4.0 ASSESSMENT OF REMEDIAL OPTIONS

In this section we present the results of the workshop discussions and model analyses that relate to the assessment of the remedial actions listed in Table 3. In keeping with the discussions on the final two days of the June workshop, this section is organized around the nine ecosystem indicators listed in Table 6, and is divided into eight subsections. The first two indicators, algal biomass (and composition) and water clarity, are the subject of Section 4.1; they are so closely related to each other that it was inappropriate to discuss them separately. The remaining 7 subsections each deal with an individual indicator.

The subsections are organized into four parts. In the introduction, the indicator is defined and its relationship to one or more impaired uses within the Bay is clarified. As well, the introduction includes, where appropriate, a summary of the evidence that the uses of concern are in fact impaired. The second part addresses the issue of targets for improvements to the indicator. Where possible, actual targets are presented; otherwise suggestions are offered as to how the targets might be defined. The third part comprises the actual assessment of remedial actions - what the effects of their implementation on the indicator might be; what uncertainties constrain our ability to predict these effects with confidence; and what research needs are highlighted by these uncertainties. Finally, in the fourth part we summarize the conclusions of the assessment, especially with respect to priorities for implementation of remedial actions or for future research and data collection.

As noted in the previous discussion of the Bay of Quinte ecosystem model, many of the actions and indicators of interest to the RAP are inextricably linked to one another. This poses a significant challenge for assessment,
since it is difficult to evaluate the effects of one action in isolation. For example, one can't really say what phosphorus controls will do to water clarity without knowing how changes in macrophytes have affected other biota.

The highly coupled nature of this system has another implication that affects the discussions to follow. For the most part, the same set of remedial actions warrant consideration for each of the first six ecosystem indicators (Table 6), since all are related to biotic interactions and nutrient dynamics. Once the likely effects of these actions have been discussed once (in Section 4.1) there is little point in repeating the assessment for the other related indicators. Accordingly, Section 4.1 is relatively long, and includes a comprehensive assessment of several potential actions and their ecosystem effects, while Sections 4.2-4.5 are relatively brief. Readers interested in the indicators covered by these latter sections should, therefore, review the material in Section 4.1 as well as the other sections of interest. Essentially, Section 4.1 contains a detailed discussion of the expected ecosystem effects of both bottom-up and top-down controls on phytoplankton.

4.1 Water Clarity and Algal Community Structure

4.1.1 Introduction

Water clarity was chosen as the primary indicator of degraded aesthetics in the Bay of Quinte. In addition to impairing the visual appeal of the Bay, turbid water conditions may affect the use of the Bay for recreation. The MOE standard for minimum water clarity for swimming is 0.5 m (secchi depth); however, turbidity may significantly affect the use of a waterbody by many people before this minimum is reached.
Algal community structure (biomass and species composition) is directly related to two of the impaired uses listed in Table 5, namely:

- reduced quality of water used for drinking; and
- degraded aesthetics.

Water clarity and hence degraded aesthetics are directly influenced by algal density while both biomass and species composition potentially contribute to problems of taste and odour. Algae may also contribute to degraded aesthetics by causing scums on the water surface, boat hulls, and various physical features (e.g., shoreline, docks).

When attached to boat hulls, algae reduce their efficiency and lead to increased fuel and maintenance costs. Algal scums on commercial fishing nets may also reduce efficiency of some gear types, especially gill nets. These effects are related to the ninth impaired use in Table 5.

Finally, both water clarity, and algal biomass through its effect on clarity, may influence macrophyte development in the Bay. Thus these indicators are also related to the 5th, 6th and 7th impaired uses in Table 5.

Water clarity and excessive algae problems occur principally in the Upper Bay. Accordingly the discussion of remedial options which follows is directed towards this area.

4.1.2 Targets

Targets have already been proposed for algal densities for the Upper Bay (K. Nicholls, OMOE, personal communication). To achieve acceptable water quality with
respect to drinking water, algal densities at water treatment intakes should be on the order of 2000 to 3000 ASU/ml. Although related to density, odour is strongly influenced by the species composition of algae and an independent criterion of reaching threshold odour numbers less than 4 has also been recommended. For the Upper Bay as a whole, the proposed objective is to reduce algal biomass to a range of 4 - 5 mm³/L. It is expected that achieving this latter objective would also meet the criteria for drinking-water quality.

Targets for water clarity have not been previously defined. In general, the proposed targets should be consistent with those proposed for algal biomass, imply a significant improvement in the visual appeal of the Upper Bay, and allow for expansion of macrophytes where turbid waters are presently limiting this process. Nicholls and Hurley (1988) have analyzed data from the Bay of Quinte which suggest that a algal biomass of 4-5 mm³/L would lead to a light extinction parameter (Epar) of 1.23-1.30 m⁻¹. In the mid-1970s, light extinction coefficients in the Upper Bay averaged 1.88 m⁻¹, while in more recent years the average value has declined to 1.50 m⁻¹ (Michalski 1987). A further reduction to 1.25 m⁻¹ would imply a significant improvement in water clarity and a substantial increase in the area for potential macrophyte development (from approx. 30 km² in the mid-1970s to approx. 45 km²: calculations from Nicholls and Hurley 1988).

4.1.3 Remedial Actions

The conceptual model (Figure 4a) illustrates a complex pattern of ecological processes through which eight of the thirteen proposed remedial actions may affect algal
community structure and water clarity in the Bay of Quinte. These effects may occur through two major pathways:

- bottom-up regulation of nutrients within the Bay, in particular the concentrations of phosphorus and nitrogen; and/or

- top-down regulation of algal density, via grazing by zooplankton and benthos which in turn are affected by a web of biotic interactions, driven ultimately by piscivore predation and the structure and area of aquatic macrophytes.

These two pathways are not independent, but rather are inter-related through their common link with macrophyte development within the Bay. Disregarding secondary effects that may arise from this inter-connection, three of the proposed actions are primarily related to bottom-up regulation, namely:

- decreased loading of phosphorus;
- increased hydraulic flushing; and
- increased loading of nitrate-nitrogen.

The conceptual model suggests that the first two of these actions could lead to change in both algal density and species composition while the last would affect the species composition alone.

Another four actions relate primarily to top-down regulation through effects on the piscivore community or on aquatic macrophytes:

- decreased harvest of piscivores;
- increased stocking of piscivores;
- rehabilitation/creation of spawning habitat; and
- macrophyte enhancement.
An increase in the area and diversity of macrophytes is hypothesized to lead to increased habitat for piscivores and other components of the aquatic ecosystem. Finally, the ninth action, decreased sediment loadings to the Bay, could affect water clarity directly.

**Strategy for Assessment of Options**

Two lines of evidence will be used to assess these remedial actions. As described in Section 3.2.1, the eutrophication simulation model was constructed to assist in the analysis of various bottom-up remedial actions related to phosphorus control in the Bay. These actions include: 1) imposing stricter STP controls; 2) construction of storm sewer retention facilities; 3) reduction of industrial inputs; 4) implementation of conservation agricultural land use practices; 5) introduction of a flushing flow to the Upper Bay via the Murray Canal; and 6) treating the sludge from water treatment plants before returning it to the Bay. For these actions, simulation model output will be used as a primary means for analyzing the potential to achieve significant phosphorus reductions. The simulation model does not integrate any influences of top-down controls, however. Assessment of those actions intended to affect water clarity and algal community structure without manipulation of surface water phosphorus concentrations (e.g., piscivore harvest, planting macrophytes) will be based upon evidence discussed at the June workshop.

The primary output produced by the eutrophication simulation model is average summer surface water phosphorus concentration, particularly in the Upper Bay. Using relationships from Nicholls and Hurley (1988), we will convert predicted phosphorus levels to three other indicators relevant to the targets discussed above: algal
biomass (mm$^3$/L), light extinction (m$^{-1}$), and the maximum area for potential macrophyte development. It must be emphasized, however, that these calculations are all based on a phosphorus-algal biomass relationship that ignores the influence of other (i.e., top-down) controls on algae. As Nicholls and Hurley point out, these other controls appear to have has an important influence in some years in the past.

