# Androscoggin River Modeling Report
# And Alternative Analysis
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# Executive Summary

This study focuses on Gulf Island Pond, which is a large impoundment that extends for 14 miles from Lewiston to Turner. A four-mile segment upstream of Gulf Island dam is on Maine's 303d non-attainment list. The Clean Water Act requires that a TMDL (Total Maximum Daily Load) be completed for this water segment. A water quality model was developed by DEP using data collected both historically and in the summer of 2000. The following findings were made:

1. Water Quality Conditions

- The Androscoggin River has historically had poor water quality. A low point was reached in the 1960's when it was ranked as one of the ten most polluted rivers in the nation.
- The Androscoggin River's water quality has improved dramatically since the 1960's due to many actions including the mandatory requirement of secondary treatment; voluntary pollution prevent efforts and additional regulatory requirements at three paper mills; and the installation of an instream oxygen diffuser (GIPOP) at Gulf Island Pond in 1992.
- Data taken from 1993 to 2000 indicate little improvement has occurred in Gulf Island Pond's dissolved oxygen levels since the initial improvements from GIPOP in 1992.
- The data indicate that class C daily minimum and monthly average dissolved oxygen criteria are not met in 10% and 23%, respectively, of the total pond volume. Most of the non-attainment is restricted to a 4-mile stretch above the dam in the deeper portions of the pond.
- Algae blooms occur in Gulf Island Pond every summer. The algae blooms contribute to the dissolved oxygen depletion and violate the water classification narrative criteria for meeting designated uses of water contact recreation.

2. Model Predictions in Gulf Island Pond with GIPOP at 92000 PPD

- Point sources at licensed limits:
  - Daily minimum DO criteria (5 ppm) not met for a length of 13 river miles and 55% of pond volume
  - Monthly average DO criteria (6.5 ppm) not met for a length of 38 river
  - miles and 72% of pond volume
  - Maximum chlorophyll a of 19 ppb and length of 7 miles exceeds the algae bloom threshold of 8 ppb.
- Point sources at actual discharge levels:
  - Daily minimum DO criteria (5 ppm) not met for a length of 4 river miles and 11% of pond volume
  - Monthly average DO criteria (6.5 ppm) not met for a length of 4 river
  - miles and 20% of pond volume
  - Maximum chlorophyll a of 17 ppb and length of 7 miles exceeds the algae bloom threshold of 8 ppb.

- Point sources at actual levels except TP at 67% of actual levels:
  - Daily minimum DO criteria (5 ppm) not met for a length of 4 river miles and 7% of pond volume
  - Monthly average DO criteria (6.5 ppm) not met for a length of 4 river
  - miles and 15% pond volume
  - Maximum chlorophyll a of 12 ppb and length of 4.5 miles exceeds the algae bloom threshold of 8 ppb.
- Point sources at actual levels except TP at 40% of actual levels:
  - Daily minimum DO criteria (5 ppm) not met for a length of 4 river miles and 6% of pond volume
  - Monthly average DO criteria (6.5 ppm) not met for a length of 4 river
  - miles and 9% pond volume
  - Maximum chlorophyll a approaching 8 ppb and the entire length of the pond is under the algae bloom threshold of 8 ppb.

- Point sources at levels of zero discharge:
  - Daily minimum DO criteria (5 ppm) is met in entire pond volume
  - Monthly average DO criteria (6.5 ppm) is met everywhere except in areas hydraulically isolated by thermal stratification (length of 1 river
  - miles and 1% pond volume)
  - Maximum chlorophyll a of 2 ppb and the entire length of the pond is under the algae bloom threshold of 8 ppb.
- Point Sources at 40% of actual TP levels with reduced levels of BOD/TSS:
  - <u>BOD/TSS 10% of actual</u> 1% and 4% of the pond volume is predicted to not meet minimum and monthly average, DO criteria, respectively.
  - <u>BOD/TSS 25% of actual</u> 2% and 4% of the pond volume is predicted to not meet minimum and monthly average, DO criteria, respectively.
  - <u>BOD/TSS 50% of actual</u> 4% and 6% of the pond volume is predicted to not meet minimum and monthly average, criteria, respectively.

