simulations. The exception occurs in Cook Bay where TP is significantly lower and less variable for the CanWet Present Scenario data than for the MOE data (see Figures 7.2 and 7.3, Stations C1, C6 and C9 and Keswick Intake). The more variable results from the MOE loading data simulation likely result from the higher frequency of the loading data provided. The CanWet loadings are based on monthly averages uniformly distributed to each day while the MOE data are daily values and therefore include significant daily variations in both flow and loading.

The modeled output for the CanWet Present Scenario model run results in higher total nitrogen (TN) concentrations in the lake than the model run using MOE input data. The model run with the MOE loading input correlates more closely with the MOE in-lake measurements as shown in Figures 7.4 and 7.5.

There is no substantial difference in Chlorophyll “a” levels between the results of the two simulations at the deep water stations (see Figure 7.6 and 7.7). However, the CanWet model loading simulation predicts lower Chlorophyll “a” in the shallow water of Cook Bay than the MOE loading simulation in early spring and late fall (see for example Figures 7.6 and 7.7, MOE in-lake Stations C1, C6 and Keswick Intake).

In summary, the model results with the CanWet Present Scenario loading data are very similar to the model results from the MOE loading simulation. The exception occurs in the shallow areas of Cook Bay as discussed above.
7.2 Future Scenario

The simulation of the Future Scenario was performed with the future loading data predicted by the CanWet model. The 2001 data used for the hydrodynamic simulations of the MOE and Present Scenario loading conditions were also used as input for the Future Scenario simulation, as 2001 would be as representative as any other year of hydrodynamic conditions. Also, the use of the 2001 hydrodynamic conditions allows for a direct comparison of the impacts of future changes to the nutrient loads. Figures 7.8 to 7.13 compare the results for TP, TN and Chlorophyll “a” from the Present Scenario (CanWet loadings) and Future Scenario simulations and the measurements at the MOE in-lake stations and at the intakes. The model results show no substantial changes to TP and TN concentrations, or to Chlorophyll “a” in the deep water areas of the lake. There is however a notable increase to all three indicators in Cook Bay, particularly in the spring and fall seasons. It is possible that there is insufficient response time for the deepwater areas to reflect the increase in nutrient loading from the streams, since the model was only run for an eight month period.

A potentially important process that is not presently represented with the MIKE3/ECO Lab model is the sequestering of phosphorus within shallow water sediments and subsequent release under stormy conditions either later in the year it was deposited or, more importantly, in future years. In other words, neither the model nor the available data provide information to determine whether the lake bed sediments may act as both a sink and source of phosphorus attenuating and regulating the loading of phosphorus to deeper waters. More information is required on year-to-year changes to phosphorus levels within the lakebed sediments to assess this potentially important process to phosphorus loading. The present ECO Lab model is not configured to track the mass balance of phosphorus within the lakebed sediment and water column. Changes should be made to the ECO Lab model to allow this tracking of phosphorus. This may assist in better understanding the potentially important processes of storage and future release of phosphorus from lakebed sediment.

Dissolved oxygen predicted for the Present (with both MOE and CanWet loads) and Future Scenarios are compared to the measured data in Figure 7.14. In general, the model predicted a small decrease in DO levels for the Future Scenario (typically in the range of 0.25 mg/l at the lakebed). Although a decrease of this magnitude would not be expected to cause significant changes to the lake ecosystem and the deepwater fisheries, caution is advised. An eight month simulation period may not be sufficient to evaluate influences of increased loading, particularly considering the residence time for the lake is approximately 10 years. Also, as discussed above, temporary sequestering and future release of phosphorus in sediments has not been considered in the model simulation or evaluated with field data. Further discussion is provided in Sections 8 and 9.
Figure 7.1a Total Loading Data for all tributaries (April to November) from MOE, Present Scenario and Future Scenario
Figure 7.1b  Phosphorus Loads by Source (April to November) from MOE, Present Scenario and Future Scenario

