Lake Ontario Model Calibration and Baseline Scenario (Revised)

Prepared for
Regions of York and Durham

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1. Background and Purpose

For effluent discharges, the Ministry of Environment (MOE) has guidelines for the near field effluent mixing and far field effluent dilution requirements. In 2006, computer modelling to assess near field effluent mixing and plume dispersion was completed as part of the Schedule C Class Environmental Assessment (Class EA) for the Duffin Creek WPCP Stage 3 expansion. The Expansion EA identified the preferred solution for expanding treatment capacity at the Duffin Creek WPCP to 630 ML/d. This expansion is referred to as the Stage 3 expansion, as it is the third phase of plant development. It includes expansion and enhancement of treatment processes at the Duffin Creek WPCP to provide 630 ML/d capacity, while also providing nitrification and phosphorus removal capacity. This additional capacity is key to the plant meeting its Certificate of Approval mass loading limit of 311 kg/d for TP at both current and future flows. The expansion also provides for expansion and upgrade of the sludge treatment facilities.

The CORMIX model was used to estimate the near field mixing ratio. The underlying model assumption was to use calm lake conditions. It showed that the Ministry of the Environment (MOE) mixing guideline of 20:1 for the near field zone will be met by the existing outfall until the flows reach an average day flow of 560 ML/d. However, as a condition of approval for the Stage 3 Expansion, MOE required that the flow from the outfall should not exceed 520 ML/d.

In 2006, outfall discharge modelling was also completed to assess far field dilution and to see whether the treated discharge, after initial dilution and dispersion, meets Provincial Water Quality Objectives (PWQOs) for total phosphorus (TP) and un-ionized ammonia (UIA).

The MIKE-3 hydrodynamic and water quality model, a three-dimensional model, was used to delineate the outfall plume and identify the mixing zones for TP and UIA. The modelling results helped to identify the preferred expansion alternative; in particular the need to provide additional phosphorus and ammonia removal as part of the plant expansion and establish stricter TP and ammonia limits for the expanded plant. These stricter TP and ammonia limits are now part of the existing CofA requirements for the plant.

Since the modelling work carried out in 2006, MOE has approved a new operating limit of 520 ML/d for the existing outfall and additional background lake data has become available. As a result the MIKE-3 model has been updated and re-calibrated, and a new baseline scenario of 520 ML/d flow has been run.

The purpose of this report is to describe the CORMIX and MIKE-3 models. In particular, the report details the results of re-calibration of the MIKE-3 model using updated water quality and Acoustic Doppler Current Profiler (ADCP) data. In addition to updating and calibrating the models, results from the baseline scenario run (520 ML/d) are also presented to provide a basis for future comparisons.

Finally, it should be noted that plant flows at 520 and 630 ML/d referred to in this report refer to average dry weather flows (ADWF). Only ADWF have been modeled in either
CORMIX or MIKE-3 (i.e. wet weather flows are not considered in these analyses). However, peak wet weather flows (PWWF) have been considered in determining the hydraulic capacity of the diffuser.
2. **Overview of Lake-wide Processes**

2.1 **Background**

During the period of the 1960s to the early 1980s, eutrophication as a result of growing populations in the Great Lakes watershed was significantly deteriorating the water quality in Lake Ontario. Phosphorus concentrations, generally accepted to be the limiting nutrient for algal growth in Lake Ontario, were measured as high as 30 ug/L in the offshore in the 1970s (Stevens and Neilson, 1987). Growth of phytoplankton in the offshore and *Cladophora* in the near-shore were creating problems such as zones of oxygen depletion (due to algal decay), toxins associated with cyanobacteria blooms and fouling of beaches and clogging of cooling water intakes. In response to this problem, the Great Lakes Water Quality Agreement was signed in 1972 which led to specific nutrient loading targets being identified in 1978 and again in 1987. The implementation of this agreement resulted in spending on the order of $9B, primarily for the construction and upgrade of wastewater treatment plants. Improvements in lake water quality as a result of these measures were almost immediately noticed and TP concentrations in the offshore dramatically declined in the 1970s and 80s to less than 20 ug/L. Reductions in *Cladophora* growth in the lower Lake Ontario were documented and P-management strategies implemented through the GLWQA were deemed successful (Painter and Kamaitis, 1987).

Today concentrations of TP in the offshore of Lake Ontario are below the water quality objective of 10 ug/L and, as of 2010, continue to decline (Environment Canada, no date). While this decline is positive from the point of view of controlling eutrophication, it is seen as having negative consequences for the ecosystem and fisheries. Phosphorus concentrations are necessary to sustain growth of algae and zooplankton and there is concern that continuing decreases in levels may result in collapse of the fishery (Thornburn, 2011; Holleck, no date).

Despite achieving the reduced phosphorus targets in the offshore waters of Lake Ontario, a resurgence of *Cladophora* growth has attracted attention, particularly in the last decade. This resurgence coincided with the introduction to Lake Ontario of Zebra and Quagga mussels (Dreissenids), invasive species which are thought to play a critical role in promoting *Cladophora* growth by:

- reducing turbidity in the water thereby allowing light to penetrate to greater depths,
- increasing the supply of bioavailable phosphorus by converting particulate phosphorus to soluble reactive phosphorus, and
- colonizing sandy areas thereby providing hard surfaces for *Cladophora* attachment in areas that were previously unsuitable.

It is difficult to understate the role of the dreissenids infestation in “re-engineering” the ecosystem of Lake Ontario since the 1990s. Mussel beds now cover the entire lake bottom in many areas of the lake and light penetration depths have increased from around 5 meters to
as much as 20 meters (Howell, 2012). As a result, the near-shore environment has dramatically changed since the years when the original Great Lakes Water Quality Agreement was developed and the *Cladophora* problem has become worse despite exceeding reduced phosphorus targets in the offshore environment. Recent and ongoing research is therefore focusing on the dynamics and phosphorus in the nearshore environment (Howell, 2012, Auer, 2011, Thorburn, 2001).

### 2.2 Near-shore environment

The near-shore environment typically corresponds to offshore depths in the range of 10 to 20 m and is loosely defined as the zone in which the lake interacts strongly with the lakebed, shoreline, tributaries and people (Howell, 2012). In Lake Ontario, colonization by dreissenid mussel beds is widespread throughout the near-shore environment and growth of *Cladophora* seems to only be limited by the availability of light, hard substrate for attachment and phosphorus. Given the relationship between phosphorus loadings and human activity, greater production of *Cladophora* might be expected to occur in areas of high population density in the vicinity of point source loadings. *Cladophora* appears to be a lake-wide problem, however, and there is no indication that growth is more abundant in these areas. A possible reason for this is that near-shore phosphorus concentrations are influenced by an array of factors including:

- exchanges with the offshore environment,
- local discharges including tributary and point source loads (*e.g.* stormwater, wastewater treatment plants),
- interactions with the lakebed including wave-induced re-suspension of sediments (Howell, 2012) and release of soluble reactive phosphorus from Zebra mussel beds (Martin, 2010), and
- along-shore currents which transport phosphorus along the predominant west-east current that exists on the north shore of Lake Ontario (Leon, 2009).

*Cladophora* growth in the near-shore environment has been shown to be sensitive to soluble reactive phosphorus concentrations in the range of 1 to 2 ug/L (Tomlinson *et al.*, 2011). As a result, a leading management strategy for controlling *Cladophora* growth might center on minimizing soluble reactive phosphorus loading to the near-shore zone. However, measurements in the offshore environment have been reported in the range of 1.4 to 2.5 ug/L with higher concentrations measured closer to shore (Auer, 2011). As a consequence, there is debate as to whether the ambient concentrations of soluble reactive phosphorus (both offshore and alongshore) lie within a range that is sensitive to load management. In addition, the role that Dreissenids play in converting particulate to soluble phosphorus must be taken in account. For example, higher concentrations of soluble reactive phosphorus have been measured above mussel-beds relative to other non-colonized substrate. This suggests that soluble reactive phosphorus released by Dreissenids could be more important than external inputs (Martin, 2010). Ambient conditions, exchanges with the mussel beds and transport of phosphorus alongshore are key areas of ongoing research into the causes for *Cladophora* growth.
2.3 Phosphorus Loadings from Tributaries

The Niagara River is the largest contributor of phosphorus loading to Lake Ontario and is typically considered to be the main driver of TP concentrations in the offshore. Tributaries such as streams and rivers around the lake contribute loads equivalent to 50% to 70% of the load from the Niagara River and wastewater treatment plants 15 to 20% (Makarewicz et al., 2012). These loads are considered important drivers of phosphorus concentrations in the near-shore environment. Tributary loads, in particular, have the potential to influence the near-shore environment as they tend to discharge right at the shoreline. Moreover, modelling studies have shown that along-shore currents are more significant than cross-shore currents so that phosphorus from tributaries is likely to have a higher retention time in the near-shore environment, thereby creating more impacts on water quality.

It should be noted, however, that there can be significant uncertainty related to the calculation of tributary loadings. While flow rates from streams and rivers can be recorded on a continuous basis, concentration data from tributaries tend to be sparse and often omit periods of high flow due to snowmelt or rainfall events. This creates biases in the data sets which could lead to an underestimation of phosphorus loading calculation (Bowen and Booty, 2012). More work is currently underway by TRCA and others to further assess a more accurate prediction of phosphorous loading due to surface runoff from streams and local storm sewer systems.