<u>3. Model Predictions with Two Oxygen Injection Systems (Upper and Lower Narrows)</u>

- Point sources at actual levels except TP at 67% of actual levels; and oxygen injection rates of 45000 and 90000 PPD, respectively, at Upper and Lower Narrows:
  - Daily minimum (5 ppm) and monthly average DO criteria (6.5 ppm) are met everywhere except in areas hydraulically isolated by thermal stratification (length of 1 river mile and 1% pond volume)
  - Maximum chlorophyll a of 12 ppb and length of 4.5 miles exceeding the algae bloom threshold of 8 ppb.
- Point sources at actual levels except TP at 40% of actual levels; and oxygen injection rates of 35000 and 70000 PPD, respectively, at Upper and Lower Narrows:
  - Daily minimum (5 ppm) and monthly average DO criteria (6.5 ppm) are met everywhere except in areas hydraulically isolated by thermal stratification (length of 1 river mile and 1% pond volume)
  - Maximum chlorophyll a approaching 8 ppb and the entire length of the pond is under the algae bloom threshold of 8 ppb.

4. The oxygen diffuser (GIPOP) is an important source of oxygen for Gulf Island Pond that eliminates non-attainment of dissolved oxygen in about 30% of the pond volume.

- Without GIPOP, the model predicts that non-attainment for the daily minimum and monthly average DO criteria would exist in 10% and 29% of the pond volume respectively with all point sources at zero discharge.
- Without GIPOP, treatment abatement alternatives investigated for point sources are ineffective.

5. A component analysis was undertaken to determine the most significant sources of dissolved oxygen depletion in Gulf Island Pond.

Sources of Impact in the DO Non-Attainment Area (40 to 70 foot depth)

- Sediment oxygen demand (SOD) is the largest source accounting for 5 to 6.5 ppm of dissolved oxygen depletion.
- Point source carbonaceous BOD collectively accounts for as much as 2 ppm dissolved oxygen depletion.
- Algal respiration and non-point sources are less significant and each account for less than 0.5 ppm dissolved oxygen depletion.

Pollutant Loads Entering Gulf Island Pond

- BOD – Paper mills account for 83%, municipal discharges 2%, and natural and non-point sources 15%.
- Total Suspended Solids (TSS) – Natural and non-point sources account for 64%, paper mills 35%, and municipal discharges 1%.
- Total Phosphorus – Paper mills account for 77%, municipal discharges 13%, and natural and non-point sources 10%.

6. An analysis of the origin of SOD indicates that non-point and natural sources collectively account for approximately one-half and point sources the other half. The majority of SOD is derived from the settling and decay of algae.
7. An analysis of hydropower generation at Gulf Island dam indicates that operational modes of generating power do not appear to be negatively affecting the dissolved oxygen levels in the pond.

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## Introduction

The Androscoggin River originates at the outlet of Umbagog Lake in Errol, New Hampshire, and empties into Merrymeeting Bay at Brunswick, Maine. The river flow is regulated from a series of lakes in the upper watershed that store a significant amount of water. As a result, a minimum flow of 1550 cfs can usually be maintained at Errol. New Hampshire. The entire river in Maine is classified C, which is Maine's lowest legal classification. Class C water quality still supports the fishable and swimmable goals of the Clean Water Act (CWA).

The Androscoggin River has had a long history of very poor water quality. A low point was reached in the 1960's when it was recognized as one of the ten most polluted rivers nationally. Considerable cleanup progress has been accomplished over the years up to a point where dissolved oxygen criteria are met everywhere except in the deeper portions of Gulf Island Pond.

The area of interest in this study is Gulf Island Pond, a large impoundment with a total volume of 2.5 billion cubic feet. Gulf Island dam is located in Lewiston-Auburn and impounds the Androscoggin River for a distance of 14.5 miles up to the towns of Greene and Leeds on its east bank and Turner on its west bank. Gulf Island Pond has a mean depth of 21 feet and maximum depth of 80 feet at its deep hole located approximately 1500 feet upstream from the dam.

Gulf Island Pond is on Maine's 303d list of non-attainment segments. Dissolved oxygen is listed as the parameter of non-attainment and point and both non-point sources are cited as the reasons for the non-attainment. Class C minimum dissolved oxygen criteria currently require that ambient levels exceed a minimum of 5 ppm and 60% of saturation and exceed a monthly average of 6.5 ppm. As a result of being on the 303d list, the CWA requires that a Total Maximum Daily Load (TMDL) be developed to bring this water body into compliance with class C dissolved oxygen criteria. This TMDL has a high level of priority on the 303d list with a projected completion date before 2003.