Total Annual Phosphorous Loading from all sources:
MOE (Present, 2001): 28,861 kg
Greenland (Present, 2001): 27,752 kg
Greenland (Future): 50,681 kg
Figure 7.1c  Nitrogen Loads by Source (April to November) from MOE, Present Scenario and Future Scenario
Figure 7.2a  TP Comparison for MOE and CanWet Present Scenario Input
Figure 7.2b  TP Comparison for MOE and CanWet Present Scenario Input
Figure 7.2c  TP Comparison for MOE and CanWet Present Scenario Input
Figure 7.3   TP Comparison for MOE and CanWet Present Scenario Input
Figure 7.4a  TN Comparison for MOE and CanWet Present Scenario Input
Figure 7.4b  TN Comparison for MOE and CanWet Present Scenario Input
Figure 7.4c  TN Comparison for MOE and CanWet Present Scenario Input
Figure 7.5  TN Comparison for MOE and CanWet Present Scenario Input
Figure 7.6a  Chlorophyll “a” Comparison for MOE and CanWet Present Scenario Input
Figure 7.6b  Chlorophyll “a” Comparison for MOE and CanWet Present Scenario Input
Figure 7.6c  Chlorophyll “a” Comparison for MOE and CanWet Present Scenario Input
Figure 7.7 Chlorophyll “a” Comparison for MOE and CanWet Present Scenario Input
Figure 7.8a  TP Comparison for CanWet Present and Future Scenario Input
Figure 7.8b  TP Comparison for CanWet Present and Future Scenario Input
Figure 7.8c  TP Comparison for CanWet Present and Future Scenario Input
Figure 7.9   TP Comparison for CanWet Present and Future Scenario Input
Figure 7.10a  TN Comparison for CanWet Present and Future Scenario Input
Figure 7.10b  TN Comparison for CanWet Present and Future Scenario Input
Figure 7.10c  TN Comparison for CanWet Present and Future Scenario Input
Figure 7.11    TN Comparison for CanWet Present and Future Scenario Input
Figure 7.12a  Chlorophyll “a” Comparison for CanWet Present and Future Scenario Input
Figure 7.12b  Chlorophyll “a” Comparison for CanWet Present and Future Scenario Input
Figure 7.12c  Chlorophyll “a” Comparison for CanWet Present and Future Scenario Input
Figure 7.13  Chlorophyll “a” Comparison for CanWet Present and Future Scenario Input
Figure 7.14a  DO Comparison for MOE Data, CanWet Present and Future Scenario Input
Figure 7.14b  DO Comparison for MOE Data, CanWet Present and Future Scenario Input
Dissolved Oxygen Level Profile at S15

**Figure 7.14c**  DO Comparison for MOE Data, CanWet Present and Future Scenario Input
Dissolved Oxygen Level Profile at K42

Figure 7.14d  DO Comparison for MOE Data, CanWet Present and Future Scenario Input
Figure 7.14e  DO Comparison for MOE Data, CanWet Present and Future Scenario Input
Dissolved Oxygen Level Profile at C9

Figure 7.14f  DO Comparison for MOE Data, CanWet Present and Future Scenario Input
Dissolved Oxygen Level Profile at C6

Figure 7.14g  DO Comparison for MOE Data, CanWet Present and Future Scenario Input
Figure 7.14h  DO Comparison for MOE Data, CanWet Present and Future Scenario Input
Figure 7.15a  MOE Secchi Calibration 2001 Comparison
Figure 7.15b  MOE Secchi Calibration 2001 Comparison
Figure 7.15c  MOE Secchi Calibration 2001 Comparison
8  MONITORING RECOMMENDATIONS

This numerical modeling investigation has improved the understanding of the complex hydrodynamic and ecological processes in Lake Simcoe. In addition, it highlighted certain parameters and processes that are critical to the process of oxygen depletion within the hypolimnion. This understanding has revealed important shortcomings in the ability of the selected model, at this stage of development, to simulate the key processes and in the data available to describe these processes.

