5.0 TIME VARYING SIMULATIONS OF THE MIXING ZONE

5.1 Mixing Zone Analyses

The mixing zone is an area where waters of one quality mix with another. In some instances or jurisdictions, this zone is a region where concentrations of an effluent may greatly exceed certain water quality objectives, and it is necessary to define various sub-zones within it where acute or chronic water quality standards are exceeded. In other cases, the mixing zone is simply a region where water, which may or may not exceed certain objectives, joins and mixes with that of a receiving body having somewhat different, but similar, characteristics.

The Ontario Ministry of the Environment defines a mixing zone as an area where the water quality does not comply with one or more of the Provincial Water Quality Objectives (PWQO). By this definition, when rivers (as well as other point or diffuse discharges from industrial effluents, for example) mix with lakes or other tributaries, there may or may not be exceedences of the PWQO for many parameters. In other cases, the background water quality of the receiving body may already exceed the PWQO, making it difficult to define the mechanical mixing zone using this definition.

It is evident from the figures and tables presented earlier, however, that the mixing zone of the Nottawasaga River does not present a situation where acute water quality conditions are present. It is of value to define locations where PWQO’s are exceeded, however, and/or to prepare contour maps showing zones of various concentrations, whether these concentrations are below or above the PWQO’s.

The numerical modelling conducted for this project can be used to estimate dilution contours for the Nottawasaga River in Nottawasaga Bay following a maximum concentration approach or a probabilistic approach. The maximum concentration plume can be determined by noting the maximum concentration in each model cell over the entire modelling period and then consolidating the individual maxima into a single plume. However, this plume does not provide information about how often such large concentrations occur in different regions of the bay near the river confluence. Furthermore, time varying winds and density circulation in the bay continuously change the plume shape over time.

Hence, the second method was employed herein to consider the time varying excess concentration plume that results from time-varying lake elevations, inflow volumes and concentrations, winds and other meteorological conditions. The method chosen to summarize these results is the probabilistic plume envelope (Kolluru, et al. 2003). The probabilistic plume envelope can be shown in either tabular form as an exceedence value for each grid cell, or in graphical form as a contour plot shown on GIS site maps.

River water quality and discharge data from the CANWET model (Greenland, 2006) were used as input to the GEMSS model for defining probabilistic plumes from the Nottawasaga River in Nottawasaga Bay for:

- Existing Land Use Conditions
- Future Land Use Conditions
The CANWET model is a watershed nutrient model which was designed to simulate the quality of runoff from various land uses in the Nottawasaga River watershed. The "Existing" land use condition was derived from 2002 satellite images and other land use data. The "Future" land use scenario represents a future land use in which approved developments specified in Official Plans are built out (horizon year 2026) and sewage treatment plants are operating at projected volumes.

The latter set of CANWET modelling results did not include the effects of urban storm water best management practices. These would certainly be employed with future development and their benefits will be assessed through future CANWET simulations.

The CANWET model includes a module which calculates constituent concentrations in stream segments and river reaches. The results of this in-stream module, called STREAMPLAN, were used in GEMSS for the mixing zone analysis. The STREAMPLAN data for the mouth of the Nottawasaga River (and which were used in the mixing zone modelling) are provided in Appendix C, and include monthly discharges and concentrations for both land use cases.

5.2 Existing Land Use

The mixing zone modelling began by examining the existing land use results from the STREAMPLAN model and preparing input concentrations of those variables not provided (but used in GEMSS). These variables, such as various forms of phosphorus and nitrogen (i.e., particulate, dissolved, etc.) were generated from relationships derived during model calibration to the 2005 field data.

The next step involved scanning the STREAMPLAN results to isolate those periods when river discharge and loadings would combine to present a maximum loading/maximum plume condition. In the ten year period from 1995 to 2004, the condition of highest combined TP and TN loading was found to occur in March 2003 (highest TP loading and second highest TN loading). Table 5-1 gives the river discharge, concentrations and loads through this period.

The February 1st to April 1st, 2003 data sets were subsequently assembled to simulate the March plumes and background conditions in February. This included the STREAMPLAN concentrations of total phosphorus (TP) and total nitrogen (TN), all of the hourly meteorological data (including global solar radiation in 2003), discharge data for the Nottawasaga River, and river response temperatures which were calculated from the meteorological data. The model was then run to simulate all forms of each water quality parameter in each cell of the model (see Figures 4-17 and 4-18 for the cell locations) for surface, mid-depth and bottom cells, and the results were saved hourly for all water quality constituents in all cells.