Numerous point sources discharge to the Androscoggin River above Gulf Island Pond and can potentially influence its water quality. Paper mills discharge to the river in Berlin, NH (Pulp and Paper of America), Rumford, ME (Mead Westvaco Corp), and Jay, ME (International Paper Co). Municipal point sources are located in New Hampshire (Berlin and Gorham); and in Maine (Bethel, Rumford-Mexico, and Livermore Falls). The collective dilution of the river 7-day 10-year low flow (7Q10 flow) to all point source discharges above Gulf Island Pond is only 8.6:1. The low dilution that is available for point source discharges and the poor capacity provided by the pond to assimilate wastes both result in a difficult situation for maintaining adequate water quality. Sources of non-point source pollution include land use activities related primarily to residential development, silviculture, and agriculture.

A modeling study was undertaken by the DEP and consultants to the three paper mills from 1980 to 1985. A result of that study was that no level of point source control could result in attainment of dissolved oxygen criteria everywhere in Gulf Island Pond. A major cause of the non-attainment in the pond was determined to be from the sediment oxygen demand that was believed to be derived from the historical accumulation of wastes in the pond. To mitigate this impact, an in-stream oxygenation diffuser was put in Gulf Island Pond approximately five miles upstream of Gulf Island dam. A cooperative agreement was reached between the three paper mills and a public utility company (now Florida Power and Light) that owns the dam and its hydropower generating facility. The aeration system became known as Gulf Island Pond Oxygenation Project (GIPOP). The aeration system was installed in the summer of 1992 and immediate improvements of dissolved oxygen in the pond became evident.

A number of waste treatment improvements have been realized at the paper mills as a result of voluntary pollution prevention efforts and regulatory requirements. Gulf Island Pond has been monitored closely since 1985 to document the improvements in water quality. As expected, the data have shown significant improvements of dissolved oxygen levels in Gulf Island Pond, but some non-attainment of class C dissolved oxygen criteria persists every summer in the deeper portions of the pond.

This modeling analysis updates the prior effort with newer data. Four major issues are also explored that weren't considered in the original modeling analysis.

1. What is the origin of the sediment oxygen demand (SOD) that continues to be a major cause of oxygen depletion in Gulf Island Pond? Can anything be done to reduce SOD?
2. Algae blooms are now experienced on the pond every summer. To what extent does algae affect dissolved oxygen levels on the pond? How much will nutrient input reductions improve water quality?
3. Can the monthly average dissolved oxygen criteria of 6.5 ppm be maintained in the Androscoggin River and Gulf Island Pond?
4. What other actions are necessary to improve water quality in Gulf Island Pond?

## Summary of Gulf Island Pond Data

The quantity and scope of water quality data taken on the Androscoggin River by DEP and the GIPOP cooperative in the last two decades is extensive. The data taken over six years (1992-1995, and 1998, 1999) illustrated the following (figure 1):

1. Initially after the installation of GIPOP in 1992, significant improvements in Gulf Island Pond's dissolved oxygen levels resulted immediately.
2. There appears to be minimal additional incremental improvement in dissolved oxygen trends since 1993.
3. About 10% of the pond volume does not meet class C minimum dissolved oxygen criteria in the more critical summers (93, 95, 99) of low flow and high water temperature. About 23% of the pond volume does not meet monthly average DO criteria of 6.5 ppm in critical summers.

4. The Class C DO non-attainment is typically limited to that portion of the pond four miles upriver from the dam at depths of 35 to 70 feet.

5. Algae blooms occur every summer.

Gulf Island Pond is monitored continuously in the summer for dissolved oxygen and temperature at Turner Bridge, 1.5 feet from the river bottom and above the dam off a floating module at depths of five, twenty, thirty-five, fifty, and sixty-three feet. Monitoring was formerly done off the face of the dam, but it was determined that this was not a good monitoring location. As a result the floating module system was installed in 1999. Some of the daily minimum dissolved oxygen data collected by the monitor prior to 1999 may not be representative of the actual water quality in most of the areas near the dam. The dissolved oxygen readings just above the dam are of primary interest due to the fact that this is where the D.O. sag point (location in the river of the lowest dissolved oxygen readings) usually occurs.

In addition to the continuous monitor data, DEP sampled the pond at seven to nine locations from Turner Bridge to Gulf Island dam in the summers of 1992-95, 1998, 1999 and 2000. The 1992 to 1995, 1998 and 1999 data were taken as a continuing effort to observe water quality trends in the pond. Sampling was usually undertaken weekly for dissolved oxygen and temperature (taken as depth profiles), and some nutrient and *chlorophyll a* data was taken in 1998. The effort in 1999 involved twice weekly dissolved oxygen and temperature sampling and typically weekly *chlorophyll a* sampling. These data were taken in a summer when a 7-day 10-year low flow (7Q10) was nearly reached. In addition, the GIPOP cooperative agreed to start GIPOP up earlier and inject 25% more oxygen during the times of higher river temperature (>24 $^{o}$C). The 1999 data provide valuable information regarding the factors that influence dissolved oxygen levels in the Gulf Island Pond. It is discussed separately in the next section of this report.