2.4 Phosphorus Loadings from the Duffin Creek WPCP

During the Stage 3 Expansion, new effluent limits were established through consultation with MOE and other stakeholders based on the receiving water impact assessment. With the commissioning of the Stage 3 Expansion in the fall of 2009, the new effluent limits came into effect. The new effluent limits for total phosphorus are detailed in Table 2-1. These effluent limits are in place for average day flows up to and 630MLD at which time a separate Class EA will be conducted for flows above 630MLD.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Effluent Limit before Stage 3 Expansion</th>
<th>Effluent Limit after Stage 3 Expansion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Phosphorus Concentration</td>
<td>1.0 mg/L</td>
<td>0.8 mg/L</td>
</tr>
<tr>
<td>Total Phosphorus Loading</td>
<td>420 kg/day</td>
<td>311 kg/day</td>
</tr>
</tbody>
</table>

The new effluent limits have resulted in improved effluent water quality being discharged to the receiving water. Figure 2-1 illustrates the actual phosphorous loading to the receiving water from 2004 to 2011. The total phosphorus loadings decreased with the commissioning of the Stage 3 Expansion in 2009.
FIGURE 2-1
Yearly Total Phosphorous Loading from the Duffin Creek WPCP from 2004 to 2011
3. **Effluent and Mixing Zone Requirements**

The Ministry of Environment (MOE) requires that lake ambient conditions and effluent discharges be evaluated through lake modelling to meet surface water quality objectives and for deriving effluent requirements. The water quality objectives are referred to as Provincial Water Quality Objectives (PWQO) and are discussed below.

A mixing zone around the diffuser is necessary to ensure adequate dilution. According to Policy 5 of the MOE’s Water Management\(^1\), a mixing zone should be designed to be as small as possible and not interfere with beneficial uses such as water supply intakes, other effluent discharges, bathing beaches, fish spawning areas, or fish migration routes. Water Management provides the following definition of a mixing zone:

> A mixing zone is defined as an area of water contiguous to a point source or definable non-point source where the water quality does not comply with one or more of the Provincial Water Quality Objectives.

The basic mixing zone elements are divided into “near field” modelling and “far field” modelling. Each modelling element is discussed below.

### 3.1 Provincial Water Quality Objectives

The PWQO are criteria which serve as chemical and physical surrogates of healthy populations of aquatic biota. They represent a satisfactory level of quality for surface waters. The PWQO for Total phosphorous (TP), un-ionized ammonia (UIA), and E. coli are presented in Table 3-1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Concentration Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Un-ionized ammonia (UIA)(^1)</td>
<td>20 ug/L</td>
</tr>
<tr>
<td>Total ammonia nitrogen (TAN)(^2)</td>
<td>500 ug/L</td>
</tr>
<tr>
<td>Total phosphorus (TP)(^1)</td>
<td>20 ug/L</td>
</tr>
<tr>
<td>E. coli(^1)</td>
<td>100 E. coli per 100 mL</td>
</tr>
</tbody>
</table>

\(^1\) Provincial Water Quality Objective (PWQO) \(^2\) IJC Drinking Water Standard

**Total Phosphorus**

To avoid nuisance concentrations of algae in lakes, average total phosphorus concentrations for the ice-free period should not exceed 20 ug/L\(^2\). The PWQO for TP is intended to reduce the occurrence of algal blooms in Lake Ontario for which phosphorous is assumed to be the limiting nutrient. This can be explained in terms of the Redfield ratio for Lake Ontario which, based on measured ambient concentrations of soluble reactive phosphorus SRP less than 0.01

mg P/L and nitrite+nitrate of around 0.4 mg N/L, is greater than 40:1. Generally, it is assumed that phosphorus limited environments are characterized by Redfield ratios of greater than 16:1. It should be noted, however, that the occurrence of algal blooms is very complex and involves other factors such as the bio-availability of the phosphorous, relative concentrations of other nutrients (e.g. dissolved inorganic nitrogen, DIN), water clarity and water temperature.

**E. coli**

The PWQO for bacterial quality maintains suitable conditions for recreational purposes and for the protection of human health, and is based on maintaining less than 100 E. coli per 100 mL sample. Disinfection of all flows from the Duffin Creek WPCP ensures that discharged effluent is well below the PWQO for E. coli: the geometric mean for 2011 was 7 E. coli per 100 mL. For this reason, simulation results for E. coli in the effluent plume are not presented in this report.

**Ammonia**

The UIA PWQO is for the protection of aquatic life and has been set at 20 ug/L to avoid chronic effects and 100 ug/L for acute toxicity. The 20:1 initial mixing ratio provides sufficient dilution to meet PWQO for UIA at the edge of the near field mixing. A limit for Total Ammonia Nitrogen at drinking water intakes has been set at 500 ug/L by the International Joint Commission.

### 3.2 Near Field Zone Requirements

The “near field” mixing zone refers to the portion of the effluent plume that extends from the diffuser outlets (ports) to the location where the discharged plume has effectively completed its initial mixing with the ambient lake water, as caused by buoyancy and momentum differences.

The CORMIX model has been used to estimate the dilution ratio in the near field mixing zone. This model is specifically designed to assist in the prediction of plume mixing behavior from various types of outfall configurations, under various lake and effluent conditions.

In the event that PWQO cannot be met in the near field mixing zone, a far field model is used to delineate the mixing zone required to meet PWQO and evaluate whether this zone interferes with “beneficial uses”.

### 3.3 Far Field Effluent and Dilution Requirements

After dilution due to initial mixing is established, the next procedure is to determine dilution of the effluent plume in the far-field zone. Dilution beyond the initial near-field zone is usually associated with ambient lake processes (offshore currents, dispersion, etc.) and tends to occur at a greatly reduced rate in comparison to the initial mixing within the near field. Modelling the far-field effluent plume and associated dilution is accomplished using a whole lake model, such as MIKE 3, wherein the main purpose is to determine the size of the mixing zone. In particular, the plumes’ potential effects on Lake water quality and surrounding water uses (e.g. drinking water intakes, near shore recreation, etc) are identified. The MIKE -3 model was calibrated to represent realistic simulations of the lake conditions. It was then used to simulate the plume with respect to PWQO for TP and UIA over the critical April to November period. The extent of the plume was then defined based on both average concentrations and the 90th percentile isopleths. A 90th percentile criterion was chosen because it is conservative and screens out
extreme events which have no impact on the environment. For example, nuisance species such as *Cladophora* have a doubling time on the order of two days. As a result, spikes in TP levels that take place over a shorter time period do not provide the conditions for growth.

Although under most conditions this is not an issue, a further concern that could be raised is meeting the total ammonia drinking water standard of 500 ug/L at the location of the Ajax WSP intake. To address this, the MIKE-3 model was also used to simulate total ammonia concentrations at the Ajax WSP intake.
4. CORMIX Model and Near Field Analysis

CORMIX is a mixing zone model for assessment of near field dilution and mixing zones resulting from continuous point source discharges such as the Duffin WPCP outfall. Diffuser performance is assessed using the average annual daily flow by reporting the initial dilution at the edge of the near field region where momentum associated with the effluent jet has fully dissipated. The User’s Guide for CORMIX states that predictions of dilutions and concentrations in the effluent plume are accurate to within +/- 50%. However, comparisons with field data suggest higher levels of accuracy are achieved with the CORMIX model (Abdel-Gawad, 1985; McCorquodale, 2007). The CORMIX model is a standard tool approved by the MOE for calculating initial dilution in the near-field region and, as such, gives a good basis of comparison for performance of different outfall alternatives. The subsection below describes the selection of key input parameters.

4.1 Key Input Parameters

The basic characteristics used in the CORMIX model relate to the location and configuration of the outfall diffuser, effluent flow, and the ambient lake conditions. New data collected since the Expansion EA in 2006 was used to update and calibrate the CORMIX model. A description of those changes is summarized below.

4.1.1 Ambient Lake Currents

Lake currents are measured with Acoustic Doppler Current Profilers (ADCP). A number of ADCPs are located in the vicinity of the outfall as depicted in Figure 4-1.
The OPG ADCP operates year round and has been functional since 2001. Current speed data for the OPG station is in Table 4-1. The other meters were deployed in 2007 but only for portions of the year. Current speed data for the other stations is in Table 4-2. The OPG location is considered to characterize the required bottom currents most accurately, due to its proximity to and similar depth as outfall diffuser. Accordingly, OPG ADCP data from 2001-2010 was used in the CORMIX model.

For lake currents, the MOE specifies the use of the 25th percentile for quantifying ambient conditions i.e. the lake current below which 25 percent of the measured current data may be found. In accordance, the OPG ADCP data were partitioned by season and the yearly data were enumerated to determine the 25th percentile. For current speeds, using the 25th percentile results in more conservative predictions of dilution rates than would be obtained using average speeds (the 50th percentile). This follows the general principle established in Procedure B-1-5 in which the 75th percentile is specified for ambient water quality constituents such as temperature and pH\(^3\).

It is well known that during the late fall to early spring period, higher current speeds are observed due to higher energy storms passing through the lake. Recorded lake current speeds from 2001-2010 are presented in Table 4.1 according to season. The current speed used for the CORMIX model was the average for the spring – summer season which was 0.044 m/s. The spring – summer season is considered the critical period for calculating mixing in the near field zone because lower current speeds contribute to less mixing energy.