This database was then assessed to compute probability envelopes for TP and TN. Through time, the concentrations in each cell vary in response to changing currents in the lake, the changing momentum of the plume, and changing concentrations in the river. However, the probability of a particular concentration can be determined for each cell, and the following contour plots give the probability of exceedence of particular concentrations of TP and TN for this period. As noted above, these results represent near maximum load condition for defining the mixing zone for current / existing land use conditions.
**TABLE 5 – 1**

Existing Land Use - Monthly Flows, Concentrations and Loading for TP and TN in Early 2003

<table>
<thead>
<tr>
<th>Month of 2003</th>
<th>Flow (m$^{3}$/s)</th>
<th>TP (mg/L)</th>
<th>TP (tonnes)</th>
<th>TN (mg/L)</th>
<th>TN (tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>7.90</td>
<td>0.0033</td>
<td>0.07</td>
<td>1.25</td>
<td>26.40</td>
</tr>
<tr>
<td>February *</td>
<td>4.48</td>
<td>0.0097</td>
<td>0.11</td>
<td>1.73</td>
<td>18.78</td>
</tr>
<tr>
<td>March *</td>
<td>85.52</td>
<td>0.0549</td>
<td>12.58</td>
<td>1.79</td>
<td>410.80</td>
</tr>
<tr>
<td>April</td>
<td>76.07</td>
<td>0.0099</td>
<td>1.95</td>
<td>1.13</td>
<td>222.93</td>
</tr>
</tbody>
</table>

**TABLE 5 – 2**

Future Land Use - Monthly Flows, Concentrations and Loading for TP and TN in Early 2003

<table>
<thead>
<tr>
<th>Month of 2003</th>
<th>Flow (m$^{3}$/s)</th>
<th>TP (mg/L)</th>
<th>TP (tonnes)</th>
<th>TN (mg/L)</th>
<th>TN (tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>9.26</td>
<td>0.0064</td>
<td>0.16</td>
<td>1.74</td>
<td>43.22</td>
</tr>
<tr>
<td>February *</td>
<td>5.01</td>
<td>0.0138</td>
<td>0.17</td>
<td>2.74</td>
<td>33.25</td>
</tr>
<tr>
<td>March *</td>
<td>87.22</td>
<td>0.0477</td>
<td>11.14</td>
<td>1.74</td>
<td>405.89</td>
</tr>
<tr>
<td>April</td>
<td>76.28</td>
<td>0.0102</td>
<td>2.02</td>
<td>1.18</td>
<td>232.70</td>
</tr>
</tbody>
</table>

* Simulation Period
It must be noted that the CANWET STREAMPLAN modelling process provides average monthly discharges and average monthly loads / and concentrations. This lends itself well to models with relatively long time steps but is not perfectly suited for mixing zone calculations which use short time steps and hourly data. Hence, the mixing zone probability maps shown in the following plots give reasonable representations of the areas where the plume from the Nottawasaga River will reside over time (as compared to a “snapshot” at a given time) and can be used as a tool for showing the changes, (or sensitivity of changes) from present to future land use, when simulations extend over more than monthly time steps.

5.2.1 Total Phosphorus

Four maps were prepared to show the probability plume for the mixing zone. The first two of these were created to show the near-field / hydraulic mixing zone which occurs near the river mouth. The third and fourth were prepared to show the near-field and far-field / passive plumes in Nottawasaga Bay as compared to the interim Provincial Water Quality Objective for phosphorus (0.01 mg/L for open water).

Figures 5-1 and 5-2 map the areas near the river mouth associated with the probability of TP concentrations of 0.03 mg/L and 0.02 mg/L, respectively, during this maximum loading condition. The background concentration was taken to be 0.006 mg/L for these two simulations based on an average of field data from our monitoring in the summer of 2005. As shown in both figures, the river discharge mixes quickly with the lake and the 50% probability area (which is certainly the average limit of the hydraulic mixing zone) covers an area of 1.2 km² to 1.9 km². The point where the probability of finding TP concentrations of 0.03 mg/L or 0.02 mg/L is also reached very quickly offshore from the mouth (1400 m to 2500 m, respectively). In all, these probability plumes closely replicate the initial mixing shown in aerial images of the plume (discussed in Section 3.8) and add further to our understanding of the dilution processes at work.