In the summer of 2000, during the month of August, weekly sampling of the pond was done. *Chlorophyll a*, nutrients, ultimate BOD, and secchi depth data were collected at five locations; four locations on the pond and one location at the inlet to the pond (Twin Bridges at Rte 219), in addition to the dissolved oxygen and temperature profiles. The 2000 data were collected primarily to calibrate a water quality model for algae and nutrient interactions on the pond and to determine their effect on dissolved oxygen.

The *chlorophyll a* data taken in the summers from 1998 to 2000 (Figure 2) often exceeded 8 ppb, indicating that algae blooms occurred each summer. The 1999 data best illustrate dry weather conditions; in contrast, relatively wet summers were experienced in 1998 and 2000. In the summer of 1999, the *chlorophyll a* levels were typically around 10 to 30 ppb and peaked at 45 to 50 ppb. Total phosphorus and orthophosphorus were typically in the range of 40 to 60 ppb and 20 to 30 ppb, respectively, in 1998 and 2000, easily supporting bloom conditions in a large impoundment. In the summer of 1999 no phosphorus data were taken, except on August 31, when a TP range of 58 to 82 ppb was observed in the pond.

A number of studies involving the tracking of dye tracers were undertaken in the 1980's by DEP and USGS to more fully understand the travel time of pollutants entering the Androscoggin River. The results of these studies indicate that the cumulative river travel time from Berlin, within a range of river flow of 5000 to 2000 cfs at Rumford are as follows: two to three days to Rumford; three to five days to the Twin Bridges on route 219 (the inlet to Gulf Island Pond); and seven to sixteen days to Gulf Island dam (Figure 3). Hence under most summertime flow conditions the travel time within Gulf Island Pond ranges from four to eleven days over a distance of 14 miles. The river travel time from Berlin to pond inlet at Turner is only three to five days over a distance of 93 river miles.

## Summary of Summer 1999 Data

The 1999 data illustrate that during critical summers (high temperature and flow approaching 7Q10), the deeper portions of Gulf Island Pond could remain chemically stratified (poorly mixed vertically but without temperature gradient) for extended periods of time. The stratification results in a partial mixing of bottom waters. The pond is most sensitive to pollutant loadings during this stratified state. This limits the assimilative capacity of the pond; accordingly, the low vertical transfer of dissolved oxygen to bottom waters must be accounted for when representing the design “worse case” conditions for the model prediction runs.

A stronger density gradient occurs at a depth of 58 to 66 feet near the dam, where a thermal stratification occurs. Thermal stratification is defined as a change of at least $1^{o}C$ per meter of vertical depth. The location where this occurs in the water column is referred to as the thermocline. The waters above and below the thermocline are the epilimnion and hypolimnion, respectively. The hypolimnetic volume of Gulf Island Pond is usually less than 1% of the total pond volume. The difference between a chemically stratified and thermally stratified water body can be explained as follows. In the former, there is some low level of vertical mixing, but in the latter, vertical mixing of chemical constituents (notably dissolved oxygen) for all practical purposes can be zero for extended time periods. The chemical stratification is a weak gradient that is more easily broken up by minor meteorological or runoff events than a thermal stratification that could remained fixed for several weeks.

The percentage of the pond that does not meet DO criteria has historically been used as a comparative planning tool. The 1999 data were analyzed to determine the percentage of pond volume that does not attain DO criteria. This process begins by first plotting the dissolved oxygen data taken biweekly from June 7 to September 14 on graphical representations of Gulf Island Pond for each sampling day (see appendix). The percentage of the total volume of the pond that did not attain minimum class C DO criteria is calculated, and the non-attainment area on the graphical representations is represented by light gray shading. The thermocline is represented by a boldface heavy line. The volume of the pond that did not meet minimum class C DO criteria varied from less than 1% to 10% of the total pond volume. The hypolimnetic volume is also calculated and was found to be usually < 1% of the total pond volume. The thermocline typically occurs at a depth of 58 to 66 feet. When the July data are averaged for the entire month, it can be deduced that 23% of the pond volume did not meet monthly average DO criteria of 6.5 ppm.