---

### TABLE 4-1
**25th Percentile Lake Current Speeds for OPG Station**

<table>
<thead>
<tr>
<th>Year/Season</th>
<th>Jan – Mar (m/s)</th>
<th>Apr- Jun (m/s)</th>
<th>Jul – Sep (m/s)</th>
<th>Oct – Dec (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>0.081</td>
<td>0.034</td>
<td>0.041</td>
<td>0.068</td>
</tr>
<tr>
<td>2002</td>
<td>0.109</td>
<td>0.05</td>
<td>0.0407</td>
<td>0.075</td>
</tr>
<tr>
<td>2003</td>
<td>0.071</td>
<td>0.045</td>
<td>0.044</td>
<td>n/a</td>
</tr>
<tr>
<td>2004</td>
<td>n/a</td>
<td>n/a</td>
<td>0.055</td>
<td>0.058</td>
</tr>
<tr>
<td>2005</td>
<td>0.051</td>
<td>0.039</td>
<td>0.067</td>
<td>n/a</td>
</tr>
<tr>
<td>2006</td>
<td>0.057</td>
<td>0.058</td>
<td>0.057</td>
<td>n/a</td>
</tr>
<tr>
<td>2007</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>0.072</td>
</tr>
<tr>
<td>2008</td>
<td>0.092</td>
<td>0.057</td>
<td>0.011</td>
<td>0.107</td>
</tr>
<tr>
<td>2009</td>
<td>0.06</td>
<td>0.031</td>
<td>0.039</td>
<td>0.05</td>
</tr>
<tr>
<td>2010</td>
<td>0.047</td>
<td>0.038</td>
<td>0.048</td>
<td>0.06</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>0.065</strong></td>
<td><strong>0.044</strong></td>
<td><strong>0.044</strong></td>
<td><strong>0.07</strong></td>
</tr>
</tbody>
</table>

### TABLE 4-2
**25th Percentile Lake Current Speeds for additional Stations**

<table>
<thead>
<tr>
<th>Year</th>
<th>Location</th>
<th>25th Percentile (m/s)</th>
<th>Start Time</th>
<th>End Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>MOE Offshore</td>
<td>0.036</td>
<td>Apr 3</td>
<td>Nov 26</td>
</tr>
<tr>
<td>2007</td>
<td>Moe Nearshore</td>
<td>0.023</td>
<td>Apr 3</td>
<td>Nov 26</td>
</tr>
<tr>
<td>2007</td>
<td>NWRI</td>
<td>0.041</td>
<td>Apr 10</td>
<td>Jul 9</td>
</tr>
<tr>
<td>2007</td>
<td>NWRI</td>
<td>0.124</td>
<td>Jul 12</td>
<td>Oct 23</td>
</tr>
</tbody>
</table>

4.1.2 **Existing Outfall Diffuser**

The existing outfall extends 1.1 kilometers into the lake with a 183m diffuser that has 63 evenly spaced ports. The ports are arranged in a staged diffuser configuration, staggered at an angle of 22.5° to the centre line to allow for maximum dispersion of the effluent. The existing configuration is consistent with the 2006 configuration and has not changed.

4.1.3 **Effluent flow and Port Opening Size**

The diffuser port diameter and opening schedule is established based on the available head loss in the outfall at peak flow conditions. The CORMIX model was run using the port diameter to determine the initial dilution ratio at average day flow. In the Expansion EA, the port opening of 0.225m was used for an average day flow of 520MLD. In the Outfall EA, the baseline scenario is using the same port opening of 0.225m at 520MLD.

Based on preliminary findings, the hydraulic capacity of the outfall is approximately 2,000 ML/d, assuming a Hazen William C factor of 90, and all 63 ports fully open with a discharge diameter of 0.45m. Further hydraulic analysis will be performed during Phase 2 of the EA.

4.1.4 **Summary of Input Parameters**

A number of key input variables and parameters for the CORMIX model have changed since the Expansion EA. These are detailed in Table 4-3 and 4-4.
### TABLE 4-3
Key CORMIX Model Input Variables

<table>
<thead>
<tr>
<th>Model Input Variable</th>
<th>2006 (Expansion EA)</th>
<th>2011 (Outfall EA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source of Current Speed Data</td>
<td>OPG ADCP station 2001</td>
<td>OPG ADCP station 2001-2010</td>
</tr>
<tr>
<td>Current Speed</td>
<td>4 cm/s (25th percentile of OPG data from 2001)</td>
<td>4.4 cm/s (25th percentile of OPG data from 2001-2010)</td>
</tr>
<tr>
<td>Average depth of diffuser</td>
<td>9 m (based on low lake level)</td>
<td>10.2 m (based on average lake level which the best practice used on other outfall studies in Lake Ontario)</td>
</tr>
</tbody>
</table>

The parameters used in CORMIX are listed below.

### TABLE 4-4
Key CORMIX Model Input Parameters

<table>
<thead>
<tr>
<th>Model parameter</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average depth of diffuser</td>
<td>10.2 m</td>
<td>Based on average lake level and depth at mid point of the diffuser.</td>
</tr>
<tr>
<td>Diffuser distance offshore</td>
<td>914 m</td>
<td>Physical characteristic of outfall</td>
</tr>
<tr>
<td>Port diameter</td>
<td>0.225 m @ 520 MLD</td>
<td>Physical characteristic of outfall diffuser</td>
</tr>
<tr>
<td>Riser height</td>
<td>1.0 m</td>
<td>Physical characteristic of outfall diffuser</td>
</tr>
<tr>
<td>Staged diffuser configuration perpendicular to current</td>
<td>Gamma = 90, Theta = 0, beta = 0, Sigma = 270</td>
<td>Physical orientation of diffuser ports</td>
</tr>
<tr>
<td>Number of ports</td>
<td>63</td>
<td>Physical characteristic of outfall diffuser</td>
</tr>
<tr>
<td>Port spacing</td>
<td>2.9 m (183 m length / 63)</td>
<td>Physical characteristic of outfall diffuser</td>
</tr>
<tr>
<td>Receiving water environment</td>
<td>Unbounded</td>
<td>Physical characteristic of outfall environment</td>
</tr>
<tr>
<td>Density current</td>
<td>Uniform</td>
<td>Default assumption non-stratified conditions</td>
</tr>
<tr>
<td>Ambient Current Speed</td>
<td>0.044 m/s</td>
<td>25th percentiles for the spring – summer season</td>
</tr>
<tr>
<td>Wind Speed</td>
<td>5 m/s</td>
<td>Based on recommended CORMIX method</td>
</tr>
<tr>
<td>Bottom friction</td>
<td>0.035 Manning’s N</td>
<td>Default assumption – relatively smooth bottom</td>
</tr>
<tr>
<td>Ambient water temperature</td>
<td>15 °C</td>
<td>Average for spring / summer season</td>
</tr>
<tr>
<td>Effluent temperature as difference from ambient</td>
<td>+2, +5, -2 °C</td>
<td>The temperature difference was found to have no impact on the dilutions and initial plume behavior.</td>
</tr>
<tr>
<td>Effluent Flow</td>
<td>520 ML/d</td>
<td>Effluent flow through diffuser</td>
</tr>
</tbody>
</table>
4.2 Results

With the above input variables and parameters, the CORMIX model was run and the results are detailed in Table 4-5. At the baseline flow of 520 MLD, the CORMIX model predicted the dilution within the near field mixing zone (the mixing ratio) to be 22.8:1. As shown in Fig. 4-2, the distance offshore and downstream (east) for the near-field mixing zone was 413m and 45m respectively.

With a 22.8:1 mixing ratio calculated using the CORMIX software, the mixing zone for TP extends outside the near-field mixing zone. As such, a far-field analysis is required to further delineate the edge of the mixing zone. The MIKE-3 model is used for this purpose.

<table>
<thead>
<tr>
<th>Flow (MLD)</th>
<th>Mixing Ratio</th>
<th>X downstream (m)</th>
<th>Y Offshore (m)</th>
<th>Half-Width (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>520</td>
<td>22.8 : 1</td>
<td>51</td>
<td>366</td>
<td>153</td>
</tr>
</tbody>
</table>

Figure 4-2 shows the coordinate system used by CORMIX.
5. MIKE-3 Model Set-Up

The DHI Software MIKE-3 platforms, a three-dimensional hydrodynamic and water quality model, was used to delineate the effluent plume as it extends outside of the near field mixing zone. This tool is used to assess whether the treated discharge, after initial mixing and subsequent dispersion, meets the PWQOs. The use of a three-dimensional model is critical to this task because Lake Ontario is thermally stratified during the summer months. This stratification should be accounted for in three dimensions to accurately model the currents in the near shore environment.

5.1 Model History and Data Use

Historically this model has been used for the last 15-20 years and is approved for use by the Ministry of Environment (MOE). It uses baseline data from the whole lake. Most recently, the model was calibrated during the preparation of the Schedule C Class Environmental Assessment for “Provision of Additional Capacity at the Duffin Creek Water Pollution Control Plant” (September 2006). The model calibration and the associated results were used by the MOE to make project and approval related decisions.

The model has since been improved upon. It now uses a new refined grid of Lake Ontario with 90 m resolution, which allows the existing diffuser to be spread over two grids. This has resulted in an improved simulation of the effluent plume momentum and the advection-dispersion process in the far-field.