As is always the case in numerical modeling investigations of complex processes, the first effort to setup and test a model results in improved understanding but also highlights the limitations of our knowledge, whether that knowledge is represented by the available data, the theoretical understanding or the representation of the understanding within the algorithms of the selected model.

Therefore, this section provides recommendations for additional data gathering to improve the ability to predict the processes of interest, and particularly oxygen depletion in the hypolimnion. Recommendations for model refinements are summarized in Section 9.2.

8.1  Water and Sediment Quality Monitoring

The most important lesson learned from the development of the hydrodynamic and water quality model was the need to address two monitoring objectives if the MIKE3/ECO Lab Model is to be improved to the point where its predictions are accurate enough to fine tune the management objectives for Lake Simcoe.

At present, the MOE and the LSRCA have a very good monitoring network for providing temporal and spatial resolution of nutrient loading to the lake and lake response. This monitoring strategy was used to develop the empirical model of lake response that was employed to set the existing LSEMS loading and water quality targets, and allows the agencies to track the response of the lake and the watershed to remedial efforts. The program is focused on total nutrient loadings to the lake however, and so is not well suited to development and calibration of the MIKE3/ECO Lab hydrodynamic and ecologic model.

Development and set up of the hydrodynamic and ecologic model required data that was not available from the existing monitoring programs. Most critical was the need for data on the partitioning of nutrient sources and in-lake nutrient concentrations into inorganic, organic and particulate forms of carbon, nitrogen and phosphorus. Calibration of primary production in the ECO Lab model is very sensitive to inorganic phosphorus concentrations, for example, and these were estimated or established by the fit of the model to the measured data.
A monitoring program that includes measurements of nutrient forms would provide better loading terms for the model, and guide calibration of model coefficients based on observed responses of nutrient forms in the lake. In addition, this would allow better modeling of remedial and loading reduction strategies. For example, measurements of phosphorus forms in different sources would show differing proportions of total phosphorus present as inorganic (and hence bio-available as termed in the model) in contrast to particulate (and hence more rapidly settled and less bio-available) forms. The model could then be calibrated to these forms of nutrients and used to predict the response of the lake to loadings of different forms and to direct remedial efforts on the basis of reducing the most bio-available sources as a priority. Alternatively, it may be possible to implement a simpler formulation within the model based on the existing data.

In addition, in order to describe the layer of concentrated oxygen depletion located at the thermocline, resulting from the significant difference in settling rates between the different densities of the epilimnion and the hypolimnion, it will be important to sample nutrients and determine settling rates at different water depths representing the different zones through the depth profile. The model simulations of increased phosphorus loading in the future scenario predicted only slight changes to in-lake concentrations of phosphorus, chlorophyll or DO. It was cautioned that there was evidence though of higher phosphorus and Chlorophyll “a” levels within the shallow areas of the lake. It is not known whether these changes may lead to increased phosphorus levels in the nearshore sediments, potentially becoming available for re-suspension in future years. There is no existing information on long-term changes to phosphorus levels in the lakebed sediment. A monitoring program is recommended. The influence of wind and waves on re-suspension of sediment and resultant effects on phosphorus dynamics in shallow areas of the lake were not well modeled, particularly in shallow area. Further research or monitoring of sediment phosphorus dynamics, as influenced by wind and oxygen conditions, would therefore be useful;

We therefore recommend that the LSRCA and the MOE develop a monitoring program that is focused on measurement of:

- the forms of nutrients entering the lake from different sources at different times of the year;
- the forms of nutrients present in different parts of the lake at different times of the year;
- nutrient levels and settling through the depth profile;
- changes to phosphorus levels in the lake bed sediment.

The program should be carried out for one year initially, and the results should be used to improve the calibration of the model. The monitoring need not be as spatially or temporally intensive as the existing program but should include measurement of organic and inorganic, dissolved and particulate forms of phosphorus, nitrogen and carbon as follows:
Loading source measurements:
- the major tributary inflows to the lake;
- a subset of smaller tributaries draining specific land uses (i.e. cropland, pastureland, wetland, natural runoff);
- urban runoff from older areas and from newer areas with higher-level stormwater controls;
- polder drainage;
- one or two sewage treatment plants;
- atmospheric deposition; and
- measurements made during the spring freshet, one to two summer storms and one to two base flow periods for all sources.