The percentage of the pond that did not meet class C DO criteria (NA Volume) is compared to the measured *chlorophyll a* levels taken over the entire summer (Figure 4). There appears to be a good correlation of NA Volume to *chlorophyll a*. The higher *chlorophyll a* levels usually occurred during time periods when there was larger volume DO non-attainment. This could imply that the high levels of algae measured are a contributing factor to the DO non-attainment.

The temperature of river water entering the pond as compared to the existing pond temperature is an important factor describing pollutant transport mechanisms. When the incoming river water is warmer than the pond temperature, flow of the warmer less dense water is across the surface of the pond. There is minimal mixing of the deeper pond waters under this condition, which typically results in a stratification and lower DO in deeper areas of the pond. In contrast, when the water temperature of incoming water is cooler than the pond temperature, the denser cooler water sinks closer to the pond bottom. Mixing of the deeper pond waters is promoted under this condition that typically results in higher DO in the deeper areas of the pond.

The 1999 data can be used to illustrate this. The temperature of the river water that enters Gulf Island Pond at Turner Bridge is compared to the water temperature at a depth of 50 feet near Gulf Island dam and both are compared to the NA Volume (Figure 5). A depth of 50 feet is chosen, since that is the depth at the continuous DO / temperature monitor at the dam where DO non-attainment first occurs.

In figure 5, the thicker boldface line represents the incoming water temperature at the Turner Bridge continuous monitor and the thinner line represents the temperature at a depth of 50 feet near the dam. When the thicker line is higher than the thinner one, river flow of the warmer river water is sliding across the pond surface promoting both a thermal and chemical stratification. It can be observed that the largest NA Volume typically occurs during stratification periods. Conversely, when the thick line is below the thinner one, the incoming water is cooler and flow sinks to deeper parts of the pond. This promotes vertical mixing of the pond and a lower NA Volume is observed.

River flow can also be added as another comparison variable (Figure 6). The river flow was relatively stable throughout the summer with limited runoff events. Flow dropped to a minimum level of 1730 cfs at the end of August, slightly higher than 7Q10 (1600 cfs). There appears to be little correlation of river flow to NA Volume. However, it can be observed that runoff events probably played major roles in promoting the pond mixing. Large runoff events occurred in mid July and mid September, and a smaller runoff event was experienced in mid August just prior to the pond's mixing. The cooler water temperature that typically results following precipitation events together with the increased river flow probably resulted in a mixing of the pond.

Finally the *chlorophyll a* data are compared to chemical stratification patterns (Figure 7). It can be observed that maximum *chlorophyll a* occurs during a state of pond stratification. During pond mixing the *chlorophyll a* levels typically decreased. This is due to the added dilution obtained from mixing of the pond's surface and bottom waters, increased river flow and the possibility that algae blooms are flushed out by the surge of runoff.

## Water Quality Model

A water quality modeling analysis of the Androscoggin River from Berlin, NH, to Lewiston, ME, was undertaken by DEP. This involves two separate modeling efforts; the use of a steady state, one-dimensional model (Qual2EU) for the upper Androscoggin; and the use of a multi-dimensional, time variable model (WASP) for Gulf Island Pond. Most of this effort in this report focuses on the modeling of Gulf Island Pond with WASP (Water Quality Analysis Simulation Program).

The application of mathematical modeling techniques to water quality problems has proven to be a powerful tool in water resource management. As a diagnostic tool it permits the abstraction of a highly complex real world. Realizing that no one can ever detail all the physical phenomena that comprise our natural world, the modeler attempts to identify and include only the phenomena, be they natural or man-made, that are relevant to the water quality problems under consideration. As a predictive tool, mathematical modeling permits the forecasting and evaluation of the effects of changes in the surrounding environment on water quality. Some water quality problems are of such a complex nature that mathematical models provides the only real means for predicting the source of impacts and possible management alternatives to correct problems within the limits of the model's assumptions and precision.

The modeling analysis for the Androscoggin River involves two separate efforts. Since the data have always shown that water quality chemistry in the upper Androscoggin (Berlin to Turner) is uniform both vertically and laterally, the model simulation here is a steady state, one-dimensional analysis. The model Qual2EU was used for this effort.

Conversely Gulf Island Pond's water quality varies vertically. For example, the dissolved oxygen levels are typically lower as measurements get deeper along a vertical profile. The differences, vertically, are important, but they cannot be accounted for using a one-dimensional analysis such as QuaL2EU. For this reason, the model, WASP, was used to simulate water quality conditions in Gulf Island Pond. Both Qual2EU and WASP are EPA supported models. The models are linked by using the water quality at the end of the Qual2EU simulation for the initial boundary conditions of the WASP simulation of Gulf Island Pond.