In addition to other data, the Region and TRCA and MOE monitoring results were also used to establish ambient water quality conditions. Newly available water quality and current data were used to refine the model input parameters. The calibration with new water quality data and the current data was successful; though, some locations had better model agreement than others. Generally, the model has better current predictions in the weakly stratified or non-stratified periods of the year. The temperature response of the model was good for the entire period of simulation.

5.2 Model Parameters

The MIKE-3 model is based on the fully non-linear three dimensional representation of mass, momentum and energy fluid motion. The model has the additional capacity of nesting fine grid models inside coarse grids to allow detailed modelling of areas of interest. The non-hydrostatic (and non steady-state) version of the model was used as it provides the most accurate simulations for Lake Ontario.

Key model parameters used in the MIKE-3 model are presented in Table 5-1.
TABLE 5-1
Model input parameters used in MIKE-3 simulation software

<table>
<thead>
<tr>
<th>Model input parameter</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation engine</td>
<td>Non-hydrostatic</td>
<td>Allows dynamic simulation of water quality over time including buoyancy forcing in vertical direction</td>
</tr>
<tr>
<td>Time step</td>
<td>30 s</td>
<td>Maximum allowable time step that maintains Max Courant # below 6.5</td>
</tr>
<tr>
<td>Transport scheme</td>
<td>Quickest-Sharp</td>
<td>Standard modelling practice in MIKE-3 for high correlations with observed data</td>
</tr>
<tr>
<td>Smagorinsky coefficient</td>
<td>0.4 (mixed k/e)</td>
<td>Turbulence scheme used to determine dispersion rates. Default parameter in MIKE-3</td>
</tr>
<tr>
<td>Dispersion factors</td>
<td>0.1 horizontal, 0.001 vertical</td>
<td>Default horizontal parameter in MIKE-3, vertical value from calibration trials</td>
</tr>
<tr>
<td>Wind stress coefficient</td>
<td>Variable function at low wind speeds and higher coefficients at high wind speeds</td>
<td>Function calibrated to fit model to measured current speeds as per standard MIKE-3 modelling practice</td>
</tr>
<tr>
<td>Heat exchange coefficients</td>
<td>0.5, 0.9, 0.395, 0.571, -1, -75, 0.1, 1, as ordered</td>
<td>Default model parameters - solar A and B from calibration, daylight savings time and standard longitude for solar timing</td>
</tr>
<tr>
<td>Vertical resolution</td>
<td>40 layers at 2 m thickness</td>
<td>Provides coverage to 80 m depth, assumes a single layer beneath</td>
</tr>
<tr>
<td>Bed roughness</td>
<td>0.05</td>
<td>Default value, sensitivity is low for this parameter</td>
</tr>
<tr>
<td>Advection-Dispersion factors</td>
<td>Default values using eddy viscosity relationship</td>
<td>Used in calculation of mixing</td>
</tr>
</tbody>
</table>

Since the completion of Class EA, the model was updated based on the following new information:

- A new refined grid of Lake Ontario of 90 m resolution.
- New current information used for model calibration: In 2007 three new Acoustic Doppler Current Profiler (ADCP) current meters were installed in the area; two by MOE and one by National Water Research Institution (NWRI). In the earlier modelling, current information was obtained from only one current meter installed by Ontario Power Generation (OPG).
• New Wind Field from the National Oceanic and Atmospheric Administration (NOAA) Mesoscale Atmospheric model – other studies with City and CCIW have found that wind fields provide better accuracy than a single airport station.

• Higher vertical resolution – Other studies have shown better accuracy resulting from it.

• Used a more accurate transport-advection scheme in the model.

• New 90m grid allowed existing diffuser to be spread over two grid elements.

• Water quality results based on testing undertaken by the Regions and the TRCA for the years 2007, 2008 and 2009.

• Stricter effluent limits with respect to total phosphorus.

• Lake levels for the simulation were based on measured 2007 levels as shown in Table 4-2. (Lake levels for 2007 started out the year higher than the long term mean but by May the levels dropped to normal and then through the summer the levels dropped between 14 to 18 cm below average.)”

<table>
<thead>
<tr>
<th>TABLE 5-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake levels used for MIKE-3 model simulation as compared to long term averages</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Month</th>
<th>J</th>
<th>F</th>
<th>M</th>
<th>A</th>
<th>M</th>
<th>J</th>
<th>J</th>
<th>A</th>
<th>S</th>
<th>O</th>
<th>N</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>74.98</td>
<td>74.97</td>
<td>74.85</td>
<td>75.01</td>
<td>75.05</td>
<td>74.98</td>
<td>74.86</td>
<td>74.71</td>
<td>74.56</td>
<td>74.42</td>
<td>74.31</td>
<td>74.32</td>
</tr>
<tr>
<td>Long Term Average</td>
<td>74.56</td>
<td>74.6</td>
<td>74.68</td>
<td>74.88</td>
<td>75.01</td>
<td>75.05</td>
<td>75</td>
<td>74.88</td>
<td>74.74</td>
<td>74.61</td>
<td>74.54</td>
<td>74.53</td>
</tr>
</tbody>
</table>

A summary of the changes in the modelling parameters since the 2006 Expansion EA are summarized in Table 5-3.

<table>
<thead>
<tr>
<th>TABLE 5-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIKE-3 Model Characteristics – 2006 and 2011</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter/Assumption</th>
<th>2006 (Expansion EA)</th>
<th>2011 (Outfall EA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution for Nested Grid</td>
<td>135 m</td>
<td>90 m</td>
</tr>
<tr>
<td>Modelling Period</td>
<td>April – Sep 2001 (6 months)</td>
<td>April – November 2007 (8 months)</td>
</tr>
<tr>
<td>Current Data</td>
<td>Based on data from 1 station</td>
<td>Based on data from 4 stations</td>
</tr>
<tr>
<td>Ambient TP</td>
<td>0.01 mg/L</td>
<td>0.01 mg/L in the nearshore 0.007 mg/L in the offshore</td>
</tr>
<tr>
<td>Ambient Ammonia</td>
<td>0.0 mg/L</td>
<td>0.008 mg/L</td>
</tr>
<tr>
<td>Average flows</td>
<td>560 ML/d</td>
<td>520 ML/d</td>
</tr>
<tr>
<td>Effluent TP</td>
<td>1 mg/L</td>
<td>0.6 mg/L</td>
</tr>
</tbody>
</table>
The updates made to the model as outlined in Table 5-2 have led to improved calibration to measured temperature and current velocity data.

### 5.3 Model Set-Up under Lake Ontario Ambient Conditions

Bathymetry, the lake bottom elevations that exist across an area of interest, influences a lake’s assimilation capacity. The MIKE-3 Lake Ontario model is based on a 2,430 m coarse grid that extends across the whole lake. Within this coarse grid, nested grids of 810, 270 and 90 m are used to focus in on the area around the Duffin Creek outfall/diffuser. The bathymetry of the lake was obtained from the National Oceans and Atmospheric Administration (NOAA) project for Great Lakes Bathymetry, available on CD, Volume G2 (www.ngdc.noaa.gov/mgg/greatlakes/).

The location of the nested grids areas within the whole lake environment is presented in Figure 5-1. The 90 m fine grid around the outfall diffuser is presented in Figure 5-2. It should be noted that the model grid has been rotated so that a horizontal east-west shoreline is produced for the 90 m grid; this is a standard technique for modelling shoreline features.
FIGURE 5-2
Bathymetry of the Duffin Creek WPCP Study Area (90 m Fine resolution Grid)
Other data used in the model included water quality, temperature, pH and currents. The use of this data is as follows:

- The existing background (or ambient) water quality is used to model the area of the plume in which FWQO are exceeded. The existing nearshore ambient water quality for Lake Ontario was determined using the Regions, TRCA and MOE monitoring data.
- Ambient temperature in the lake, and more specifically the difference with respect to the effluent temperature, impacts the buoyancy of the effluent plume and dispersion of the effluent plume once it is discharged.
- Lake currents speed and direction, will affect the rate of dispersion and direction of the effluent plume.
- Temperature, together with pH, determines the speciation of total ammonia nitrogen between the ionized (NH₄⁺) and the toxic un-ionized forms (NH₃).

The model was initially simulated based on hourly wind speed and direction from Pearson Airport and then subsequently using data for the wind field across Lake Ontario as provided by NOAA, which proved more accurate. Additional meteorological data consisting of air temperature, relative humidity and cloudiness were also used to provide the thermodynamic forces responsible for heating and cooling of the lake water.

Daily water surface elevation data at Kingston were provided to the model to maintain observed water depths. Hydraulic flow (daily) from the Niagara River was applied at the mouth of the river. As such, the stage at Kingston and the flow from the Niagara River established the boundary conditions for the lake. In addition, to capture the effect of local inflows on the mixing zone, flows from Duffins Creek were accounted for in the model. Water temperatures from the Environment Canada buoy in Lake Erie augment the Niagara River flow data. The cooling water flow from the Pickering NGS was not included in the model because this cooling water discharge is confined to the very near-shore area and does not influence the area of interest around the Duffin Creek effluent outfall. Model calibrations results presented in section 6, which do not include the hydraulic and thermal impact from the NGS, show good calibration to data from the OPG ADCP and thus confirm that the Pickering NGS cooling water does not significantly impact the mixing behaviour in this region. Moreover, it is our opinion that the current operation and potential future decommissioning of the Pickering NGS would not impact the mixing behaviour of the effluent plume.