In-Lake response measurements:
- at several points in the water column before spring overturn;
- in the epilimnion (above and below the euphotic zone), the hypolimnion and 1 m off the bottom of the lake during early and late stratification;
- in the lake during fall overturn;
- in the lake in late winter;
- carbon, nitrogen and phosphorus content of phytoplankton and zooplankton during early and late summer;
- nutrient content in surficial sediments in deep (Kempenfelt Bay) and shallow areas of the lake (including but not limited to Cook Bay);
- nutrient content and form in settling particulate material in mid to late summer by means of “sediment traps” in deep (Kempenfelt Bay) and shallow areas of the lake (including but not limited to Cook Bay).

It would be advisable to plan for a second year of monitoring to provide an independent verification data set and to address some of the longer-term questions such as phosphorus concentration changes in the lakebed sediment.

8.2 Sampling for Extension to Entire Year Model

The Lake Simcoe model was calibrated for the period from the beginning of April to mid November to capture spring and fall isothermal conditions and the summer stratification period. Water quality in the lake is not monitored for the spring period (April to June) or during the winter (November to March). We recommend periodic winter and spring sampling to establish the dynamics of the lake during these periods. Year round sampling and development of the winter module would provide a “continuous response” model for Lake Simcoe that would allow modeling of long-term responses, more in line with the lake’s hydraulic residence time of ten years. This would address the problems in setting initial conditions for the model in the absence of in-lake data at the start of the ice-free
season. This would also assist in the evaluation of the possible influence of temporary storage and future release of phosphorus within nearshore lakebed sediment.

8.3 Meteorological Data Inputs

The hydrodynamic model requires and is sensitive to accurate measurements of photosynthetically active radiation (“PAR”). A reliable local monitoring program would benefit future refinements of the model. At present, waves and wind are measured at a buoy deployed in the north central area of the lake. This buoy provides the infrastructure necessary to mount a “PAR” collector in the most useful location to provide model input. We recommend that a “PAR” data collector be mounted on the buoy.

8.4 Ecological Surveys

8.4.1 Zebra mussels

Water clarity and its relationship to algae and the available habitat for aquatic macrophytes in Lake Simcoe are modified by filter feeding of zebra mussels in the lake. The generalized zebra mussel module for the MIKE ECO Lab model is still under development by the DHI but it would also be possible to develop a lake-specific module. This is clearly a research requirement and key information needs to be collected for Lake Simcoe in order to begin the task, including:

- Amount and type of substrate colonized by zebra mussels in Lake Simcoe, obtained by a lake-wide survey;
- Depth and distribution of zebra mussel colonization obtained by a lake-wide survey;
- Density of zebra mussels, obtained by substrate and depth specific measurements applied to the substrate survey results;
- Filtering rate of zebra mussels from literature review;
- Nutrient excretion by zebra mussels from literature review; and
- Temperature dependence of zebra mussel filtration from literature review.

It is our understanding that data on filtering rate, nutrient excretion rate and temperature dependence may be obtained from modeling studies currently underway in Lake Erie but distribution data for Lake Simcoe are not available. Efforts to collect and incorporate these data are encouraged for future work.
8.4.2  *Aquatic Vegetation*

A complete hydrodynamic model of ecological dynamics in Lake Simcoe should incorporate the growth and senescence of aquatic macrophytes as a nutrient source and sink, their respiratory influence on oxygen dynamics in the lake, their contribution of particulate organic carbon to the general lake circulation, and resultant decomposition and oxygen demand. The MIKE ECO Lab model contains functions for “benthic vegetation” but calibration could only be attempted. Improved modeling of these processes, requires information that is not available for Lake Simcoe, including:

- Amount of lake substrate colonized by aquatic macrophytes, obtained by a lake-wide survey;
- Depth and distribution of aquatic macrophytes in Lake Simcoe, obtained by a lake-wide survey; and
- Spatial distribution of aquatic macrophyte plant biomass in Lake Simcoe, obtained by taking site specific measurements and applying results across the entire lake.
9 CONCLUSIONS AND RECOMMENDATIONS

9.1 Summary and Conclusions

a. A 3-D hydrodynamic and water quality model that simulates the lake response to phosphorus loading from the watershed has been developed using the DHI MIKE3 hydrodynamic module coupled with the ECO Lab water quality/eutrophication module. The model provides approximations of dissolved oxygen concentrations, including end of summer hypolimnetic dissolved oxygen concentrations based on annual phosphorus loads but further refinement is required to make these predictions useful as a management tool.

b. The model can be used to quantify the response of the lake to loadings of phosphorus and ultimately, other pollutants of interest. In addition, the model output can ultimately be used to estimate fish habitat volumes, which are a function of the volume of water present in the hypolimnion with the required temperature and dissolved oxygen levels. Most importantly, the model can be used as a tool to better understand the physical and biological processes in the lake. Further refinement is required to the biological processes modeling in particular, in order to improve the accuracy of the model and to make it useful for these purposes.

c. The model was set up to simulate water quality during the ice-free period, from April 1 to November 30. This coincides with availability of MOE data for the open water stations for calibration. It allows water quality to be modeled during the key period of interest – the summer growth season and the end of summer period of minimum dissolved oxygen saturation in the hypolimnion.

d. The MIKE3 hydrodynamic model was calibrated with data from 2001 and was able to reproduce water levels, temperature profile with depth and time series temperature data with reasonably good accuracy. The model successfully simulated the thermocline development in the early summer and the thermocline disappearance in the fall. The discrepancy between modeled and measured temperature profiles at some stations during isolated time frames, for example July 13 at K45 and K39 and Sept. 3 at K45, is likely due to the use of spatially constant wind data as opposed to spatially varied data.

e. The ECO Lab water quality module was calibrated with 2001 MOE in-lake measurements and water quality data at the various intakes on the lake. Calibration of this module was time a time consuming effort reflecting the complexity of the processes simulated by the model, the detailed data requirements for the model and the resultant need to make estimates and assess model sensitivity in the absence of measured data. The ECO Lab module includes 71 parameters to be adjusted during the model calibration. Though
default values are provided for a number of these parameters based on their physical meaning, there are still 22 parameters that are site specific and must be adjusted through the calibration process.

f. The model reproduced Total Phosphorus concentrations well in deep water and distinguished differences in water quality between different sites in the lake. Values were over-predicted at some of the shallow water stations such as C1 (Cook Bay). This over-prediction likely resulted from the inappropriate specification of nutrient loading from the Holland River and in particular partitioning of Total P into organic and inorganic components.

g. The model reproduced the Total Nitrogen concentrations well in deep water. Values were under-predicted at some of the shallow water stations in Cook Bay.

h. Generally, the model calibrated well for Chlorophyll “a”. The algal blooms in early spring, the beginning of summer, the end of summer, and the end of fall were successfully simulated. Algal production relies on three factors: solar radiation (PAR), temperature, and nutrients. In the early spring, the diatoms grow quickly due to rising temperatures and PAR intensifying. The growth reaches a peak in early May, which corresponds to the peak PAR values. Green algae becomes dominant from the beginning of summer. The algae peak in the early summer is likely caused by the quick growth of green algae due to high temperatures, while the peak at the end of summer is likely caused by high temperatures and the second peak of PAR. At the end of the fall, the peak of algae growth may be related to increased nutrient levels, which may result from the sloughing of benthic vegetation. The model over-predicted the algae concentration in shallow water areas. This over-prediction is likely caused by an incorrect assumption on the proportion of inorganic and organic nutrients due to lack of data differentiating the two.