**Bottom-Up Controls**

**Controls on Upper Bay Phosphorus Concentrations**

**Simulating the Past**

As discussed in Section 3.2.1 verification of the model can be achieved, to a certain extent, by examining the model's ability to simulate the past. If the model can accurately simulate historical patterns using the same techniques that it uses to predict the future, confidence in the model's forecast is greatly increased.

Initial attempts to simulate historical surface water phosphorus concentrations were unsuccessful. When the two-box model of sediment P-dynamics (Minns 1986b) was used, simulation results accurately reflected pre-1975 conditions, but departed considerably from observation in the post-1975 period. Use of the three-box model described earlier resulted in a much better fit to the entire historical period (Figure 8). Accordingly, the scenario results presented below were obtained using the three-box model. Interpretation of the results, however, should allow for the fact that there remains considerable uncertainty regarding the nature of sediment P-dynamics, and that the model's predictions are quite sensitive to changing assumptions about this process.
Figure 8. Comparison of observed and simulated summer phosphorus concentrations in the Upper Bay. Period of comparison encompasses those years for which integrated measures were taken from the Bay.
Model Scenarios

Twelve scenarios are used to simulate the six remedial options discussed above (Table 9). Each scenario consists of a series of three model runs, with the appropriate model variables modified to simulate the implementation of the remedial action. Phosphorus concentrations within the Bay are a function not only of internal and external loadings, but also of the Bay's hydrologic regime. The effect of a remedial action may vary considerably, depending on the hydrological conditions subsequent to its implementation. The Bay's hydrology is influenced primarily by tributary inflow, Lake Ontario levels, and backflow from Lake Ontario. The Bay experiences considerable variation in its hydrologic regime from one year to the next. For this reason, each scenario is repeated using three contrasting sets of hydrologic conditions, selected from historical data for dry (1977), average (1973), and wet (1981) years. Each year's tributary flow data was coupled with appropriate lake level and backflow data to simulate as natural conditions as possible. The purpose of using non-varying sets of data to simulate future conditions is to eliminate "noise" caused by hydrologic conditions in the simulated response to remedial actions.

All scenarios were implemented assuming an annual population growth rate of 0.06% using 1981 census data as a base. The same growth rate was used to simulate increases in STP inputs, unless specific remedial actions were simulated.

Model Results

In the first scenario, no controls are implemented. Therefore, any future declines in Upper Bay phosphorus concentrations in this scenario are the result of a delayed response to past changes in P-loadings to the Bay. Such a
Table 9: Eutrophication model scenarios.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description of Phosphorus Control Measures*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No remedial actions</td>
</tr>
<tr>
<td>2</td>
<td>STP effluent controls implemented; summer effluent concentration set at 0.3 mg/L, other times of year effluent concentration set at 0.7 mg/L.</td>
</tr>
<tr>
<td>3</td>
<td>STP effluent controls implemented; summer effluent concentration set at 0.1 mg/L, other times of year effluent concentration set at 0.5 mg/L.</td>
</tr>
<tr>
<td>4</td>
<td>Industrial loads set at 70% of 1988 levels.</td>
</tr>
<tr>
<td>5</td>
<td>Industrial loads set at 40% of 1988 levels.</td>
</tr>
<tr>
<td>6</td>
<td>Elimination of discharge of stormwater loads directly into the Bay.</td>
</tr>
<tr>
<td>7</td>
<td>Tributary loads reduced by 10%.</td>
</tr>
<tr>
<td>8</td>
<td>Tributary loads reduced by 16%.</td>
</tr>
<tr>
<td>9</td>
<td>Flushing flow of 20 m$^3$/sec introduced to the upper Bay during the summer.</td>
</tr>
<tr>
<td>10</td>
<td>Flushing flow of 35 m$^3$/sec introduced to the upper Bay during the summer.</td>
</tr>
<tr>
<td>11</td>
<td>Elimination of discharge of water treatment plant sludge directly into the Bay.</td>
</tr>
<tr>
<td>12</td>
<td>Combination of Scenarios 2, 4, 6, 7, 10, 11.</td>
</tr>
</tbody>
</table>

* All remedial actions are simulated beginning in 1990
delayed response will occur as the sediment phosphorus pool changes in response to decreased inputs from sedimentation.

The "no action" scenario results in summer phosphorus concentrations in the Upper Bay in 1995 of from 31.71 to 42.68 ug/L (Table 10a), depending on the hydrologic regime simulated (lowest concentrations are achieved when "high flow" conditions are used). Using the empirical regressions of Nicholls and Hurley (1988) these phosphorus concentrations suggest algal biomass levels of 5.89 to 7.96 mm³/L, and light extinction values of 1.35 to 1.49 m⁻¹. In the early 1980s, when the last whole Upper Bay integrated phosphorus measurements were made, concentrations were in the 45-55 ug/L range. Thus, without taking any further action, phosphorus levels in the Bay are predicted to decline to levels that approach, but do not achieve the targets proposed above. These changes are the result of internal phosphorus loadings (from sediments) declining over time in importance as a source of phosphorus to the Bay (Figure 9).

As expected, the various control options simulated by scenarios 2-12 all bring about declines in summer phosphorus levels relative to the "no action" scenario (Table 10a, Figure 10). By the year 2005, a further decline in phosphorus concentrations of approximately 2.5 ug/L is predicted, for all scenarios (Table 10b). Overall, however, declines which result from each of the control options (and even for the multiple control option - Scenario 12) are small relative to the effects due to declines in sediment phosphorus reflux.

The relative effects of controls on the various sources of phosphorus loads to the Bay (Scenarios 2-8,11) generally reflect the relative magnitude of loadings from these sources (Table 11). River inputs are by far the largest
Figure 9. Relative contribution of different sources of phosphorus to the summer (May - Oct.) P-load in the Upper Bay. "Other" sources include storm sewers, industrial effluent, and treated sludge from water treatment plants. Results are for Scenario 1.
Figure 10. Results of the twelve control option scenarios. Shown are the ranges of phosphorus concentrations in the Upper Bay under high and low flow regimes for the years 1995 and 2005. Cross-hatching shows area of overlap.
Table 10: Results of the twelve model scenarios for the years a) 1995 and b) 2005. Range of results reflect the three alternative hydrological conditions simulated.

a) 1995:

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Phosphorous Conc. (ug/L)</th>
<th>Algal Biomass (mm3/L)</th>
<th>Light Extinc. (m-1)</th>
<th>Potential Macro. Area (km2)</th>
<th>Net Sed. P Reflux (kg/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>31.71-42.68</td>
<td>5.89-7.96</td>
<td>1.35-1.49</td>
<td>39.56-36.97</td>
<td>118.52-78.87</td>
</tr>
<tr>
<td>2</td>
<td>30.73-41.16</td>
<td>5.71-7.67</td>
<td>1.34-1.47</td>
<td>39.81-37.31</td>
<td>117.02-78.87</td>
</tr>
<tr>
<td>3</td>
<td>29.76-39.52</td>
<td>5.53-7.36</td>
<td>1.33-1.45</td>
<td>40.05-37.69</td>
<td>116.25-80.97</td>
</tr>
<tr>
<td>4</td>
<td>31.10-41.50</td>
<td>5.78-7.73</td>
<td>1.34-1.47</td>
<td>39.72-37.24</td>
<td>118.36-77.97</td>
</tr>
<tr>
<td>5</td>
<td>30.79-41.12</td>
<td>5.72-7.66</td>
<td>1.34-1.47</td>
<td>39.79-37.32</td>
<td>118.20-78.54</td>
</tr>
<tr>
<td>6</td>
<td>30.38-40.71</td>
<td>5.64-7.59</td>
<td>1.34-1.46</td>
<td>39.90-37.42</td>
<td>118.01-78.54</td>
</tr>
<tr>
<td>7</td>
<td>29.73-40.71</td>
<td>5.52-7.59</td>
<td>1.33-1.46</td>
<td>40.06-37.42</td>
<td>115.47-75.72</td>
</tr>
<tr>
<td>8</td>
<td>28.54-39.44</td>
<td>5.30-7.35</td>
<td>1.32-1.45</td>
<td>40.26-37.71</td>
<td>113.64-74.70</td>
</tr>
<tr>
<td>9</td>
<td>29.39-37.64</td>
<td>5.46-7.01</td>
<td>1.33-1.43</td>
<td>40.15-38.13</td>
<td>120.03-89.97</td>
</tr>
<tr>
<td>10</td>
<td>27.96-34.66</td>
<td>5.19-6.45</td>
<td>1.31-1.39</td>
<td>40.51-38.84</td>
<td>121.01-96.75</td>
</tr>
<tr>
<td>11</td>
<td>31.25-42.10</td>
<td>5.81-7.85</td>
<td>1.35-1.48</td>
<td>39.68-37.10</td>
<td>118.45-78.61</td>
</tr>
<tr>
<td>12</td>
<td>23.86-29.26</td>
<td>4.42-5.43</td>
<td>1.26-1.32</td>
<td>41.58-40.18</td>
<td>114.47-96.12</td>
</tr>
</tbody>
</table>

b) 2005:

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Phosphorous Conc. (ug/L)</th>
<th>Algal Biomass (mm3/L)</th>
<th>Light Extinc. (m-1)</th>
<th>Potential Macro. Area (km2)</th>
<th>Net Sed. P Reflux (kg/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>29.37-38.90</td>
<td>5.45-7.25</td>
<td>1.33-1.44</td>
<td>40.15-37.84</td>
<td>89.16-54.60</td>
</tr>
<tr>
<td>2</td>
<td>28.31-37.14</td>
<td>5.25-6.91</td>
<td>1.31-1.42</td>
<td>40.42-38.25</td>
<td>87.15-55.47</td>
</tr>
<tr>
<td>3</td>
<td>27.24-35.27</td>
<td>5.05-6.56</td>
<td>1.30-1.40</td>
<td>40.70-38.69</td>
<td>85.93-57.05</td>
</tr>
<tr>
<td>4</td>
<td>28.64-37.52</td>
<td>5.32-6.99</td>
<td>1.32-1.43</td>
<td>40.34-38.16</td>
<td>88.89-55.00</td>
</tr>
<tr>
<td>5</td>
<td>28.29-37.12</td>
<td>5.25-6.91</td>
<td>1.31-1.42</td>
<td>40.43-38.25</td>
<td>88.63-55.40</td>
</tr>
<tr>
<td>6</td>
<td>27.97-36.66</td>
<td>5.19-6.82</td>
<td>1.31-1.41</td>
<td>40.51-38.36</td>
<td>87.72-55.40</td>
</tr>
<tr>
<td>7</td>
<td>27.33-36.75</td>
<td>5.07-6.84</td>
<td>1.30-1.42</td>
<td>40.67-38.34</td>
<td>85.37-51.99</td>
</tr>
<tr>
<td>8</td>
<td>26.10-35.36</td>
<td>4.84-6.58</td>
<td>1.29-1.40</td>
<td>40.99-38.67</td>
<td>83.10-50.53</td>
</tr>
<tr>
<td>9</td>
<td>27.29-34.24</td>
<td>5.06-6.37</td>
<td>1.30-1.38</td>
<td>40.68-38.94</td>
<td>90.09-64.21</td>
</tr>
<tr>
<td>10</td>
<td>26.02-31.58</td>
<td>4.82-5.87</td>
<td>1.28-1.35</td>
<td>41.01-39.60</td>
<td>90.85-69.61</td>
</tr>
<tr>
<td>11</td>
<td>28.89-38.26</td>
<td>5.36-7.12</td>
<td>1.32-1.43</td>
<td>40.27-37.98</td>
<td>88.91-55.52</td>
</tr>
<tr>
<td>12</td>
<td>24.77-29.81</td>
<td>4.02-4.78</td>
<td>1.23-1.28</td>
<td>42.18-41.07</td>
<td>82.69-66.82</td>
</tr>
</tbody>
</table>
Table 11: Summer phosphorus loadings (kg/day) for each source before and after controls implemented according to the scenarios listed in Table 9.

<table>
<thead>
<tr>
<th>Source Scenario</th>
<th>Phosphorus loading (kg/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1989</td>
</tr>
<tr>
<td>STP1</td>
<td>2</td>
</tr>
<tr>
<td>STP1</td>
<td>3</td>
</tr>
<tr>
<td>Industry</td>
<td>4</td>
</tr>
<tr>
<td>Industry</td>
<td>5</td>
</tr>
<tr>
<td>Storm Sewers</td>
<td>6</td>
</tr>
<tr>
<td>Tributaries2</td>
<td>7</td>
</tr>
<tr>
<td>Tributaries2</td>
<td>8</td>
</tr>
<tr>
<td>WTP Sludge2</td>
<td>11</td>
</tr>
</tbody>
</table>

1. STP loadings increase with increasing population, all other sources are unaffected.

2. Figures are derived assuming "normal" hydrologic conditions.

3. Figures are derived assuming summer STP effluent concentrations of 0.5 mg/L.
source of phosphorus to the Bay, especially since the decline in inputs from both STPs and sediments that has occurred during the 1970s and 80s (Figure 9). Based on a comparison of changes in total loadings alone, one might expect a greater impact than is predicted of conservation land use practices. The absence of a greater impact is due to the fact that river inputs of phosphorus are correlated to river flows, which in turn affect flushing. Thus when high flow conditions occur, increases in phosphorus loadings to the Bay are offset partially by increased hydraulic flushing. Furthermore, Scenario 8 (16% reduction in tributary P-loads) may not be realistic, given that it implies a 40% reduction in agricultural phosphorus inputs.

Controls on the other sources are less effective, although the reduction of summer STP effluent concentrations to 0.1 mg/L (Scenario 3) approaches the less extreme tributary control scenario (#7). Elimination of stormwater inputs has an effect comparable to STP controls, while reductions in industrial inputs have even less impact. Finally, the treatment of water treatment plant sludge prior to its return to the Bay has only a minor effect. While the phosphorus concentrations are very high in this sludge prior to treatment, the total mass of phosphorus is small relative to other sources (Table 11).

The pumping of Lake Ontario water into the Upper Bay has an effect comparable to or greater than that due to reductions in tributary loadings (Scenarios 9,10). In addition, this option yields less variability than the others due to hydrological effects, since it is in itself an hydrologic perturbation (Figure 10). In the limit, this option has the potential to reduce Upper Bay phosphorus levels to levels approaching those found in Lake Ontario, without requiring any further controls on sources within the
Bay's catchment. It is rather difficult to rationalize such a solution in an "ecosystem approach" context, however.

Finally, Scenario 12 combines several of the options into a single remedial strategy which includes controls on all the sources discussed and a flushing flow of 35 m$^3$/sec. Under this scenario, the targets for algal density and water clarity are easily reached by 2005 for high flow conditions, and are nearly reached even under low flows (Table 10b).

These model results suggest two things. First, even in the absence of further controls, it would appear that significant improvements in the water quality of the Upper Bay can be expected. Second, while few of the control options, if used alone, will produce substantially greater benefits than the "do nothing more" option, the cumulative effect of their implementation may be more significant. The choice of the best controls to implement will of course depend on other factors (e.g., costs, technical feasibility, etc.), but the model results presented here suggest that positive benefits are achievable.

There are at least two reasons, however, why these results should be viewed with caution. First, the future predictions depend a great deal on our assumptions regarding the processes governing sediment phosphorus dynamics. It would seem wise to consider the reduction of uncertainty about these processes as an important part of any recommended remedial strategy. Second, the variability in model predictions introduced by year to year differences in the hydrology of the Bay is large relative to the predicted changes due to controls. This is most evident from Figure 10, where it can be seen that the ranges in predicted phosphorus concentrations overlap for all scenarios. Thus in a wet year predicted phosphorus concentrations are lower for
the no action scenario than the values predicted for a dry year for Scenario 12 (multiple controls).