The model was setup to provide continuous simulations from April to November. This period is the most sensitive time for taste and odour problems at water treatment plants and is also the most productive period for aquatic growth. In addition, the continuous simulations cover the periods when low dilutions would occur due to slower currents. (Cool weather periods are associated with the higher energy events in the Great Lakes when current speeds are higher.) Integrating the hourly predictions was used to determine the plume delineation thereby providing the spatial extent of the regions where the PWQOs are achieved or exceeded.
6. MIKE-3 Model Calibration

Calibration involves testing the model to see how closely it simulates existing conditions. Once it is calibrated, the model can be used to determine the effluent plume behaviour and assess the water quality impacts due to the effluent discharge. The model was calibrated based on the existing data described above, including bathymetry, water quality, pH, currents and temperature.

Extensive testing was performed on the model to ensure the accuracy of the predictions. Many simulations have been made with different airports around the lake and, of these, Pearson has consistently provided the best agreement with observed data. NOAA has made available the hourly wind field covering Lake Ontario at a 5 km resolution. The wind field is more reliable than Pearson as it does not have any missing data or zero values. In addition, the wind field more accurately represents the effects of pressure cells over the lake surface. Wind based on one station is uni-directional over the lake, while the NOAA data is variable and more realistic. An Acoustic Doppler Current Profilers (ADCP) has been deployed by Ontario Power Generation at Pickering NGS for many years. The data collected has been used to calibrate the hydrodynamic currents predicted by the MIKE-3 model.

The accuracy of the model predictions are based on the Fourier Norm, or F-norm, which calculates the variance between observed and modeled current velocities. Assessing model calibration based on the variance between observed and modeled results is a standard statistical technique that is used in many scientific disciplines. In practical terms, the velocity is computed as a V component in the onshore-offshore (north-south) direction and the U component in the alongshore (east-west) direction. Equation (1) describes the Fourier Norm as:

\[ F_N = \frac{\| \vec{v}_o - \vec{v}_c \|}{\| \vec{v}_o \|} \text{ where } \| \vec{v}_o \| = \left( \frac{1}{N} \sum_{i=1}^{N} |\vec{v}_o - \vec{v}_c| \right)^{\frac{1}{2}} \]  

and \( v_o \) = observed data and \( v_c \) = computed data. A sample calculation would be:

\[ \frac{((U_o - U_c)^2 + (V_o - V_c)^2)}{(U_o^2 + V_o^2)} \]

A value of 0 means the model prediction is identical to the ADCP data. A value of 1 or more means the difference between the predicted vector component and observed vector component is larger than the amplitude of the vector. The F-norm score is a standard test of the model predictions and experience indicates that the good scores are usually in the range of 0.9, lower scores say 0.8 are very good and rare. The data are based on either 60 or 30 minute samples depending on how often the ADCP stores data. Our results for current velocity show F-norm values ranging from 0.6 to 0.9. Therefore, the model fit is considered to be in the range of very good to good. The basis for evaluating model calibration using F-norm is the modeller’s experience and expert opinion and is outlined in Table 6-1.
<table>
<thead>
<tr>
<th>F-norm</th>
<th>Qualitative assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Perfect model calibration</td>
</tr>
<tr>
<td>Less than 0.9</td>
<td>Very good</td>
</tr>
<tr>
<td>0.9 to 1</td>
<td>Good</td>
</tr>
<tr>
<td>Greater than 1</td>
<td>Poor</td>
</tr>
</tbody>
</table>

The model run was initiated in the spring time when the lake is thermally well-mixed at 4°C. This is a standard technique for model initiation because it allows a uniform temperature to be assigned throughout the lake. The model can then simulate the currents and heating/cooling through the summer and fall period. The temperatures and velocities predicted by the model are stored at hourly/half-hourly intervals, depending on the ADCP sampling frequencies. The F-norm is then calculated from the observations and model predictions.

The vertical resolution (Z-Coordinate system) was 2 m with 40 layers, sufficient depth for thermal stratification events to be well reproduced. Below a depth of 80 m, the lake bottom was assumed to exist as a single well mixed layer.

The wind stress was initially set constant at 0.0026, however predicted speeds were often greater than the observations, so the stress was reduced and set to vary depending on wind strength. The predicted speeds reduced to levels in better agreement with the observations.

Figures 6-1 and 6-2 show the predicted current speeds and directions for the OPG ADCP data from 2007 at the 1m depth layer. However, the ADCP only recorded data from October to December. From a modelling perspective, the trends are predicted correctly and results are acceptable.
FIGURE 6-1
Comparison of Modelled Lake Current SPEED with OPG – ADCP Measurements

[Graph showing comparison between ADCP measurements and modelled speeds over time.]
FIGURE 6-2
Comparison of Modelled Lake Current Direction with OPG-ADCP Measurements

ADCP [deg]
Model Direction [deg]

OPG Surface

Direction

100 150 200 250 300 350 400

The overall F-norm for the OPG ADCP was 0.67, a very good score meaning the model was able to accurately simulate the currents late in the year even after starting in May.

The NWRI ADCP data was partitioned into two periods as the meter was pulled for servicing from the water for several days at the start of July, the missing data were replaced with zero speed and direction to provide a complete data set. Figures 6-3 and 6-4 show the current speed and direction results at the 5 m depth layer.
FIGURE 6.4
NWRI Current Direction Comparisons – 5 m Depth - 2007

NWRI 5m Direction

ADCP Direction [deg]  Model Direction [deg]

The 5 m layer F-norm for this period was 0.84; a very good result. By comparison, the results using Pearson Airport wind data indicated a poor calibration with F-norm value of 1.32. Table 6-2 provides a breakdown of the F-norm scores for the three depths.

**TABLE 6-2**
NWRI F-norm DATA – 2007

<table>
<thead>
<tr>
<th>Month</th>
<th>5m depth</th>
<th>10m depth</th>
<th>18m Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>April - November</td>
<td>0.84</td>
<td>0.89</td>
<td>1.06</td>
</tr>
<tr>
<td>April-May</td>
<td>0.89</td>
<td>0.94</td>
<td>0.91</td>
</tr>
<tr>
<td>May 1 – June 1</td>
<td>0.98</td>
<td>0.97</td>
<td>0.93</td>
</tr>
<tr>
<td>June 1 – July 1</td>
<td>0.99</td>
<td>1.07</td>
<td>1.09</td>
</tr>
<tr>
<td>July-August</td>
<td>0.75</td>
<td>0.80</td>
<td>1.11</td>
</tr>
<tr>
<td>August- September</td>
<td>0.82</td>
<td>0.93</td>
<td>1.24</td>
</tr>
<tr>
<td>September-October</td>
<td>0.72</td>
<td>0.77</td>
<td>1.06</td>
</tr>
<tr>
<td>October-November</td>
<td>0.57</td>
<td>0.62</td>
<td>0.99</td>
</tr>
</tbody>
</table>

The MOE Offshore ADCP had continuous records from April to October. The overall F-norm score was 0.854 at the 1 m depth, which is very good. Figures 6-5 and 6-6 show the current speed and direction time series. As with the NWRI data, the directional agreement is very good but the current speed variance is what reduces the correlation. Table 6-3 provides more details of the F-norm analysis.

**TABLE 6-3**
MOE Offshore F-norm Data – 2007

<table>
<thead>
<tr>
<th>Month</th>
<th>1 m depth</th>
<th>6 m depth</th>
<th>12 m depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apr - Nov</td>
<td>0.85</td>
<td>0.88</td>
<td>1.01</td>
</tr>
<tr>
<td>May – Jun</td>
<td>0.83</td>
<td>0.91</td>
<td>1.15</td>
</tr>
<tr>
<td>Jun – Jul</td>
<td>0.98</td>
<td>0.95</td>
<td>1.22</td>
</tr>
<tr>
<td>Jul – Aug</td>
<td>0.95</td>
<td>0.92</td>
<td>1.04</td>
</tr>
<tr>
<td>Aug – Sep</td>
<td>0.81</td>
<td>0.95</td>
<td>0.94</td>
</tr>
<tr>
<td>Sep – Oct</td>
<td>0.82</td>
<td>0.86</td>
<td>0.93</td>
</tr>
<tr>
<td>Oct - Nov</td>
<td>0.66</td>
<td>0.63</td>
<td>0.67</td>
</tr>
</tbody>
</table>
FIGURE 6-5
MCE Offshore ADCP Comparisons – 2007
FIGURE 6-6
MOE Offshore ADCP Comparisons - 2007

MOE Offshore Direction

[Graph showing ADCP and Model Direction comparisons from April to November 2007]
The MOE nearshore ADCP also had a long term record and the overall score was 0.90 at the 1 m depth. The meter depth was only 6 m. The data from July onwards had many small data gaps which made analysis difficult as data replacement was required. The missing data was at depth as it appears the lake elevation may have fluctuated and the bottom bin was often missing. Figures 6-7 and 6-8 show the comparisons. Table 6-4 provides more details of the F-norm analysis. The nearshore zone has much higher frequency current reversals and is dominated by an easterly current direction.