i. Results from the Present and Future scenario runs showed little change in nutrient levels (P, N) for the lake with the exception of Cook Bay. In general, the model predicted a small decrease in DO levels for the future scenario (typically in the range of 0.25 mg/l at the lakebed). Although a decrease of this magnitude would not be expected to cause significant changes to the lake ecosystem and the deepwater fisheries, caution is advised. Longer term influences associated with storage and build up of phosphorus in the water column (lake residence time is approximately 10 years) and lake bed sediments have not been considered in the current application of the model.

j. Much of the value of the model will be realized through use of the model, improvements in its predictive accuracy, and in particular, through the visualization tools that allow the user to observe and appreciate the circulation patterns that develop in response to varying wind conditions and the impacts on temperature, nutrient concentrations and DO levels. In particular, the high
nutrient loading in areas such as Cook Bay is very clear. High P loads and warm temperatures cause algal growth in Cook Bay and oxygen depletion. Although temperatures in Cook Bay are generally too high in the summer months to support cold water fish, detritus from Cook Bay may have impacts on other areas of the lake. Issues such as this can be explored by LSRCA, with the model, providing an additional tool to the monitoring programs and empirical models of lake response.

9.2 Recommendations for Numerical Model Input and Process Refinements

a. A comprehensive list of monitoring recommendations is provided in Section 8. The most critical of these relates to data requirements for calibrating the hydrodynamic/water quality model. The model required data that was not available from the existing monitoring programs. Most critical were the need for data on the partitioning of nutrient sources and in-lake nutrient concentrations into inorganic, organic and particulate forms of carbon, nitrogen and phosphorus, and descriptions through the water column Calibration of primary production is very sensitive to inorganic phosphorus concentrations. More detailed calibration data will allow for a better understanding of the processes and improvements to model calibration.

b. The comparison of the model predicted and measured DO profiles indicated that generally the model was unable to simulate the conditions of strong stratification in DO. The temperature stratification is reproduced well by the model and this indicates that the model reproduces well the density difference effect that dampens vertical diffusion across the thermocline. However, the ECO Lab model as it is currently formulated is unable to account for the different settling rates in water of different temperatures and resulting densities. As a result the abrupt change from oxygen production (with the euphotic zone) to oxygen depletion in the lower part of the epilimnion (below the euphotic zone) and through the hypolimnion, is not simulated. Therefore, it is likely that this is the primary reason for the inability of the model to reproduce strong stratification in the DO towards the end of summer. It is recommended that a revised algorithm for settling that has density (or water temperature) as a variable be developed and implemented within ECO Lab. One advantage of the ECO Lab model is that these changes can be made directly within the model code.

c. The model was set up and calibrated to simulate the period from March to November because monitoring data was limited to this period and the MIKE3 model is not currently set up to model winter (ice cover) conditions. It is recommended that the model ultimately be extended to the full year so that consecutive years can be run. This would provide a “continuous response” model for Lake Simcoe that would allow modeling of long-term responses, more in line with the lake’s hydraulic residence time of ten years.
d. Calibration of the model currently includes estimating initial conditions because data collection does not begin until June, and the model must be run from April in order to capture lake processes at the beginning of the season. As recommended in Section 8, extending the data collection period would provide useful input to the calibration process.

e. Wind data from Lagoon City was applied to the entire lake on the basis that it would not cause significant impacts on the prediction of temperature profiles over the period of weeks. However, for individual storm events the influence of spatial variation of winds over the lake may be significant. While use of a spatially constant wind speed for the entire lake is likely the primary explanation for these differences, other factors influencing the internal dynamics of the thermocline fluctuations, such as bottom friction, may play a secondary role in observed differences between measured and predicted temperature profiles.

f. ADCP data was collected during the project and a qualitative comparison of measured and modeled values was undertaken. It is recommended that the model be run for the period coinciding with the ADCP data (June/July 2005) in order to validate the hydrodynamic model. Additional ADCP data may also be required.