Increase Nitrogen Inputs

In oligotrophic and mesotrophic systems phosphorus is typically the first limiting nutrient. When lakes are loaded with phosphorus and artificially eutrophied, as the Bay of Quinte was, the phosphorus limitation may be overcome and primary production can continue until the next least abundant major nutrient, typically nitrogen, becomes limiting. Nicholls and Carney (1986) demonstrated that nitrogen was limiting during August 1975 in the upper Bay. In these conditions algae unable to fix nitrogen from the atmospheric pool are excluded; the blue-green algae with nitrogen-fixing capabilities can outcompete those without this ability (Wetzel 1975). Blue-green algae (primarily Aphanizomenon and Anabaena species) have dominated the phytoplankton community of the Bay in late summer, presumably because nitrogen has, at times, been limiting.

The historical problems that communities on the Bay of Quinte have had with the taste and odour of their drinking water are well known. The problem has traditionally been linked to the presence of blue-green algae. The nitrogen:phosphorus ratio of the Upper Bay is typically on the order of 15-20:1, a ratio of about 30:1 may be required before green algae gain much competitive advantage. Artificial addition of nitrate-nitrogen to the bay has been suggested as a method of increasing the N:P ratio and thereby shifting species composition of algae away from blue-greens.

---

1. Due to the large uncertainties associated with the dynamics of nitrogen in the Bay, no model results have been presented in this section.
A reduction in blue-green and total algal biomass precipitated by reduced phosphorus concentrations in surface waters is anticipated to ameliorate, at least to some extent, the taste and odour problems. The P-control scenarios discussed above may therefore be sufficient to eliminate or at least greatly reduce this historical problem. An increase in the N:P ratio brought about by artificial addition of nitrate-nitrogen is also expected to bring about shifts in algal species composition away from blue-greens. Total algal biomass may not decrease, however.

Algae other than blue-greens may play a role in affecting water taste and odour, although the relationships, if any, are poorly defined. Addition of nitrate-nitrogen may not, therefore, result in significant benefits to water taste and odour. A better understanding is needed of the relative contribution of other algae to water taste and odour problems.

**Reduced Sediment Loadings**

The role of suspended sediments in affecting water clarity should be divided into effects from river sediment loads and resuspension of in place sediments. The effect of river loads is likely restricted in area compared to sediment resuspension. However, the Trent river probably imports a lot of dissolved organic matter that contributes to high background light extinction in the Upper Bay.

Millard (1986) has calculated that most of the variation in light extinction in the Bay is explained by phytoplankton. Adding ash concentration to regressions between light extinction and chlorophyll-a did little to help explain variance in light extinction ($r^2$ increased from 75.2% to 79.9% using Upper Bay data 1977-78). Light extinction was correlated with ash, ($r^2 = 31.5$%) suggesting
that ash was related to algal biomass and was not solely an index of mineral content in the water column from suspended sediments. The slope of the light extinction vs ash relationship was 250 times smaller than for light extinction vs chlorophyll-a, suggesting that, compared to chlorophyll, ash was much less effective in light extinction.

**Top-Down Controls**

Before discussing the four remedial actions related to top-down control of algal biomass and water clarity, it is worth briefly summarizing the conceptual basis for considering these controls. Essentially, the top-down controls are hypothesized to regulate algal biomass, and therefore water clarity, by stimulating increased grazing pressures on phytoplankton. Three of the actions are intended to directly influence piscivore abundance, while the fourth concerns increasing the area and structural diversity of macrophytes. Ultimately, these changes (in piscivores and macrophytes) are linked to increases in grazing pressures, via a number of pathways as summarized in Figure 4a.

To assess the potential for these actions to influence algal community structure and water clarity, we must therefore consider not only the likelihood of the action having the expected proximate effect (on piscivores or macrophytes), but also the likelihood that the linkages between changes in piscivores or macrophytes and algal density are also valid. In the text to follow, we first address the likely proximate effect of the four remedial actions. Then we consider the evidence for the other linkages in Figure 4a that relate to these actions. Finally, we briefly summarize an overall conclusion for top-down controls on algal community structure and water clarity.
Decreased Harvest of Piscivores

Decreasing the harvest of piscivores in the Bay of Quinte is unlikely to have a significant effect on piscivore abundance in the Bay. The only piscivore in the Bay that is presently subject to intense exploitation is the walleye: current harvests approximate 100,000 kg annually, or 15-20% of the eastern Lake Ontario walleye population (Bowlby et al. 1988). Abundance of walleye in the Bay appears to be largely related to year-class phenomena, however; a strong spawner recruit relationship does not exist. It is not well understood what controls the walleye population size but the density of the white perch population, weather patterns and water temperature near the time of hatch all probably have a strong influence (Bowlby et al. 1988).

In addition, movements of walleye between the Bay of Quinte and the eastern basin of Lake Ontario are extensive (Bowlby et al. 1988). Thus even if attempts to increase the numbers of walleye recruiting in the Bay are successful, changes in abundance may be limited by emigration. Overall, it is unlikely that harvest controls will have a dramatic effect on walleye abundance, unless exploitation rates are extremely high.

Other piscivore species within the Bay (e.g., northern pike, smallmouth bass, largemouth bass, longnose gar, muskellunge, and bowfin) do not undergo extensive movements between the Bay and Lake Ontario (J. Christie, OMNR, pers. comm.). However, the current harvests of these species are low (A. Mathers, OMNR, pers. comm.). Further, it is generally held that these species are being controlled at relatively low abundance levels by habitat conditions such as water levels and/or macrophyte absence. Overall, therefore, harvest controls are unlikely to lead to increases in the abundance of these species, at least in the
absence of other environmental changes. On the other hand, harvest controls may be necessary to maintain high relative abundances once rehabilitation of these populations has occurred.

**Increased Stocking of Piscivores**

Stocking of piscivorous fish was also concluded to be unlikely to produce significant increases in piscivore abundance, for the following reasons:

1. The current status of culturing of walleye, smallmouth bass, and northern pike would not allow for extensive stocking of young fish (J. Christie, OMNR, pers. comm.);

2. As stated above, habitat conditions, not harvest levels are believed to be limiting the populations of species other than walleye; and

3. The current stocks of these species are already large enough to allow population expansion if the environmental conditions changed.

**Rehabilitation/Creation of Spawning Habitat**

There is no evidence that spawning habitat (except macrophytes) is currently limiting the production of piscivores within the Bay of Quinte. As mentioned above, walleye recruitment appears to be related to environmental factors other than physical habitat. Successful spawning of other piscivores, such as pike, may depend on macrophytes; however; the possibility of creating additional macrophyte habitat is discussed below. Other than macrophytes, it is felt that creation of spawning habitat would not have a significant effect on the abundance of any of the piscivores listed above.
Macrophyte Enhancement

The final top-down action concerns the planting of macrophytes. From the conceptual model (Figure 4a) it can be seen that not only planting of macrophytes but also changes in sediment phosphorus concentrations and in water clarity can influence macrophyte area and structural diversity. Here, we consider the potential for enhancement of macrophytes in the Bay, due to any of these causes.

Planting Macrophytes

Macrophyte planting has been successfully employed as a wetland rehabilitation measure at other sites. For example, in an experimental study, milfoil was successfully replaced by Potamogeton amplifolius in Chataqua Lake (Storch et al.). Clipping experiments have also released desirable species from competition (Agami and Waisel 1986).

The success of plantings appears to be dependent on protection of the site from intense wave action. At Loch Leven in Scotland 80% of macrophyte loss was from waves, 20% from herbivory (Jupp and Spence 1977). Successful plantings at Rondeau Provincial Park (Hanna 1986) also appear related to the presence of protection from waves.

Macrophyte distribution throughout the Bay was studied at 41 sites in 1987 (B. Dushenko, Queen’s University, unpubl. data). Sites were classified by plant cover, and the classes were correlated with chemical and physical parameters. Dense vegetation grew on sediments with elevated nutrient concentrations (P, Mg) with high value of organic C, silt and metals (except Cu), and with low pH. The sites with dense vegetation also had low shore slopes and low exposure (measured as fetch).
In the United States, a predictive index for the success of planting marine marshes has been derived from data from a large number of salt marshes, which have generally been planted with *Spartina* and sea grasses (Knursen et al. 1981). Exposure (fetch), shore slope, the indentation or straightness of the shore and the particle sizes of sediment make up most of the points of the index. From Dushenko's work it is apparent that sites in the Bay of Quinte could similarly be evaluated for their capacity for revegetation.