The kinetic representation of the WASP model is quite complex and mathematically relates the relevant factors to dissolved oxygen production and depletion. A flow chart representation of the model (Figure 7a) details the many processes involved. The "sources and sinks" of dissolved oxygen include algae growth and respiration, which in turn are driven by light and nutrient interactions, carbonaceous BOD decay, nitrification, atmospheric reaeration, sediment oxygen demand, sediment nutrient sources (fluxes), and the settling of particulate portions of pollutants. The model includes input sections for point and non-point sources of pollution, and upstream and downstream boundaries.

The modeling analysis undertaken by DEP and the GIPOP cooperative from 1980 to 1985 was used as a basis for setting up the model structure. The upper Androscoggin was segmented into 16 reaches (Figure 8). Gulf Island Pond was segmented into 60 reaches (Figure 9). In the former effort by consultants to the GIPOP cooperative, Gulf Island Pond was segmented into 123 reaches. DEP does not feel that this level of detail is necessary and hence the reduction of segmentation, which also results a less burdensome management of the model output.

A flow balance is typically calculated for a modeling analysis whenever there is a significant change of drainage area over the modeled stretch, and the river flow is likely to change from the initial upstream boundary conditions. The portion of the Androscoggin considered for the modeling effort is 107 miles long and the drainage area increases from 1200 square miles in Berlin to 2863 square miles at Gulf Island dam. Historic gaging information from USGS was used whenever possible. Gaging information is available on the Androscoggin River at Gorham, Rumford, and Auburn and on the following tributaries; the Wild River, Ellis River, Swift River, Nezinscot River, and Little Androscoggin River. The larger tributaries were generally inputted into the model as point sources and the smaller tributaries inputted as distributed incremental flow. A drainage area adjustment at 7Q10 of 0.086 cfs /$mi^2$ was calculated from available gaging data for tributaries without gaging information (Table 1).

## Calibration of Gulf Island Pond Chemical Data

The data collected in the summer of 2000 were used as a basis for re-calibrating a water quality model of Gulf Island Pond. Older data (1984) were used for model verification. Satisfactory results were obtained when comparing a match of modeled Vs observed for various chemical parameters. The calibration / verification process is typically undertaken to give the model greater reliability when predicting "worse case" water quality conditions.

Since the non-attainment of dissolved oxygen in the Androscoggin is limited to Gulf Island Pond, the modeling discussed in this report is an effort focused primarily on the pond. For the most part, parameter rate inputs to the model of the Upper Androscoggin was not changed, except for the addition of nutrient and algae interactions. The inputs to the Qual2EU model were thoroughly checked to assure that they are now consistent with present day conditions. In some cases point source inputs were changed to reflect current licensed values.

Algae as phytoplankton, is generally not a significant contributor to the dissolved oxygen depletion in the upper Androscoggin. As a result, most of the changes to the Qual2EU model are not deemed to be significant and are not discussed in this report. (The one exception to this statement is the dissolved phosphorus uptake rate, which is discussed later in the report.) For a description of the Qual2EU parameter rate inputs used in the model, one should consult Table 2.

The data collected in August of 2000 are used for model re-calibration of Gulf Island Pond. Whenever possible, the parameter rates used in the former effort were used. In some cases, the older rates were not well documented. Some minor changes from the 1980's effort are noted. First is the 2000 data set re-calibrated BOD decay rate of 0.03 per day (1984 rate 0.05 per day). The algae settling rate of 0.5 meter/day is higher than the older rate of 0.5 ft/day. A summary of all the model parameter rates together with the rationale used to assign the rates is explained in Table 2.

When simulating algae and nutrients with a model, a continuous effort over a long time period is often needed to successfully account for the variability that typically occurs in this environment. River flow (Figure 10), *chlorophyll a*, nutrients, and dissolved oxygen levels were all highly variable in the month of August 2000. To account for this variability, WASP was run in a time variable mode over the entire month of August. The model re-calibration of the August 2000 data is plotted for carbonaceous BOD (CBOD), total nitrogen (TN), total phosphorus (TP), *chlorophyll a* (CHLA), and dissolved oxygen (DO). The calibration is usually a time series plot of individual sampling locations.