g. A key unknown is the potential for long-term changes to phosphorus levels in the lake bed sediment and the possibility this may contribute to annual variability in phosphorus loading (i.e. as the potential for re-suspension and release of this phosphorus varies from year to year as a result of variable wind and wave climate). In order to assist in the development of an improved understanding of this process and its influence on ecological processes in the lake (in combination with the proposed data collection on sediment quality described in Section 8.1), the following model refinements are recommended: i) make changes to the model to track changes to phosphorus levels in the sediment; ii) evaluate the sediment dynamics – initially this could be achieved in a simple manner, but eventually it may require a lakewide model of wave generation and transformation to be linked to the hydrodynamic model. Currently, the influence of wind-waves (on re-suspension of sediment and contribution to currents) are not considered in the model.

h. The ECO Lab model should be refined to include an algorithm to describe the filtering influence of zebra mussels;

i. The ECO Lab model describing the influence of macrophyte growth and senescence should be refined once information on macrophyte spatial coverage and growth for Lake Simcoe are developed.
j. The model should be continually updated and improved upon as new data becomes available. This will allow the LSRCA to better understand the dynamics of Lake Simcoe and to refine targets.

k. Training and support (in addition to that provided for in the original Scope of Work) will be required to maximize the benefits of the model for the management of Lake Simcoe. If and when the model is refined in the future it is recommended that future users of the model participate in frequent Internet and teleconferences with consultants to participate in the inevitable journey of discovery associated with the model testing and application. This experience would be far more valuable than reading a user manual or a report on findings. The model is a tool that helps us to better understand the complex processes in the lake.
REFERENCES

Danish Hydraulics Institute, 2004. DHI Eutrophication Model 1 – ECO Lab Template

Danish Hydraulics Institute, 2004. DHI MIKE 3 Hydrodynamic Model Technical Manuals


APPENDIX A:
TEMPERATURE CALIBRATION
RESULTS AT MOE STATIONS
Figure A.1a  Temperature Profile Comparison at E51
Figure A.1b  Temperature Profile Comparison at E51
Figure A.1c  Temperature Profile Comparison at E51
Figure A.2a  Temperature Profile Comparison at K45
Figure A.2b  Temperature Profile Comparison at K45
Figure A.2c  Temperature Profile Comparison at K45
Figure A.3a  Temperature Profile Comparison at S15
Figure A.3b  Temperature Profile Comparison at S15
Figure A.3c  Temperature Profile Comparison at S15
Temperature Profile at K42
May 26th, 2002