The importance of fetch was shown experimentally by Bristow et al. (1977) when flue tiles containing four species planted in sediment were placed in sites exposed to the southwest at three sites in the Bay. No plants survived, and the 15-lb containers were overturned in several places. In 1987-88 containers with sediment and plants were placed in areas of the Bay rated exposed to sheltered. At the most exposed site the containers moved during the winter; the others remained in place.

Wind and wave action are augmented by ice movement, which may be important in areas sheltered from fetch. In Hay Bay, pressure ridges associated with upturned small floes scraping along the shore were observed in 1987-88. Geis (1985) described the erosive effects of grounded ice as extending up to 50 m offshore in some parts of the upper St. Lawrence River.

Organic contaminants in sediments can be destructive to macrophytes; no results are yet available on sediments for the Bay of Quinte, but should be by 1989. Of the inorganic contaminants, Cu apparently limits macrophyte growth (B. Dushenko, Queen's University, unpubl. data).
These studies would suggest that planting is in fact a practical means of increasing macrophyte area and altering species composition, provided the appropriate physical conditions are maintained. In particular, the sites for planting must be protected from long fetches and potential winter ice scouring. The use of artificial barriers may be required to accomplish this; in general it is thought that once the plants are well established, the need for such protection becomes much reduced.

Changes to Sediment Phosphorus Levels

One mechanism by which reductions in surface water phosphorus concentrations are hypothesized to effect the area and structure of aquatic macrophytes is through reductions in sediment phosphorus content. The reductions in Upper Bay phosphorus concentrations predicted by the eutrophication model will be associated with reduced phosphorus in sediments as well. Are such changes likely to lead to a significant impact on the Bay’s macrophyte community?

Carignan and Kalff (1980) showed that sediment was the primary source of phosphorus for growth in 9 common species of freshwater macrophytes with 3-10 percent coming from water. Because macrophytes can grow in sediments with a wide range of phosphorus contents (Carignan and Kalff 1980, Spence 1982), however, it is unlikely that reductions in sediment P will inhibit their recovery in the Bay. The surface sediment phosphorus concentration in the Bay of Quinte is presently 1.5-2.5 mg/g with a sub-surface background of 0.8-1.1 mg/g (Warwick 1980). These values span the range examined by Carignan and Kalff (1980) and expected as a result of phosphorus load reductions (Minns 1986b). A. Crowder (Queen’s University, pers. comm.) suggested that sediment phosphorus concentration could be limiting in the
extreme, but not in Quinte sediments. While a sediment phosphorus-macrophyte growth connection exists, the range of sediment phosphorus values anticipated for the Bay will not cause limitations.

Cattails (*Typha latifolia*) dominate areas of emergent macrophytes in the Bay (Crowder and Bristow 1986). The eutrophic nutrient status of the Upper Bay presumably led to the cattail domination. A decrease in sediment phosphorus may lead to increased diversity of the macrophyte community and increased areas of edge or transition in areas of emergent macrophytes. Such a favourable response has not been noted, however, by Crowder and Bristow (1986) in macrophyte surveys in 1979 and 1982. Presently it is thought that changing water levels will have the greatest effect on cattail dominance.

Water Clarity

Eutrophication model predictions for the Upper Bay suggest significant increases in the average light extinction coefficient relative to the 1970s and early 1980s. According to data presented by Nicholls and Hurley (1988), such increases in water clarity can be converted to increases in the area of the Bay in which light conditions are suitable for macrophyte development (Figure 11).

Forest et al. (1987) were able to stimulate a local recovery of macrophytes in Irondequoit Bay on the south shore of Lake Ontario, when the turbidity was lowered by alum treatments. Propagules apparently were derived from marshes running into the Bay. In Chesapeake Bay, in a tidal area of the Potomac River where there had been no growth of plants for 40 years, Carter and Rybicki (1986) described a recovery, which they attributed to a combination of water clarity and low predation. When the vegetation was re-
Figure 11. Results of the control option scenarios. Shown is the range of potential areas for macrophyte development in the Upper Bay under high and low flow regimes for the years 1995 and 2005. Cross-hatching shows areas of overlap.
established in Irondequoit the number of species increased from four to eleven and secchi disc measurements deepened to 2.1 m. In Chesapeake Bay the secchi disc measurement improved from 51.8 to 85.5 cm.

While recent declines in phosphorus loadings to the Bay have been observed, evidence for increased macrophyte development is limited. A long-time resident on the Bay has suggested that some expansion of macrophytes has occurred in recent years (G. Hammett, pers. comm.). Results of successive sampling between 1972 and 1982 along five transects in the Bay were published in 1986 (Crowder and Bristow 1986). When these lines were sampled again in 1985, little difference was found except a gradual increase in cover at Hay Bay north. Biomass in 1985 was lower than in 1972-82 showing no recovery after phosphorus reduction. The areas of submerged and floating-leaved macrophytes were estimated as 627 ha and of cattail marshes as 2824 ha using aerial photographs taken in 1979. In 1988, transects will be re-surveyed and a habitat survey should yield more information.

Finally, even though increases in water clarity will almost certainly lead to increases in the area of potential macrophyte development, the actual extent of recolonization will, as noted earlier, depend on other key physical factors such as fetch. Therefore, while planting of macrophytes and increases in water clarity seem to offer significant potential for the enhancement of macrophytes, the success of these measures will depend on the location, and/or on additional protective measures.
Effects of Changes in Macrophytes

Macrophytes --> Fish, Waterfowl, and Invertebrates

Macrophytes are known to provide food for some species of fish and waterfowl. Bluegills, for example, are listed by Engel (1987) as herbivores of submerged macrophytes in Wisconsin. Scaup and other bay ducks may consume submerged macrophytes such as pondweeds and muskgrass (Bellrose 1976). When experiments in replanting macrophytes were conducted in Chesapeake Bay it was necessary to protect the plants from fish, turtles, and ducks with wire cages, in order to get successful regeneration (Carter and Pybiki 1985).

In addition to food, macrophyte beds provide important spawning and nursery habitat for numerous fish species including piscivores, planktivores, and benthi coyres. Juvenile fish can use weed beds to escape predation and as food gathering sites. Piscivores such as pike use the structural features of macrophytes to provide ambush sites. For some species, the presence of discontinuous patches of vegetation (edge) provide important habitat features for feeding and cover. Species which utilize macrophytes for spawning include: largemouth bass, longnose gar, bowfin, muskellunge, and northern pike. Proliferation of these species has been observed as the result of increases in emergent macrophytes and high water levels.

In general, then, one would expect increases in macrophyte area and structural diversity to result in increased fish abundance, especially of warm water piscivore species. Also, increases in macrophyte area and associated invertebrate fauna should promote increased waterfowl use of these areas for staging. Staging scaup and canvasback are frequently observed feeding in association with macrophyte
beds, often offshore from wetlands (R.K. Ross, Canadian Wildlife Service, pers. comm.).

Macrophytes are also known to provide important habitat for invertebrates, particularly large zooplankton and a variety of benthic species. One of the primary reasons why increased wetland area is associated with increases in fish biomass and waterfowl use is probably related to the role of the former as a source of food.

Piscivores --> Planktivores and Benthivores

The influence of piscivores on the populations of their prey has been extensively investigated (e.g., Forney 1977); as a result of this work the following generalizations can be stated about fish feeding:

- piscivores are opportunists
- they select fish which are easiest to catch (i.e., they conserve energy by selecting the nearest target)
- they also conserve energy by selecting the largest targets they can overcome, overtake, and swallow

These considerations, together with the considerable potential for fish to vary their growth rates dramatically in response to changes in prey availability, are responsible for piscivores being able to regulate the abundance of their prey without eliminating them. Diet plasticity implies that as a certain prey organism becomes rare, it is replaced by other, more abundant species in the predator's diet. Growth variations may well provide most of the feedback in the piscivore prey linkages, however. When the piscivores are sparse relative to the prey density, their growth increases. At very low densities of piscivores, prey become very
abundant and stunted as a result of scarcity of their benthic or planktonic prey. The evidence suggests that the small prey size doesn’t slow piscivore growth because it is compensated by the reduced energy costs of obtaining prey. When prey become sparse, however, piscivore growth slows down. These feedback mechanisms prevent predator and prey from escaping each other’s control.