**TABLE 6-4**
MOE Nearshore F-norm DATA - 2007

<table>
<thead>
<tr>
<th>Month</th>
<th>Surface</th>
<th>6 m depth</th>
<th>10 m depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apr - Nov</td>
<td>0.90</td>
<td>1.01</td>
<td>NA</td>
</tr>
<tr>
<td>May – Jun</td>
<td>0.94</td>
<td>1.04</td>
<td>NA</td>
</tr>
<tr>
<td>Jun – Jul</td>
<td>0.86</td>
<td>1.00</td>
<td>NA</td>
</tr>
<tr>
<td>Jul – Aug</td>
<td>0.95</td>
<td>1.00</td>
<td>NA</td>
</tr>
<tr>
<td>Aug – Sep</td>
<td>0.81</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Sep – Oct</td>
<td>0.93</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Oct - Nov</td>
<td>0.82</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>
FIGURE 6-7
MOE Nearshore ADCP Current Speed Comparisons - 2007

[Graph showing MOE Nearshore Speed comparison between ADCP speed and model speed for the months of April to November 2007.]
FIGURE 6-8
MCE Nearshore ADCP CurrentT Direction Comparisons - 2007
Overall the model has accurate prediction in the spring and fall period. The stratified period is more challenging and the accuracy drops off, but still has good directional response while the current speeds do not. The MOE nearshore location is shallow and may be affected by longshore wave action, a behaviour not accounted for in the MIKE-3 model. The offshore meters generally underestimate peak events, which may be due to insufficient vertical resolution or not large enough wind stress.

The temperature predictions for each ADCP are shown in Figures 6-9 to 6-12.
FIGURE 6-9
Comparison of Model Temperature Predictions vs OPG Temperature Data

OPG ADCP Temperature
FIGURE 6-10
Comparison of Model Temperature Predictions vs NWRI Temperature Data

NWRI Bottom Temperature

Temperature (°C)

April 2007
May 2007
June 2007
July 2007
August 2007
September 2007
October 2007
FIGURE 6-11
Comparison of Model Temperature Predictions vs MOE Offshore Temperature Data
FIGURE 6-12
Comparison of Model Temperature Predictions vs MOE Nearshore Temperature Data

MOE Nearshore bottom Temperature

Temperature (°C)

The ADCP only measures temperature at the meter depth. The model reproduces the spring and summer period quite well. There are upwelling/downwelling events that are simulated, although the temperature dips are not as large as observed. The correlation between the MOE offshore temperature and the predicted temperature at the ADCP depth is 0.918, which is a good score.
7. **Model Correlation to TRCA Data**

The following section presents MIKE-3 simulation results for the 2008 April to November period under actual plant effluent loads and including tributary loads that impact the Ajax-Pickering waterfront. These simulation results are compared with transect data from TRCA with the purpose of identifying similarities and differences between simulated and measured results.

7.1 **Nearshore Water Quality Monitoring Data**

*Ambient Lake Levels for TP*

An extensive water quality survey program was performed for the period 2007 to 2009 by the Regions and Toronto Region Conservation Authority. Seven transects were sampled several times each year for TP, soluble reactive phosphorus, total suspended solids, conductivity and *E.coli* for a total of 24 data points. Figure 7-1 shows the locations of each transect. The figure also presents the concentrations of TP measured on 10 Sep 2012 in terms of the size of the marker as described in the legend. Plots of the complete data set for the transects can be accessed at the site [http://theskua.com/wqapp/wqapp.html](http://theskua.com/wqapp/wqapp.html). Overall these results reveal a trend in which the highest TP concentrations occur immediately at the shoreline and then decrease moving in the offshore direction.

The transect data is a valuable source of information on water quality in the near-shore environment around the Ajax-Pickering waterfront. In particular, the gradient of decreasing phosphorus concentrations in the offshore direction and the absence of “hotspots” surrounding the outfall diffuser point to the importance of other sources influencing near-shore phosphorus concentrations. Among these sources include local tributaries (including the Duffins Creek and Rouge River) and near-shore sediment deposits which are subject to “wave induced re-suspension”\(^4\). The monitoring data also provides an opportunity for comparison with MIKE-3 simulation results. The following sections describe comparisons between MIKE-3 simulations with data from the transects. In attempts to correlate these results, however, certain limitations should be noted:

- Wave induced re-suspension of sediments, which has been suggested to be a key factor influencing near-shore TP concentrations, is not accounted for in the MIKE-3 model;
- The role of sedimentation in attenuating phosphorus plumes from tributary loads and the Duffin Creek WPCP outfall is not accounted for in the MIKE-3 model;
- Water quality monitoring samples from over 50 transect points were obtained over the course of a day and thus, unlike MIKE-3 simulation results, do not capture TP concentrations at a single point in time nor represent an average over a day.

\(^4\) Martin Auer (2011) “Monitoring, Modeling and Management of Nearshore Water Quality in the Ajax-Pickering Region of Lake Ontario”
7.2 Model Inputs

The MIKE-3 model as calibrated to the baseline condition was supplemented with time-series data to represent the Duffin Creek WPCP flows for 2008, flows from two other treatment plants including Highland Creek and Ashbridges Bay, and significant tributary loadings in the vicinity of the Ajax-Pickering waterfront. TP loadings from the plants have been calculated from daily measurements of average flow and effluent TP concentrations. Loadings from tributaries were provided by TRCA between Highland Creek and Harmony Creek and were calculated based on measured flows and monthly Event Mean Concentrations (Table 7-1). In cases where no measured data was available, tributary loadings were estimated based on the size of the watershed.

**TABLE 7-1**

<table>
<thead>
<tr>
<th>Loading Source</th>
<th>TP Loading, kg/d</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average 2008</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Point Sources</strong></td>
<td></td>
</tr>
<tr>
<td>Duffin Creek WPCP</td>
<td>238</td>
</tr>
<tr>
<td>Highland Creek WWTP</td>
<td>121</td>
</tr>
<tr>
<td>Ashbridges Bay TP</td>
<td>722</td>
</tr>
<tr>
<td><strong>Tributaries</strong></td>
<td></td>
</tr>
<tr>
<td>Rouge River</td>
<td>78</td>
</tr>
<tr>
<td>Highland Creek</td>
<td>22</td>
</tr>
<tr>
<td>Duffins Creek</td>
<td>52</td>
</tr>
<tr>
<td>Lynde Creek</td>
<td>24</td>
</tr>
<tr>
<td>Pringle Creek</td>
<td>5</td>
</tr>
<tr>
<td>Corbett Creek</td>
<td>2</td>
</tr>
<tr>
<td>Oshawa Creek</td>
<td>22</td>
</tr>
<tr>
<td>Harmony Creek/Black/Farewell</td>
<td>20</td>
</tr>
</tbody>
</table>
FIGURE 7-1
Transect Locations for Water Quality Survey - Station Identification Numbers Start at Shoreline and Increase Offshore
7.3 Comparison of Results

Nearshore water quality monitoring data was translated to the MIKE-3 simulation grid in the region surrounding the Duffin Creek outfall diffuser using UTM coordinates. TP concentration isopleths were then developed based on linear interpolation of data with the assumption that TP concentrations measured at the shoreline could be extrapolated to all proximate shoreline gridpoints. For comparison to MIKE-3 simulation results from 2008, the average concentration for 2008 were selected. MIKE-3 results represent the average concentrations for the April to November simulation period whereas water quality monitoring data results represent isopleths developed based on the averages of ten sampling periods between 29-Apr and 17-Nov 2008. See results presented in Figures 7-2 and 7-3.

TP concentration isopleths developed using the water quality monitoring data show that TP concentrations tend to be highest along the shoreline and at the location of Duffins Creek. The source of the elevated shoreline TP concentrations, with the absence of a logical pathway from the diffuser, indicates that these concentrations are not directly from the diffuser. The most probable explanation for these concentrations is that they are derived from a combination of shore based loads (Duffins Creek and stormwater) and wave induced re-suspension of historic depositions of particulate phosphorous in storm runoff from tributaries like Duffins Creek. As discussed, the MIKE-3 model has not accounted for either sedimentation or re-suspension of sediments and so this behaviour is not captured in the model. Interestingly, the TP “hot-spot” simulated around the Duffin Creek diffuser using the MIKE-3 model is not detected by the water quality monitoring transect data. This suggests that MIKE-3 simulation results tend to over-predict the impacts of the outfall diffuser on local water quality. Possible reasons for this may relate to model calibration to ambient current speeds, simulation of the rapid mixing in the near-field zone, or the fact that the model simulates TP as a conservative substance that is not subject to removal by sedimentation or biological uptake.
Figure 7-2
Concentration isopleths for TP - averages of TRCA transect data for 2008

Figure 7-3
Concentration isopleths for TP – average of 2008 simulation results from MIKE3
8. Baseline Modelling – 520 ML/d

One of the conditions of the approval of the Schedule C Class Environmental Assessment for the “Provision of Additional Capacity at the Duffin Creek Water Pollution Control Plant” (September 2006) was that the outfall limitations be addressed before flows reached 520 ML/d. This is the minimum flow at which the MOE assumed that dilution requirements of 20:1 would not be met. Consequently, a constant flow of 520 ML/d is the flow considered as the baseline for modelling, which future flows and outfall configurations will be modeled against. Water quality variables simulated in the model were total phosphorus and unionized ammonia.