Temperature Profile at K42
June 10th, 2002

Temperature Profile at K42
June 23rd, 2002

Temperature Profile at K42
July 13th, 2002

Figure A.4a  Temperature Profile Comparison at K42
Figure A.4b  Temperature Profile Comparison at K42
Figure A.4c  Temperature Profile Comparison at K42
Figure A.5a  Temperature Profile Comparison at K39
Figure A.5b  Temperature Profile Comparison at K39
Figure A.5c  Temperature Profile Comparison at K39
Figure A.6a  Temperature Profile Comparison at C9
Figure A.6b  Temperature Profile Comparison at C9
Figure A.6c  Temperature Profile Comparison at C9
Figure A.7a  Temperature Profile Comparison at C6
Figure A.7b  Temperature Profile Comparison at C6
Figure A.7c  Temperature Profile Comparison at C6
Figure A.8a  Temperature Profile Comparison at C1
Figure A.8b  Temperature Profile Comparison at C1
Figure A.8c  Temperature Profile Comparison at C1
APPENDIX B:
DO CALIBRATION RESULTS AT
MOE STATIONS
Figure B.1a  Dissolved Oxygen Level Profile Comparison at E51
Figure B.1b  Dissolved Oxygen Level Profile Comparison at E51
Figure B.1c  Dissolved Oxygen Level Profile Comparison at E51
Figure B.2a  Dissolved Oxygen Level Profile Comparison at K45
Figure B.2b  Dissolved Oxygen Level Profile Comparison at K45
Figure B.2c  Dissolved Oxygen Level Profile Comparison at K45
Figure B.3a  Dissolved Oxygen Level Profile Comparison at S15
Figure B.3b  Dissolved Oxygen Level Profile Comparison at S15
Figure B.3c  Dissolved Oxygen Level Profile Comparison at S15
Figure B.4a  Dissolved Oxygen Level Profile Comparison at K42
Figure B.4b  Dissolved Oxygen Level Profile Comparison at K42
Figure B.4c  Dissolved Oxygen Level Profile Comparison at K42
Figure B.5a  Dissolved Oxygen Level Profile Comparison at K39
Figure B.5b  Dissolved Oxygen Level Profile Comparison at K39
Figure B.5c  Dissolved Oxygen Level Profile Comparison at K39
Figure B.6a  Dissolved Oxygen Level Profile Comparison at C9
Figure B.6b  Dissolved Oxygen Level Profile Comparison at C9
Figure B.6c  Dissolved Oxygen Level Profile Comparison at C9
Figure B.7a  Dissolved Oxygen Level Profile Comparison at C6
Figure B.7b  Dissolved Oxygen Level Profile Comparison at C6
Figure B.7c  Dissolved Oxygen Level Profile Comparison at C6
Figure B.8a  Dissolved Oxygen Level Profile Comparison at C1
Figure B.8b  Dissolved Oxygen Level Profile Comparison at C1
Figure B.8c  Dissolved Oxygen Level Profile Comparison at C1
APPENDIX C:
MODEL ANIMATIONS CD
(ENCLOSED)
This CD is Appendix C of the report, “Lake Simcoe Hydrodynamic and Water Quality Model” dated January 30, 2006, prepared by Baird & Associates, in association with Gartner Lee Limited for the Lake Simcoe Region Conservation Authority. The CD contains animations from the MIKE3 / ECO Lab numerical modeling. The following provides a brief description of each of the animations:

**LakeSimcoe_2002_HDModeling_Flow.Temp.avi**

This animation shows the output from the MIKE3 hydrodynamic model and specifically, hourly average currents and water temperature modeled 2001 results with MOE loading data used as input to the model. All values are depth averaged. The graph in the lower right corner of the animation shows the corresponding air temperature at Lagoon City and the date.

**LakeSimcoe_2001_EUModeling_Daily.avi**

This animation shows daily average currents, water temperature, TP, TN and Chlor A for the modeled 2001 results with MOE loading data used as input to the model. All values are depth averaged. The large map on the left side of the animation shows daily averaged currents and water temperature. The graph in the lower central region of the animation shows the corresponding air temperature at Lagoon City and the date. On the right side of the animation, model predicted TP, TN and Chlor “A” are plotted. The MOE monitoring data is also indicated by small circles in the lake. When the modeled output is the same as the monitored data, the circle is not visible. When the modeled output differs from the MOE measured data, the MOE station will be visible due to the difference in the colour indicating the TP, TN, or Chlor “A” concentration.

**LakeSimcoe_2001_EUModeling_Hourly.avi**

This animation shows hourly average currents, water temperature, TP, TN and Chlor A for the modeled 2001 results with MOE loading data used as input to the model. It is similar to the above animation, however hourly data is used instead of daily averages.

**LakeSimcoe_2001_Isosurface-14deg-Temperature.mpg**

This animation shows the 14 °C iso-surface movement during lake warming period in 2001. It also shows the flow vectors and the temperatures along two cross-sections. The color represents the temperature. The animation shows that the thermocline inside the lake responds to the change of wind more strongly than the water surface. This is why one sometimes feels the large change in water temperature at the shore after a storm event.
LakeSimcoe_2002_Therm_Currents_July1_Aug31.mpg

This animation shows the flow vectors and the temperatures during lake warming period along four cross-sections. The formulation of thermal stratification is clearly seen in the animation. That is, the water temperature at the surface is warming up due to solar radiation while the water temperature at the bottom remains unchanged. The color represents the temperature.