Planktivores --> Zooplankton

Since the now classic work of Brooks and Dodson (1965), numerous authors have provided evidence of the strong influence of size-selective planktivory on zooplankton community structure (c.f. Zaret 1980, Kerfoot and Sih 1987). It can be safely concluded that the presence of abundant planktivores will severely limit the production of large zooplankton, although other factors such as competition may also influence zooplankton size distributions (e.g., Hall et al. 1976). Since planktivorous fish including juveniles are visual predators, the size/visibility of prey is of prime importance. Therefore large and pigmented prey are more vulnerable.

Benthivores --> Benthos

The most important benthivore in the Upper Bay has been white perch and the most important food of this species is chironomids (Hurley 1986). In the recent past, the population of white perch declined dramatically from a peak in 1975 to a low in 1978 from which the adult population never recovered fully (Minns and Hurley 1986, Hurley unpublished data). Unfortunately, only six years of chironomid biomass data (not including either 1975 or 1978) are available for comparison with the white perch data and no significant correlations between chironomid biomass and white perch biomass are apparent.
In the Lower Bay, the amphipod *Pontoporeia hoyi*, which was the most important food item for white perch, recovered after the collapse of the white perch (Johnson and McNeil 1986). In other systems where chironomids are the major food for fish, changes in fish feeding pressure are known to control chironomid production (Pechlaner and Zaderer 1985). Nicholls and Hurley (1988) have hypothesized that benthic feeding white perch indirectly control the size of the *Melosira* population in the Upper Bay through their influence on the chironomid community.

Zooplankton and Benthos --> Algal Biomass

Many zooplankton feed by filtering planktonic algae and other food particles from the water. Food intake increases exponentially with body size, so that large plankters (1.5-3 mm) such as *Daphnia pulex*, *D. longispina*, and *D. pulicaria* are able to filter up to 15 mL/individual/day and consume about 200% of their body weight per day of planktonic algae (Hutchinson 1967). The nutritive value of algae depends on size and form (i.e., ease of ingestion) and biochemical structure (i.e., presence or absence of thick cellulose walls or tests). Small centric diatoms and flagellates are more favourable food items for large *Daphnia* than filamentous diatoms such as *Melosira* (Infante and Litt 1985). Not only are filamentous blue-green algae also less desirable food items (Lampert 1981), but when concentrations are high, these algae can lead to reduced egg production in *Daphnia* (Vaga et al. 1985). High density of the filamentous blue-green *Oscillatoria agardhii* in Lake Washington apparently impeded recolonization of the lake by *Daphnia* (after reduced predation pressure from *Neomysis*) because immature *Daphnia pulicaria* became entangled in *Oscillatoria* filaments and the stresses associated with the required increased clearing rates led to increased mortality (Hartmann 1984).
When the algal food sources of adequate nutritional value and ideal size for ingestion are available in lakes, zooplankton grazing can dramatically influence phytoplankton biomass. Increases in *Daphnia* populations have been associated with significant declines in phytoplankton biomass in both small and very large lakes (Edmondson 1988, Shapiro and Wright 1984, Bergquist and Carpenter 1986, Kitchell and Carpenter 1988, see also review by Northcote 1988). In some cases benefits resulting from *Daphnia* population expansions and associated improvements in lake water clarity have even exceeded those improvements resulting from major sewage diversion and sewage phosphorus removal programs (Edmondson and Litt 1982, Scavia and Fahnentstiel 1987).

In the Bay of Quinte, large bodied *Daphnia* are a minor component of the overall zooplankton biomass (Cooley et al. 1986). If *Daphnia* become more abundant, it is likely that further utilization of the "food-chain functional" algal groups (Nicholls et al. 1986) would result. In the absence of or with declining fish predation pressure, it is expected that some increase in *Daphnia* populations would result in lower densities of *Melosira* and blue-green algae as small elements of these algal groups (auxospore germination products, short filaments, hormogonia) would be utilizable. However, because *Melosira*, *Aphanizomenon*, and *Anabaena* spp comprise the bulk of the summer phytoplankton biomass, net changes in the total planktonic algal biomass may be very small despite much greater utilization of the less well represented, but more food-chain functional cryptomonads, chrysomonads, and coccoid chlorophytes (Nicholls and Hurley 1988).

Evidence for similar control of algal abundance by benthic invertebrates is scarce and may be restricted to
shallow water environments where opportunities for interaction of benthic and "planktonic" communities are created by successive sedimentation and resuspension events. Nicholls and Hurley (1988) have hypothesized that benthic feeding white perch are a major indirect influence on phytoplankton in the Upper Bay. It is believed that grazing of *Melosira* by *Chironomus* (which Johannsson and Beaver (1983) showed was significant) during quiescent periods of algal sedimentation results in a significantly smaller "inoculum" for subsequent planktonic growth during turbulent resuspension events in the Upper Bay. White perch biomass was a highly significant factor in the relationship between phytoplankton biomass and several variables including other fish species, water temperature, nutrient loading (or concentration), and hydrological flushing (Nicholls and Hurley 1988). Changes in chironomid density (as influenced by benthivore abundance) might therefore be expected to influence the phytoplankton of the Upper Bay while *Melosira* remains the most important component of the summer flora.

**Top-down controls: summary**

From the preceding discussion it is clear that there is evidence to support many of the linkages shown in the conceptual model (Figure 4a). At the same time however the complexity of biotic interactions is such that it is not possible at the present time to describe in detail the pattern of changes to fish stocks or macrophytes that is needed to encourage rehabilitation of the system. Similarly it is not possible to predict in detail the precise sequence of change in response to remedial actions. Nevertheless, at an overall level there is substantial evidence that top-down mechanisms can be significant in determining the structure and function of aquatic systems.
Northcote (1988) provides an extensive review of the evidence for the significance of top-down effects. The complexity of the mechanisms at work is evidenced by the differences in the nature and magnitude of effects reported in different studies. In addition to the grazing hypothesis upon which the model (Figure 4a) and the workshop discussions focused, Northcote offers evidence in support of an alternative hypothesis, that fish affect algae and water clarity by increasing the rate of nutrient cycling rather than by reduced zooplankton grazing. He concludes that in view of the complexity of interactions,

"...it may be naïve and simplistic to expect the structure and function of freshwater ecosystems to be 'controlled' by mainly top-down or bottom-up processes. The latter can have many important effects on the former and vice versa...".

Despite the lack of understanding of detailed mechanisms the potential importance of macrophytes may be seen at an overall level. The present condition in the Bay of Quinte itself, in which algal levels in the Upper Bay are higher than expected on the basis of phosphorus controls alone, implies that the aquatic ecosystem is in some way distorted. At the system level this distortion can be described as a deviation from the expected linear distribution of biomass in the particle size spectrum (PSS) postulated by Sheldon et al. (1972). Since Sheldon first presented the PSS model, many authors have discussed the potential for various mechanisms to affect this linear biomass-size relationship (e.g., Shapiro et al., 1975; Kerr, 1977; McQueen et al., 1986; Borgmann, 1987; Christie et al. 1987); specific application of particle size theory to the Bay of Quinte has been made by Minns et al. (1987).

Observations in other systems where macrophytes have been re-established or are naturally abundant (e.g., Rice
Lake) suggest that successful establishment could provide habitat for invertebrate production (Daphnia, isopods, amphipods, insect larvae) and for fish species (muskellunge, bass, pike) that would prey on planktivores. In contrast to the Bay of Quinte, Lake Wilcox in central Ontario has substantial areas of macrophytes and has lower algal density and greater clarity than suggested by comparison with other lakes with similar phosphorus concentrations (Michalski 1986). On balance, the evidence suggests that re-establishment of macrophytes may be an important mechanism to achieve a balanced PSS, and thus improvement in ecosystem health and water quality.