Figure 5-3(a) and 5-3(b) show the near-field and the far-field passive plumes for the existing case to illustrate the extent and probability of exceeding 0.01 mg/L total phosphorus (the PWQO). The river concentrations of TP for this simulation were 0.0097 mg/L in February and 0.055 mg/L in March with a background concentration of 0.002 mg/L (corresponding to our spring surveys and similar spring surveys by Environment Canada).

Although the March concentrations in the river are very high, the February river discharge concentrations are just below 0.01 mg/L. As the discharge is below 0.01 mg/L for half (50%) of the time, as a result, the probability of exceeding 0.01 mg/L at the mouth in just 50%. Figure 5-3(b) shows that this 50% probability level then extends northward along the shore for about 6.5 km. The probability of exceeding 0.01 mg/L TP reduces more quickly to the south-southeast along Wasaga Beach and, in this simulation, reduces to 30% or less within 7 km of the mouth.

Figure 5-3(b) also shows the overall effect of various changes in lake current speeds and directions on the river plume for these maximum TP loading / maximum plume conditions. In some periods of time in the simulation period, the river plume was directed to the northeast by lake currents, and so there is a 10% probability that a concentration of 0.01 mg/L would be equalled or exceeded in the area of
Figure 5-1: Existing Land Use – Probability Plume for 0.03 mg/L Total Phosphorus at the River Mouth

Figure 5-2: Existing Land Use – Probability Plume for 0.02 mg/L Total Phosphorus at the River Mouth
Figure 5-3(a): Existing Land Use – Probability Plume for 0.01 mg/L Total Phosphorus at the River Mouth

Figure 5-3(b): Existing Land Use – Probability Plume for 0.01 mg/L Total Phosphorus in Southern Nottawasaga Bay
Georgian Sands Beach – roughly 23 km to the north-northwest of the river mouth. On other occasions, the plume was pushed by lake currents to the southwest and the 10% probability level extends to about 3 km east of Collingwood Harbour.

5.2.2. Total Nitrogen

Two figures were prepared to show the probability plume for total nitrogen (TN). There is no PWQO for TN and, simply for illustrative purposes, the probability mapping was prepared for values exceeding 0.50 mg/L.

Figure 5-4(a) shows the near-field effect of the river plume (1.73 mg/L in February to 1.79 mg/L in March 2003) discharging into the lake with an ambient spring concentration of 0.44 mg/L (derived from our surveys and Environment Canada surveys). The reduction in concentration is shown to be relatively rapid at the river mouth. As seen in Figure 5-4(b), the probability plume for exceeding 0.50 mg/L TN is shown to be contained to the area from Spratt Point to Brooms Beach (7 km north of the river mouth to 10 km to the southwest). An exception to this is the shallow area north-northeast of Spratt Point where the modelling projected that an additional 8 km along the shore would fall within the zone where 0.50 mg/L TN has a 10% to 20% probability of being exceeded.

5.3 Future Land Use

The same process outlined above was followed for future land use simulations. The same period of time (February – March 2003) was also determined to present the maximum load condition for the future and, as a result, the following figures are directly comparable to those presented above in Section 5.2. Again, it is noteworthy that the STREAMPLAN data does not reflect water quality modifications stemming from any best management practices which would be employed with future development.

Table 5-2 (provided earlier) gives the future river discharge, and the TN and TP concentrations provided from STREAMPLAN for our modelling. As in the existing simulations shown earlier, the condition of highest combined TP and TN loadings was in March 2003, where the highest TP and second highest TN loading were found in the STREAMPLAN modelling through the 1995 to 2004 period. It is noteworthy that the STREAMPLAN model projects a slight reduction in the future concentration of TP in March but an increase in February. Thus, there is a projected to be a discharge concentration of at least 0.01 mg/L at all times in this period (i.e., the interim PWQO for lakes is exceeded 100% of the time at the immediate river mouth).

5.3.1 Total Phosphorus

Figure 5-5 maps the near-field region of the future land use plume showing probabilities of exceeding 0.02 mg/L. It was prepared to illustrate the difference in the near-field mixing zone configuration for this future case as compared to the existing case for the same conditions (Figure 5-2).