The CBOD calibration was initially problematic due to the fact that the laboratory BOD test measures algal respiration that is not included in the model output for CBOD. (The dissolved oxygen depletion for respiration is accounted for in the model in another way.) An adjustment was made to the data and hence the term "corrected" in the calibration plots. The following equation was used to correct the measured CBOD:

$CBODc = CBOD_L - PHYT \times 2.67$

where 2.67 = oxygen / carbon ratio

PHYT = Phytoplankton as carbon (ppm)

$CBOD_L$ = Laboratory uncorrected CBOD in ppm (CBOD + respiration)

CBODc = Corrected CBOD in ppm

The CBOD data are plotted as both corrected and uncorrected. A fair calibration occurs, considering the variability in river flow during the first two weeks of August. A decay rate of 0.03 per day gave the best results (figure 11). The laboratory bottle decay rate for the August-00 BOD samples was also 0.03 per day. In quiescent velocity situations such as those experienced in Gulf Island Pond, the laboratory decay rates and actual decay rates are often the same. Hence the bottle decay rate, in itself, can be used as justification for the assignment of the BOD decay rate. The difference between the 2000 BOD decay rate (.03 per day) and the 1984 BOD decay rate (.05 per day) can best be explained by the much lower level of BOD experienced in 2000. The BOD decay rate generally becomes lower as pollution levels are reduced.

The calibration of algae was complicated due to the high variability in light conditions and river flow, which resulted in a high variability of CHLA and nutrients. In the middle of August, there was a large runoff event and low light conditions from an extended period of cloud cover. This resulted in lower than normal *chlorophyll a* levels in Gulf Island Pond on the 8/15 and 8/21 sampling days, during a pond mixing event. Time functions were derived for the model input for both river flow and light as solar radiation. River flow at the Rumford gage was provided by USGS and estimates of the inflow to Gulf Island Pond by Western Hydro. For light conditions, Mead Westvaco Paper Company provided solar radiation data that could directly be inputted into the model as a time function (Figure 12). This resulted in a satisfactory model calibration of CHLA (Figure 13).

The model calibration for nutrients is displayed as TN and TP (Figures 14,15). There is a good fit of modeled to measured values. Phosphorus values initially outputted by the model were consistently high in comparison to measured values. An additional uptake component of orthophosphorus (PO4-P) had to be added. (The organic–P from the model was within measured values but it was the PO4-P that was consistently high.) This was accomplished by adding a settling component for PO4-P. Although dissolved solids do not ordinarily settle, other studies have shown that PO4-P can attach onto solids through adsorption. A settling rate of 0.5 m/day, the same rate used for all other parameters, was input to the model which subsequently resulted in a satisfactory fit of modeled to measured TP values

The BOD decay rate, reaeration rate, and the vertical dispersion rate were the main parameters adjusted to achieve a calibration of dissolved oxygen. The vertical dispersion was adjusted to achieve the proper distribution of dissolved oxygen vertically. A time function was needed to simulate the very variable conditions of vertical mixing that occurred in Gulf Island Pond in August of 2000 (Figure 9a). At the beginning of August, the pond was chemically stratified resulting in the assignment of low rates of vertical transfer.  In the middle of August, a large runoff event occurred which resulted in a nearly complete mixing of the pond.  A high rate of vertical transfer was needed to simulate the mixing caused by the increased river flow (Figure 16).  At the end of August, Gulf Island Pond entered into a less stratified condition than was experienced earlier that month.

Different rates of vertical transfer had to be assigned to some of the model reaches (18, 19, 23, 24, 41, 42, 43) near the bottom of the pond.  Model reaches (41,42,43) at the bottom of the deep hole near the dam typically needed very low rates of vertical transfer. This area of the pond is in or near the hypolimnion below the thermocline that is formed near the dam.  The density gradient formed by the thermal stratification experienced here is very resistant to mixing and hence the low rate of vertical transfer.  During the beginning of August, the dissolved oxygen readings in the hypolimnion of Gulf Island Pond were anaerobic.  The hypolimnion often remains this way for a majority of the summer.  (The hypolimnion typically is only 1% of the total volume of the pond.)  A rate of zero vertical transfer was used to simulate these conditions.  In contrast, during the runoff event experienced in the middle of August, it appears that a large slug of cooler water sank to the pond bottom right up to the dam resulting in a vertical mixing of the pond.  A very high rate of vertical tranfer (20 $cm^2$/sec) was needed to simulate this phenomena.