8.1 Existing Outfall

The existing outfall is approximately 1 km offshore with a 183m long diffuser. The diffuser was represented in the model as two sources adjacent to each other but aligned offshore. The total flow rate of 520 ML/d was apportioned into 260 ML/d for each grid cell with the exit velocity set to 2.4 m/s as calculated based in the number of ports and their dimensioning. The exit direction was offshore and the vertical angle was set to 10° above vertical. This representation allows the momentum produced by the diffuser to be captured in the model over two grid cells and one single depth layer, the bottom layer, in which flow is assumed to be released. There are no methods in the MIKE-3 software to allow variable depth i.e. spatial releases based on ambient buoyant conditions such as those predicted by near-field models like CORMIX.

8.2 Effluent Certificate of Approval Requirements

The Certificate of Approval was revised in 2007 to reflect the expansion requirements identified in the Schedule C Class EA for “Provision of Additional Capacity at the Duffin Creek Water Pollution Control Plant” and the Minister’s conditions of approval. The CofA compliance limits that were taken into consideration for use in the baseline model scenario are:

- Total Phosphorus: 0.6 mg/L (equates to the 311kg/d mass loading limit at 520MLD)
- Total Ammonia Nitrogen: 6 mg/L and 10mg/L during summer/fall (May 1 to Oct 31) and winter months (Nov 1 to Apr 30) respectively

The above concentrations were used in modelling effluent levels.

Since the Stage 3 expansion has come on-line in the fall of 2010, the plant has been performing well below the effluent compliance limits. The 2011 monthly average concentrations for total phosphorus, total ammonia nitrogen, and unionized ammonia is 0.4mg/L, 1.5 mg/L, and 0.001 mg/L respectively. The end-of-pipe unionized ammonia level is below the acute toxicity level for fish.
8.3 Provincial Water Quality Objectives

As described in Section 3, Phosphorous is considered a nuisance nutrient that may affect the surrounding aquatic environment. In particular, Total Phosphorus (TP) has been shown to contribute to increased algal formation at concentrations greater than the interim Provincial Water Quality Objective (PWQO) of 0.02 mg/L in lakes.

Un-ionized ammonia (UIA) is an important measure of the level of effluent toxicity to aquatic organisms. The PWQO for UIA is 0.02 mg/L. Un-ionized ammonia is calculated from the measured value of total ammonia based on both temperature and pH data from the measured location.

8.4 Receiving Water Characterization

Loading from Duffins Creek

Duffins Creek is a contributor to pollutant loading to the Lake. Consequently, the model was run with and without the influence of Duffins Creek for comparison purposes.

The Toronto & Region Conservation Authority (TRCA) provided time series of flow from Duffins Creek for 2007 on an hourly basis. Monthly Event Mean Concentrations (EMC) for TP was provided as well. The EMC were used as input of concentration of TP in the Creek flow. It was assumed that the ammonia levels were zero as there should be no sources along the Creek.

Ambient Lake Levels for TP

The TRCA transect data discussed in section 7 provides a valuable source of data for evaluating the ambient TP concentrations in the region surrounding the Ajax-Pickering waterfront. Figure 8-2 shows the locations of each transect, the shoreline station would be labeled 10 and then each offshore station would be 110, 140, 1,100 m offshore and 1,500 m offshore. The MOE uses the 75th percentile to define the ambient water quality. Figure 8-1 summarizes the 75th percentile for each station showing the highest TP concentrations occur immediately at the shoreline and then decrease as one moves offshore. At the location of the existing Duffin Creek WPCP outfall, the results indicated that the water quality is better than the PWQO. The ambient TP level would most likely be found at the furthest offshore stations, away from shoreline discharges and the diffuser. The average of the 75th percentile of the offshore stations is 0.01 mg/L. Regarding the TP concentrations measured at the shoreline, it is concluded that shoreline discharges and non-point loadings are responsible for these higher concentrations. This is confirmed by the fact that concentrations at sampling points surrounding the outfall diffuser are lower than concentrations measured at the shoreline. Although these shoreline loadings are not explicitly included in the MIKE-3 model, their influence is accounted for inasmuch as they contribute to the offshore ambient TP concentration of 0.01 mg/L. Plots of the complete data set for the TRCA transects can be accessed at site http://theskua.com/wqapp/wqapp.html.

Dr. Howell, of the MOE, presented results of his survey of the TP levels in Lake Ontario at the 2010 Lake Erie Millenium Network – April 2010, “Patterns in Nutrients over Dressena-Cladophora Impacted Shoreline” Slide 7 is presented, which show the TP levels offshore of Port Hope in Figure 8-2. The offshore levels of TP range from 0.004 mg/L to 0.007 mg/L.
Based on the results of surveys conducted by TRCA and Dr. Howell of the MOE, it is proposed that the ambient levels of the Lake Ontario grid (2,430 m and 810 m) resolution be set at 0.007 mg/L and the nested grids in the nearshore area of Duffins Creek ambient level set at 0.01 mg/L.
FIGURE 8-1
75th Percentile TP by Station

75th Percentile Phosphorus by Station

TP ug/L

Station Name
8.5 Total Phosphorus in Lake Ontario under the 520 ML/d Baseline Scenario

TP was modelled as a conservative parameter meaning no assimilation was assumed in the model. In reality, there would be some assimilation in the actual plume as biological processes convert the TP into biomass and this would lead to lower measured concentrations. The results presented herein are therefore conservative, and impacts under existing conditions are expected to be less.

The model was run to simulate lake conditions from April 1 to November 27 for a total of 5,750 hours. The hourly average TP levels were enumerated for the surface layer and the total number of hours the TP level was above the PWQO of 0.02 mg/L were determined with just the effluent discharge and with the added input from Duffins Creek, showing no significant difference. Figure 8-3 shows the mixing of TP as defined by the 90th percentile.
A summary of the spatial and temporal extent of the TP surface plume is presented in Table 8-1 for results simulated with and without inputs from Duffins Creek. The results indicate that Duffins Creek has minor impact on TP levels in the effluent plume, but does influence TP concentrations in the near shore. As presented in Figures 8-4, the mixing zone for the 90th percentile isopleths has an outside envelope of the most extreme movement in an area 2.5 km to the west, 2.5 km to the east, 0.2 km to the north, and 0.6 km to the south of the diffuser.

Using the 90th percentile criteria, the mixing zone is found to not impinge on the shoreline or the Ajax WSP intake. It should be noted that the peak levels will not occur simultaneously; rather each grid point will experience a peak at different times during the simulation period.

<table>
<thead>
<tr>
<th>Hours above PWQO (0.02mg/L)</th>
<th>Number of grids without Duffins Creek (90m x 90m)</th>
<th>Number of grids (90m x 90m) with Duffins Creek</th>
<th>Area (ha) without Duffins Creek</th>
<th>Area (ha) with flows from Duffins Creek</th>
</tr>
</thead>
<tbody>
<tr>
<td>4,000 to 5,000</td>
<td>1</td>
<td>1</td>
<td>0.81</td>
<td>0.81</td>
</tr>
<tr>
<td>3,000 to 4,000</td>
<td>6</td>
<td>6</td>
<td>4.8</td>
<td>4.8</td>
</tr>
<tr>
<td>2,000 to 3,000</td>
<td>30</td>
<td>32</td>
<td>24.3</td>
<td>25.9</td>
</tr>
<tr>
<td>1,000 to 2,000</td>
<td>129</td>
<td>132</td>
<td>104</td>
<td>107</td>
</tr>
<tr>
<td>100 to 1,000</td>
<td>1281</td>
<td>1319</td>
<td>1037</td>
<td>1068</td>
</tr>
</tbody>
</table>

The results presented in Figure 8-5 present average concentrations for each of the grid points for the April to November simulation period. The highest peak instantaneous level is 0.119 mg/L and is located at the discharge points, as expected. These results indicate that, on average, the mixing zone in which PWQO for TP is exceeded does not impinge on the shoreline or surrounding features such as the Ajax WSP intake.