The existing and future cases appear almost identical. Indeed, the hydraulic mixing zone (roughly the area where 0.02 mg/L would be exceeded 50% or 60% of the time) remains virtually the same as the
Figure 5-4(a): Existing Land Use – Probability Plume for 0.50 mg/L Total Nitrogen at the River Mouth

Figure 5-4(b): Existing Land Use – Probability Plume for 0.50 mg/L Total Nitrogen in Southern Nottawasaga Bay
Figure 5-5: Future Land Use – Probability Plume for 0.02 mg/L Total Phosphorus at the River Mouth
existing land use case. The effect of the slight reduction in future land use loadings for this maximum load condition is only clearly noticeable in the 10% probability area which does not reach quite as far offshore at the river mouth and to the southwest.

Figure 5-6(a) plots the future land use probability plume for 0.01 mg/L TP (the interim PWQO for TP) in the area near the river mouth, and Figure 5-6(b) shows the area covered by the far-field passive plume of 0.01 mg/L TP.

Figure 5-6(a) maps an area near the river mouth where the probability of exceeding 0.01 mg/L is relatively high. This is because the February and March 2003 river concentrations are continuously above 0.01 mg/L so there is always some mixing required to reduce concentrations (from 100%) to less than 0.01 mg/L.

Figure 5-6(b) shows the far-field passive plume for this future simulation. As discussed above, this figure shows the combined effect of periods when the plume is moved along the shore in one direction added with periods when the plume is carried along the shore in the opposite direction. Overall, the figure illustrates that there is a 10% probability that a TP concentration of 0.01 mg/L will occur or exceed out to about 3 km east of Collingwood Harbour and northwest to Georgian Sands Beach, which is about 23 km from the river mouth.

5.3.2 Total Nitrogen

Figures 5-7(a) and 5-7(b) were prepared to show the probability plume for TN resulting from future land use for this period of high TN loading (February and March 2003). The probability map was prepared for values exceeding 0.50 mg/L, for illustrative purposes.

Figure 5-7(a) maps the near-field effect of the TN plume (from 2.74 mg/L and 1.74 mg/L concentrations in the river in February and March). As shown, the probability of exceeding 0.50 mg/L falls off quite quickly in the offshore direction, but the 70% contour does extend along the shore in both directions.

Figure 5-7(b) shows the full extent of the far-field TN plume for this future case. The full extent of the 10% probability plume reaches from Brocks Beach (about 10 km southwest) to Spratt Point (7 km north of the river mouth), followed by an additional 8 km of the near-shore zone where concentrations of 0.50 mg/L are projected by the model to be exceeded 10% to 20% of the time.

5.4 Comparisons – Existing and Future Land Uses

5.4.1 Total Phosphorus

The probability plumes for the 0.03 mg/L and 0.02 mg/L simulations are quite useful for determining the maximum size of the near-field, hydraulic mixing zone. This is because river discharges in March 2003 were high and provided considerable momentum to push the river water into the lake.

Figure 5-2 (existing) and Figure 5-5 (future) show the initial hydraulic mixing zone to be limited to the area of the 50% or 60% probability contours. Beyond that, the plumes are driven by the lake currents.
Figure 5-6(a):  Future Land Use – Probability Plume for 0.01 mg/L Total Phosphorus at the River Mouth

Figure 5-6(b):  Future Land Use – Probability Plume for 0.01 mg/L Total Phosphorus in Southern Nottawasaga Bay
Figure 5-7(a): Future Land Use - Probability Plume for 0.50 mg/L Total Nitrogen at the River Mouth

Figure 5-7(b): Future Land Use - Probability Plume for 0.50 mg/L Total Nitrogen in Southern Nottawasaga Bay
Noteworthy is that there is little difference between the existing and future conditions for the 0.02 mg/L TP cases.

Figure 5-3(a) and Figure 5-6(a) compare the existing and future cases near the river mouth for 0.01 mg/L TP. Although there is an area of rapid mixing and dilution at the river mouth (from 100% exceedence of 0.01 mg/L down to 50% exceedence), shown in Figure 5-6(a) and not in Figure 5-3(a), it was noted earlier that this is simply because the simulated February concentration was 0.0097 mg/L. Had the STREAMPLAN model simulated the TP concentration to be just 0.0003 mg/L higher, the river discharge would have been at 0.01 mg/L and the river mouth plume in Figure 5-3(a) would have shown very much the same concentration contours and rapid mixing as seen in Figure 5-6(a).