4.1.4 Conclusions

Several general conclusions can be made with respect to the bottom up mechanisms outlined in the model:

1. The results of the eutrophication model analyses suggest that further reductions in Upper Bay phosphorus levels are likely to occur, even if no further actions are taken.

2. Implementation of additional controls on phosphorus loadings to the Bay will increase the magnitude of this decline, although none of the individual options alone will have a big effect (if implemented at realistic levels).

3. The combined control option (Scenario 12 in Table 9) produced results that meet the targets identified for improvements to both the water clarity and algal biomass levels in the Upper Bay.

4. The model results depend on untested assumptions regarding sedimentation and reflux. These assumptions need to be validated.

5. Model predictions of changes in water clarity and algal biomass implicitly assume that other (e.g., top-down) controls on these variables
are either ineffective or will not change in the future.

6. Decreases in phosphorus concentrations in the Bay are more likely to enhance (through increased water clarity) than inhibit (through reduced nutrient supplies) macrophytes development in the Bay.

7. Additions of nitrate-nitrogen to the Bay may lead to N:P ratios that are less favourable for blue-green algae; there are a number of unknowns, however, that need to be resolved before this option should be seriously considered. Reductions in P levels are a more desirable option for increasing N:P ratios.

8. Tributary sediments do not play an important role in influencing water clarity, except possibly on a local scale during high flow events; therefore, decreases in tributary sediment loads are not expected to result in substantial improvements in the macrophyte community.

The following general conclusions can be made with respect to top-down controls:

1. Reduced harvests or increased stocking of warm water piscivores are not expected to produce beneficial results.

2. There is no evidence that spawning habitat (except macrophytes) is currently limiting the production of piscivores in the Bay.

3. Planting of macrophytes may be a practical means of increasing macrophyte area and altering species composition, provided the appropriate physical conditions are maintained. Increases in water clarity due to reduced phosphorus concentrations in the Bay should increase the potential for this option (and for natural increases). An apparent natural increase in macrophytes has been noted recently, although its extent is unknown; planting of macrophytes may not be necessary once more information is obtained about natural regeneration.

4. The present dominance of walleye in the piscivore community of the Bay, implies a lack
of dynamic resilience to environmental changes. This issue is further discussed in Section 4.3.

4.2 Vegetation Area and Structure

4.2.1 Introduction

In combination with the physical and chemical properties of substrates and water, vegetation is a major determinant of habitat for both fish and wildlife. Both the area and diversity of habitats are important to achieving diverse and abundant fish and wildlife populations within the Bay of Quinte. This indicator is thus related to the following impaired uses (see Table 5):

- fewer opportunities for wildlife harvest and non-consumptive uses; and
- reduced or less certain longterm sport fishing opportunities.

In addition, the presently reduced area and diversity of vegetation within the Bay of Quinte ecosystem can be considered to contribute to:

- degraded aesthetics; and
- a degraded ecosystem relative to historical (1930s).

4.2.2 Targets

Ideally, the targets for improving this indicator should have both spatial and functional components. In other words, we should be specifying where we desire increased macrophytes, and what types of vegetation (e.g., emergent versus submergent, functional groups) would be most desirable. Such detailed targets have not yet been established. It is possible, however, to identify more
general targets which can be compared to predictions of the eutrophication model presented earlier. It has been suggested that a 40% increase in the overall area of macrophytes in the Bay might be a desirable and achievable target that would significantly increase habitat for warm water fish species and wildlife. According to the model predictions presented earlier (Table 10a,b, Figure 11), this target is consistent with the improvements in water clarity that might result from further controls on P-loads to the Bay.1

The establishment of more specific targets for increased vegetation within the Bay should explicitly account for areas where increased vegetation would impede navigation. As noted in the discussion of water clarity (Section 4.1), once improvement in clarity is achieved spontaneous re-appearance of aquatic macrophytes is possible. Since in the past substantial efforts were made to control macrophytes for navigational purposes, it is plausible that a similar condition will arise once water clarity improves. Explicit zoning of the Bay may be necessary to allow a balanced program of macrophyte enhancement and nearshore wetland establishment, while at the same time protecting established navigational routes.

4.2.3 Remedial Actions

Actions most appropriate to achieve an improvement in this indicator are those which would contribute to establishing aquatic macrophytes and nearshore wetlands. Hence rehabilitation of nearshore wetlands through direct manipulations (dredging, blasting, planting, etc.) and

1. Approximately 30 km² of the Upper Bay had light conditions suitable for macrophytes during the mid-1970s (K. Nicholls, OMOE, pers. comm.). Model predictions for Scenario 12 imply an increase in this area to approximately 40 km², a 33% increase.
actions which would lead to increased water clarity and the natural re-establishment of macrophyte beds (discussed in Section 4.1) are all important.

Losses of the historical populations of macrophytes in the Bay of Quinte were associated with the colonization and dominance of the macrophyte community by milfoil in the 1950s and early 1960s. Following the collapse of the native macrophyte community, the population of milfoil also collapsed and resulted in a largely defoliated system. The loss of macrophytes was also associated with the loss of wetland areas (approximately 12,000 ha prior to 1967, plus 130 ha 1967 to 1982) and active programs of macrophyte harvesting to improve navigation in the Bay.

Observations of macrophyte development in the Bay suggest that re-establishment has begun but that their areal extent remains limited. Uncertainty about their ability to become fully established pertains to sediment suitability (e.g., erosion in traditional areas) and concern for toxic sediments. The area of concern for toxic sediments, however, may be relatively limited. Successful re-establishment may be accelerated by, and possibly dependent upon, planting and protection of newly established beds from disturbance by both storms and fish, especially carp. Reduced phosphorus concentrations in sediments may also be required to achieve increased diversity of submerged macrophytes.

In view of the already substantial reductions in wetlands within the Bay, preventing further loss of wetland area should be a significant priority for the remedial action plan. Land use practices such as the creation of buffer strips along the shoreline in agricultural and urban areas are one option worth considering. Such buffers would be expected to improve nearshore environments for the
establishment of submerged macrophytes by reducing local sediment inputs.

Detrimental Effects

In addition to potentially degrading the use of the Bay for general navigation, increases in the area of aquatic vegetation may reduce property values. This is most likely where waters inshore of macrophyte beds adjoin land sought for recreational access for boating and swimming. Restrictions on nearshore land use associated with establishment of buffer strips may also be seen as undesirable by the agricultural community. Such practices are likely to remove some land from production and have other associated costs. Finally, an increase in the warm water fish community associated with macrophytes may be perceived by some anglers as a negative shift away from walleye; such a shift is generally considered unlikely, however.

4.2.4 Conclusions

To monitor improvement in this indicator, some means of quantification is required. Simply monitoring changes in the area of macrophytes is inadequate. It is important that vegetation be characterized in terms of both nearshore and offshore components, as well as submergent and emergent vegetation. In addition to increased area, the structure and diversity of vegetation within the Bay is considered important and measures of improvement in this indicator must therefore include increased zonation and edge.

A longterm rehabilitation plan is needed for the Bay which includes targets (specific areas) for different types of vegetation. In addition this plan should identify zones for vegetation control to facilitate use of the Bay for navigation. Model predictions such as those presented above
(Figure 11) can be used to identify target areas for vegetation management in the future.

The feasibility of nearshore wetland creation is well documented and rehabilitation of selected nearshore areas is expected to contribute to rehabilitation of the Bay. Conversely, the feasibility of establishing submergent macrophytes through direct manipulation is questionable; as discussed earlier, however, such an action may not be necessary. At the present time the maintenance of existing wetlands and the supplemental rehabilitation of degraded wetlands is considered essential. Similarly, a better understanding of the relative importance of internal phosphorus loadings is necessary to facilitate the establishment of priorities for bottom-up management.

4.3 Piscivore Diversity and Abundance

4.3.1 Introduction

The sixth impaired use listed in Table 5, "reduced or less certain longterm sport fishing opportunities" refers to the need for a rehabilitated ecosystem in the Bay of Quinte to provide more certain, sustained levels of sport (and commercial) fishing opportunities. This concern derives in part from the incidence of restrictions on fish consumption due to contaminant body burdens (see Section 4.7 below), but is principally related to the increasing dependence of the Bay's sport fishery on a single species, namely walleye.