The areas of the lake impacted by elevated TP levels due to the discharge are mainly toward the west and extend offshore as well as onshore. These simulations do not account for any assimilation of TP to the environment. If the surface plume is transported beyond the 90 m grid boundaries, it is likely that the plume will return at a highly diminished level since some the TP would be assimilated in the environment. The areas shown are more likely the result of slow currents and short term current reversals rather than long term buildup of TP. Observations in the past several years show this to be the case as seen in the TRCA and MOE sampling survey, the plume is not readily apparent.
8.6 Un-Ionized Ammonia Levels in Lake under 520 ML/d Baseline Scenario

Ambient Ammonia levels were surveyed in 2008 by the MOE. Figure 6-6 show the ammonia levels on survey date July 29, 2008. The entire data set can be found at http://theskua.com/ajax. The 75th percentile of all data from the five surveys is 0.008 mg/L. The ambient levels in the lake were set to this value.
The Un-Ionized Ammonia (UIA) was calculated using the predicted surface layer concentration of ammonia and the corresponding temperature in the grid, along with the pH measured at the Ajax WSP intake. Ammonia was also modelled as a conservative parameter. The Ajax data, summarized in Table 8-2, were measured daily whereas the model data were simulated hourly. It was assumed that the pH was constant over the grid for the day of record. The synoptic data were used to determine the UIA, and then the hours above the PWQO of 0.02 mg/L were enumerated. The simulation results were partitioned into a winter and summer period, as required by MOE, since the ammonia levels in the effluent vary in these periods.
TABLE 8-2
Summary of Temperature and pH Data for the Ajax WSP intake

<table>
<thead>
<tr>
<th>Month</th>
<th>Average</th>
<th>75th percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Temp</td>
<td>pH</td>
</tr>
<tr>
<td>January</td>
<td>4.33</td>
<td>8.15</td>
</tr>
<tr>
<td>February</td>
<td>2.66</td>
<td>8.17</td>
</tr>
<tr>
<td>March</td>
<td>2.98</td>
<td>8.17</td>
</tr>
<tr>
<td>April</td>
<td>4.37</td>
<td>8.18</td>
</tr>
<tr>
<td>May</td>
<td>7.15</td>
<td>8.20</td>
</tr>
<tr>
<td>June</td>
<td>7.43</td>
<td>8.10</td>
</tr>
<tr>
<td>July</td>
<td>10.19</td>
<td>8.17</td>
</tr>
<tr>
<td>August</td>
<td>15.30</td>
<td>8.15</td>
</tr>
<tr>
<td>September</td>
<td>14.69</td>
<td>8.09</td>
</tr>
<tr>
<td>October</td>
<td>12.46</td>
<td>8.09</td>
</tr>
<tr>
<td>November</td>
<td>7.39</td>
<td>8.08</td>
</tr>
</tbody>
</table>

Figures 8-6 and 8-7 (90th percentile) and Figures 8-8 and 8-9 (average concentrations) present the simulation results for UIA. The area impacted is not dominated by a particular direction, as was found with the TP results. The instantaneous winter peak level is 0.067 mg/L and the summer peak level is 0.142 mg/L. Averaging the simulated UIA levels, presented in Figures 8-8 and 8-9, gives maximum average levels of 0.019 mg/L (winter) and 0.032 mg/L (summer). The UIA levels are lower in the winter, even with the effluent ammonia level higher than summer, primarily because of the effect of colder water temperatures on the UIA factor. Figures with Duffins Creek are not included as the contribution of ammonia in the Creek discharge was assumed to be negligible and the Creek’s influence would therefore be limited to providing dilution water at its discharge point.
FIGURE 8-6
Mixing zone for UIA is non-existent as defined by the 90th percentile – Winter Period

FIGURE 8-7
Mixing zone for UIA as defined by the 90th percentile - Summer Period
Table 8-3 presents a summary of the spatial and temporal extent of the UIA surface plume. The effect of Duffins Creek is to impact dilution and shoreline distribution of the ammonia effluent plume.
## TABLE 8-3
Spatial and Temporal Extent of Surface UIA Plume

<table>
<thead>
<tr>
<th>Hours above PWQO (0.02mg/L)</th>
<th>Winter Period November 1 to April 30</th>
<th>Summer Period May 1 to October 31</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of grids (90m x 90m) without Duffins Creek</td>
<td>Number of grids (90m x 90m) with Duffins Creek</td>
</tr>
<tr>
<td>400 to 500</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>300 to 400</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>200 to 300</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>100 to 200</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>1 to 100</td>
<td>31</td>
<td>30</td>
</tr>
<tr>
<td>400 to 500</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>300 to 400</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>200 to 300</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>100 to 200</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>1 to 100</td>
<td>2,531</td>
<td>2,523</td>
</tr>
</tbody>
</table>

Using the 90th percentile isopleths, the extent of the plume in which PWQO for UIA are exceeded is:

- Winter — no area
- Summer — 90 m west, 90 m south, and 270 m east of the diffuser.

As in the TP results, the size of this plume zone is influenced by the zone of initial mixing as generated by the outfall diffuser. Beyond this zone, changing current speeds and direction influence the migration of the plume. The variable nature of current speeds and directions can be observed from the Compass Rose of current speeds at the nearby NRWI ADCP, presented in Figure 8-11.

Relevant to water quality, the predicted total ammonia nitrogen time series at the depth layer (7) representative of the Ajax Intake is shown in Figure 8-10. The peak ammonia level of 0.056 mg/L occurs in mid June and is well below the drinking water guideline of 0.5 mg/L.
FIGURE 8-10
Ajax Intake Ammonia Time Series

Ammonia at Ajax Intake depth

Ammonia (mg/L)
The Pickering NGS discharge will pull in some of the lake water with diluted effluent and then discharge it back to the lake with a small temperature increase. The increase in temperature has the potential to raise the level of UIA in that water – however the discharge is not included in this model.

**FIGURE 8-11**
Compass Rose representation of Current Speeds (in m/s) and Directions – NWRI ADCP

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### 8.7 Impact of Pickering NGS

To assess the impact of the Pickering NGS and its potential decommissioning in the future, the baseline model was rerun with inflows and outflows to the nuclear generation facility. Inflows were simulated from a single grid point at the Pickering NGS headland and outflows were simulated from opposite points of the same headland using a time-series based on recorded flows and assuming a temperature differential of 10 °C relative to the lake temperature at the discharge point.

Simulation results presented in Figures 8-12 and 8-13 compare flow vectors with and without the Pickering NGS. These results show a significant induced current in the offshore direction with the NGS outflows (Figure 8-12) that is not present in the model results.
without NGS outflows (Figure 8-13). Simulation results indicate that the impact of this induced current is to cut off and reduce current speeds in the along-shore direction. This is consistent with the results of Leon et al. that show that the NGS outflows create “thermal bars” that “drive some of the small scale circulation”\textsuperscript{5}.

Average TP concentrations are presented in Figure 8-14 and 8-15, respectively, based on simulations with and without the Pickering NGS outflows. These results are very similar with notable differences only occurring in areas with concentrations below 0.015 mg/L. In contrast, the simulated zone in which TP exceeds 0.02 mg/L is almost identical in size and shape. These simulation results indicate that, while the NGS outflows do impact the local circulation patterns and currents at the shoreline, overall impacts on the performance of the outfall diffuser are insignificant. Consequently, decommissioning of the Pickering NGS would not be expected to have a significant impact on the performance of the outfall diffuser.

\textsuperscript{5} Leon et al. (2012) “Nested 3D modeling of the spatial dynamics of nutrients and phytoplankton in a Lake Ontario nearshore zone” Journal of Great Lakes Research.
Figure 8-12
Circulation patterns as predicted by the model with the Pickering NGS inputs

Figure 8-13
Circulation patterns as predicted by the model without the Pickering NGS inputs
Figure 8-14
Average concentration isopleths at 520 MLD with the Pickering NGS

Figure 8-15
Average concentration isopleths at 520 MLD without the Pickering NGS
9. Summary and Conclusions

9.1 Summary of Results

9.1.1 CORMIX MODEL: Near-Field Analysis

The CORMIX near field analysis indicates that the initial mixing ratio of the existing diffuser is 22.8:1 at the baseline flow of 520 MLD. Based on this 22.8:1 initial mixing ratio calculated using the CORMIX software, the mixing zone extends into the far-field zone. As such, a far-field analysis was required to further delineate the mixing zone. The MIKE-3 model was used for this purpose.

9.1.2 MIKE 3 MODEL: Far-Field Analysis

The calibration with ADCP currents was successful; some locations had better model agreement than others. Generally the model has better predictions in the weakly to non-stratified periods. The temperature response of the model was very good for the entire period of simulation. The existing discharge, modelled over two grid points, simulated the momentum of the plume and the advection-dispersion process in the far-field.

The model predicted the spatial and temporal extent of the effluent plume for both TP and ammonia. UIA was subsequently determined from synoptic temperature and pH data. Integration of the hourly results and using the PWQO limits, the model results were used to define the extent of the zone in which UIA and TP PWQO were exceeded.

The results indicate that, on average, the mixing zone does not impinge on the shoreline or Ajax WSP intake. Based on the mixing zone as defined by the 90th percentile isopleth, the mixing zone extends approximately 2.5 km to the west, 2.5 km to the east, 0.2 km to the north, 0.6 km to the south of the outfall diffuser. The highest instantaneous (1 hour) level is 0.119 mg/L and is located, as expected, at the discharge points.

The results indicate that the UIA effluent plume is much smaller than that for TP. Out of 5,750 hours of simulation (April to November) the areas ranged from: 2,110 Ha between 1 and 100 hours over the PWQO and less than 30 Ha had between 400 and 500 hours. Using the same 10% above the PWQO isopleths as in the TP method, the mixing zone for UIA is:

- Winter — no area
- Summer — 90 m west, 90 m south, and 270 m east of the diffuser.

While, the peak UIA was found to be above the PWQO, the spatial and temporal extents of these exceedances are very limited; again much less than that for TP. The UIA levels at the Ajax Intake were reviewed from a drinking water quality perspective and were noted to be well below the guidelines.

The model results that included the flow from Duffins Creek showed there is some shoreline impact from the Creek with TP, while the UIA results showed the Creek flow provides some relief due to dilution, as the Creek is assumed to be free of ammonia.
10. References


Holleck, K. “Ecological Indicators and Sustainability of the Lake Ontario Ecosystem”. Cornell Biological Field Station report accessed on 18 Jan 2013 from http://www.seagrant.sunysb.edu/glsportfish/pdfs/LOnt-EcoIndicators-Fall08.pdf