The similarity between the existing and future cases is more clearly shown by comparing the 10% to 50% probability contours of Figure 5-3(b) and Figure 5-6(b). The only differences of note – and these are subtle differences – are a slightly large area of the 50% contour to the north and south of the river mouth.

Overall, the simulation for TP show that the area where the probability of exceeding 0.01 mg/L at the river mouth can be quite sensitive to small changes in river concentration. However, in the maximum loading condition for TP in the 1995 to 2004 year period, there is practically no difference between the existing and future far-field plumes for the 10% to 50% probability contours.

5.4.2 Total Nitrogen

Figures 5-4(b) and 5-7(a) show the TN plume near the river mouth for existing and future cases, respectively. It is clear that the future TN concentration in the river during February (2.74 mg/L) as compared to the existing value (1.73 mg/L) has an effect on increasing the area of higher probability. The existing 60% contour line along the shoreline north of the river increases to 70% in the future case, and the 70% becomes 80%, so there is a shoreline effect as a result of future conditions.

Figures 5-4(b) and 5-7(b) show the far-field effect of the TP concentration changes. There is no detectable change in the 10 – 40% contour lines except for a small increase in the 40% area to the north. The 50% contour also increases to the north as shown earlier in Figure 5-7(a).

In all, these TN simulations for the second highest TN loading case with future development show that certain TN concentrations are increased along the shore. The same simulations show the increases to be relatively small, however, and not influencing Nottawasaga Bay as a whole.

5.5 Summary

The “mixing zones” shown in Figures 5-1 to 5-7 cover both the hydraulic mixing zone produced by the initial momentum of the river discharge (as it pushes into the lake) and the passive plume, which subsequently results when this discharge loses its momentum and is moved offshore or along the shore by currents in the bay.
The probability plumes shown in this section for TP reflect maximum loading conditions from the river for defining the mixing zone for both current / existing and future land use conditions. These TP probability plume figures show that the initial hydraulic mixing zone encompasses no more than the area where exceedence probabilities are about 50%. This is an area of approximately 2 km² or less (as defined in Figure 5-2). At that point, lake currents predominate and control the movement of the plume into the far-field along the shore of off shore.

The far-field probability plumes (Figures 5-3(b) and 5-6(b)) which were developed from this maximum load condition for comparison to the interim Provincial Water Quality Objective for phosphorus (0.01 mg/L for open water) illustrate the general extent of the 0.01 mg/L TP plume. For both existing and future development, there was a 10% probability of TP concentrations exceeding 0.01 mg/L to reach along the shore to the area of Georgian Sands Beach (about 23 km north-northwest of the river mouth) during the two-month maximum loading simulation period. Similarly, the modelling for this period showed a 10% probability of TP concentrations exceeding 0.01 mg/L approximately 15 km southwest of the river mouth (about 3 km east of Collingwood harbour).

These same figures also illustrate the area which is more commonly influenced by the 0.01 mg/L TP plume. In these high loading simulations, the region which has 0.01 mg/L concentrations more than 50% of the time runs about 6 km along the shore at the river mouth. That region which has these concentrations more than 40% of the time extends about 14 km along the shore.

Overall, the simulations for TP show that the area where the probability of exceeding 0.01 mg/L at the river mouth can be quite sensitive to small changes in river concentration. However, in the maximum loading condition for TP in the 1995 to 2004 year period, there is practically no difference in the existing and future, far-field plumes for the 10% to 50% probability contours.

The near-field and far-field plumes shown here for total nitrogen (TN) also represent a very high loading condition (the second highest in the study period). The probability of concentrations of 0.50 mg/L were mapped for present and future land use conditions, and the future case shows an increase in concentrations near the river mouth. There is no detectable change in the 10% to 40% far-field contour lines except for small increases in the 40% and 50% areas just north of the river mouth.

In all, these TN simulations for the second highest TN loading case show that there is an extension in the probability of certain TN concentrations being increased along the shore in the future. The same simulations show the increases to be relatively small and not resulting in increased concentrations in Nottawasaga Bay as a whole.

Other TP and TN simulations using this mixing zone model will be conducted as part of the model training and transfer process, and for a variety of other purposes. It is almost certain that one or other of these simulations will show probability plumes extending into different areas that mapped in the above figures, and we certainly encourage the extension of this modelling to add to the knowledge base. However, given that the enclosed figures result from very high TP and TN loads in the Nottawasaga River, it is anticipated that the general configuration and concentrations shown herein will be found consistent with those mapped through additional work.