It is generally felt that the dominance of walleye in the sport fish harvest from the Bay of Quinte, while currently providing substantial fishing opportunities, is indicative of a system that lacks resilience to unexpected perturbations. Walleye are well known to undergo dramatic year-to-year variations in year class strength in the Bay of
Quinte as elsewhere; changes to the system that reduce the likelihood of strong year classes (e.g., climate warming), could lead to a serious decline in walleye fishing opportunities. In a system lacking significant alternative opportunities, such a decline would be highly undesirable.

Avoidance of a situation such as this requires the presence of a more diverse mix of piscivorous fish species in the Bay. While several other species are present in the Bay today, their abundance is generally insufficient to warrant a major fishery. One of the goals of the RAP, therefore, should be to increase the abundance of some or all of these less dominant species to the point where they constitute an important component of the harvest.

4.3.2 Targets

Specific quantitative targets for changes to piscivore diversity and abundance have not been developed. It is felt, however, that sustained high levels of relative abundance of walleye, northern pike, smallmouth bass, largemouth bass, longnose gar, and bowfin would constitute a major improvement in this indicator. Perhaps a reasonable target would be to maintain in the Bay an index gillnet catch per unit effort (CUE) for all species combined that is comparable to current levels, but where the index catch of no species exceeds all others by more than 10%. Alternatively, some aggregated index of species diversity (e.g., Shannon-Weiner index) might be used; these indices are generally difficult for non-technical audiences to interpret, however.
4.3.3 Remedial Actions

Most of the piscivore species listed above rely to some extent on the presence of macrophytes and associated structure as habitat. Thus the remedial actions that might be considered to bring about increases in their abundance (and diversity) are those which influence the area and structural diversity of macrophytes. These actions, which relate either to direct manipulations to macrophytes through planting, or to increasing water clarity and thus the potential area for macrophyte development, have already been discussed at length (Sections 4.1 and 4.2); they will not be re-assessed here. Actions more directly associated with changing piscivore abundance - harvest controls, stocking, spawning habitat creation - were also discussed earlier (Section 4.1); in general the conclusion was that these actions are not worth implementing as remedial measures.

While the potential for enhancement of macrophytes was discussed earlier, it is worth re-emphasizing the possible importance of "edge" (the discontinuity between a macrophyte bed and an open water area) as a structural feature of the habitat for many of these species. It was noted earlier that the enhancement of macrophytes may lead to detrimental effects on navigation; the provision of navigational channels through newly established macrophyte beds maybe serve the dual purpose of avoiding this detrimental effect and providing edge for piscivores.

For smallmouth bass, an additional action may be worth considering. Crayfish are a major component of the diet of smallmouth bass in most systems (Scott and Crossman 1973); the low levels of abundance of crayfish in the Bay may constrain the rehabilitation of this species. Thus the possibility of managing crayfish populations in the Bay
might be explored as a means of increasing the abundance of bass.

Finally, while regulating harvests may not be an appropriate action to stimulate rehabilitation of these species, it may be necessary to consider such controls in order to maintain the desired high CUE and diversity. Once a desirable fishery for, say, largemouth bass is developed, unregulated exploitation pressures may be difficult if not impossible to sustain, particularly in light of the expected future growth in demand for fishing opportunities in Ontario. In addition, the maintenance of a healthy prey biomass will be necessary to sustain an abundant piscivore community.

Detrimental Effects

While increasing the diversity of the piscivore community in the Bay is desirable from an ecological point of view, sacrificing the current walleye fishery in favour of the restoration of other species is likely to encounter considerable resistance. The present-day fishery for walleye in the Bay of Quinte is enormous. From 1984-1987, angling effort averaged over 500,000 rod-hours per year for the summer fishery; harvests averaged over 100,000 fish. The economic value of walleye fishing derbies held in the Bay in 1984 has been estimated to be greater than $5 million. Any perception that this valuable fishery might be jeopardized by remedial actions is likely to lead to a strong negative reaction on the part of anglers.

4.3.4 Conclusions

The first step towards achieving an increase in the diversity of piscivores in the Bay involves increasing the area and structural diversity of macrophytes. There is some suggestion that such increases are already occurring, in
localized areas, perhaps as a result of recent increases in water clarity. The first priority should be to confirm that such increases are occurring, and, if so, to encourage their continued development (and monitor progress).

In areas of existing macrophytes, and as new beds develop, attention should be given to the creation of edge. Selection of sites for edge creation should be guided by the need for maintenance or creation of navigational channels. In older wetlands, the removal of "old" vegetation to create edge may have the additional benefit of rejuvenating the wetland - an effect that would likely be beneficial for fish and wildlife.

Priority for the remaining actions has been discussed at length in earlier sections (4.1, 4.2); no further discussion is warranted here. The only exception to this is the possible introduction of crayfish to enhance smallmouth bass. There is considerable uncertainty regarding the feasibility of this option; before any operational scale measures are seriously considered, further research and/or pilot studies should be conducted.

4.4 Wildlife Populations

4.4.1 Introduction

The relationship between the indicator wildlife populations and the fifth impaired use of Table 5 "fewer opportunities for wildlife harvest and non-consumptive uses" is intuitively obvious. The assumption is that the potential for both consumptive and non-consumptive use of wildlife changes as wildlife populations change.
As with vegetation area and structure (Section 4.2.1) reduced wildlife populations within the Bay can be considered to contribute to:

- degraded aesthetics; and
- a degraded ecosystem relative to historical (1930s)

The primary consumptive uses of wildlife on the Bay are waterfowl hunting and muskrat trapping (A. Palilionis, OMNR, pers. comm.). Duck hunting on the Bay has declined considerably since historic times (i.e., 1920s) (Crowder et al. 1986), whereas muskrat trapping success has fluctuated considerably (Palilionis 1977).

There is little quantitative information on non-consumptive wildlife use on the Bay. It is reasonable to expect that the demand for non-consumptive use of the Bay’s wildlife has risen in recent times as part of a general societal trend. The impaired use stated above centers on opportunities, however, so the connection from use to indicator involves only accepting the assumption that the potential for non-consumptive use changes as some indicator of wildlife populations does. Lower demand for non-consumptive uses in historical times may make comparisons of actual non-consumptive uses misleading because of a higher desire, but reduced potential for non-consumptive uses today.

Very few objective assessments of changes in the Bay’s wildlife populations exist. Of those that do, Crowder et al. (1986) is the most comprehensive. They determined five obvious temporal trends in the shoreline fauna of the Bay: (1) a decrease in the numbers of breeding ducks, (2) a change in the community of ducks from blue-winged teal and American black duck to mallard, (3) a reduction of offshore
fish-eating birds, followed by increased visiting of double-crested cormorants and ring-billed gulls, (4) a slight increase in beavers since the 1930s, and (5) fluctuating populations of muskrats. Survey data of the Canadian Wildlife Service indicate a decrease in the numbers of bay ducks staging in the Bay since the 1970s (Ross 1984).

The efforts of Crowder et al. (1986) were clearly frustrated by the lack of quantitative data on temporal trends in the Bay’s wildlife populations. Anecdotal evidence may serve to illustrate general trends in the Bay’s wildlife populations. There is considerable such evidence describing higher duck numbers (particularly scaup) and species diversity in the Bay several decades ago (e.g., Peters 1951, Crowder et al. 1986). It would be reasonable to suggest that anecdotal evidence, on the whole suggests a decline in the diversity of wildlife species.

A generic indicator such as "wildlife populations" is obviously of limited use because it is so very broad in scope. More specific and easily quantifiable indicators are needed that reflect wildlife populations as a whole. Counts of numbers of individuals of single species (e.g., great blue herons, muskrats) may be useful for this, however, the implicit assumption that the selected species is an indicator of the status of other species too may limit the utility of this method. More useful indicators may be those that reflect the diversity of species present, particularly since considerable anecdotal evidence exists describing declines in species diversity in the Bay.

Useful indices of diversity usually include not just a count of the numbers of species present but include consideration of numbers of individuals and evenness of species’ distribution. Ease of interpretation may be