Another portion of Gulf Island Pond that appears to be very resistant to mixing is an area near the pond bottom in the vicinity of Lower Narrows and stretching down toward the dam.  This area is represented by model reaches 19, 23, and 24.  The depth of Gulf Island Pond changes abruptly here and this physical characteristic appears to affect mixing near the pond bottom.  This often results in very low dissolved oxygen in the bottom 5 to 10 feet from Lower Narrows to the dam.  To simulate this lower dissolved oxygen, it was necessary to assign lower rates of vertical transfer here than most of the other modeled reaches.  The rates assigned here were typically higher than those assigned for the simulation of thermal stratification, except during the runoff event.

The model calibration of dissolved oxygen is undertaken as a continuous model run over the entire month of August at the two monitor locations (Turner Bridge and Gulf Island dam) and also on individual sampling days (8/9, 8/15, 8/31).  The calibration plot at Turner Bridge (Figure 17) results in a good match of modeled to measured values and indicates that the assumed boundary inputs of dissolved oxygen at Twin Bridges are reasonable.  Calibration plots at the dam are displayed at 5, 35, and 63-foot depths (Figure 18) and indicate a good match of modeled to measured dissolved oxygen.  The data taken on the individual sampling days along the entire pond longitudinally at eight locations are also checked for model calibration and again good match results (Figures 19a,b,c).  These data are early morning readings representing the daily minimum DO, and to be consistent with the model output, must be adjusted to the daily average DO.  A diurnal adjustment was derived from the continuous monitor data at Turner Bridge and Gulf Island dam that was specific to those sampling days.  The diurnal adjustment of 0.3

ppm was added to the early morning data, which was identical for those three sampling days.

Although the 1984 data were calibrated in the previous modeling effort, the recent structure changes and additions of algae and nutrient interaction made verification of the model with this data necessary. The 1985 modeling effort was a steady state analysis over a two-week period. Light was directly measured in the field and could be input as a time function (Figure 6a). For the phosphorus calibration (displayed as PO4-P), a rather high settling rate (2.0 m/sec) had to be assigned to receive a calibration of PO4-P (figure 20). The CBOD decay rate of 0.05 per day used in the 1984 analysis gave the best results for the CBOD (figure 20) and dissolved oxygen calibration. The previously calibrated vertical dispersion rate of 7.5 $cm^2$/sec could be used in all reaches except those representing the thermal stratification near the dam (model reaches 41,42,43). Here a vertical dispersion rate of 1 $cm^2$/sec was necessary. A good fit of dissolved oxygen was obtained (figure 20a).

## Orthophosphorus Uptake Rate

In impoundments or quiescent velocity situations, phytoplankton, or floating algae are the primary algae experienced. In shallower river systems, algae that attach to the river bottom are the primary algae experienced. Phosphorus is utilized in the growth of phytoplankton and bottom attached algae. Riverine systems may also experience the uptake of dissolved phosphorus, which is primarily orthophosphorus (PO4-P), in excess of that quantity needed for growth. Hence PO4-P uptake could be very rapid and significant in situations where bottom attached algae are abundant. As previously explained, some PO4-P uptake could also occur by settling, which involves dissolved phosphorus attaching to particulate matter through adsorption

It is necessary to account for PO4-P uptake in the Upper Androscoggin. The uptake would represent phosphorus that is assimilated in the river before reaching Gulf Island Pond. This phenomenon was not accounted for in the earlier modeling effort of the Androscoggin River. The uptake rate is usually quite variable according to a number of factors. For example, if a number of consecutive cloudy days were experienced, the uptake would be less than that experienced under maximum sunlight. Although the assignment of this rate is difficult, it was determined the error introduced in the modeling by the assignment of this rate in the upper Androscoggin model should be less than assuming no PO4-P uptake occurs. For example, with no PO4-P uptake, for given point source inputs of phosphorus, the modeling would be predicting much more phosphorus entering Gulf Island Pond, than what actually occurs. This would also result in a prediction of higher phytoplankton in the pond than what actually occurs.

The older data taken in 1982 and 1984 are used to estimate phosphorus uptake in the Androscoggin River from Berlin to the entrance of Gulf Island Pond. It can be seen that with no uptake, the model output for PO4-P is consistently higher than measured PO4-P (dashed lines, Figure 21). Although Qual2EU currently does not have the capability to model bottom attached algae directly, orthophosphorus uptake can still be accounted for in the river bottom as a negative PO4-P flux. (MDEP is currently having the program structure to Qual2EU adapted through EPA support so that attached algae can be modeled in the future.) PO4-P uptake rates of 0.25 and 0.50 $mg/ft^2$-day resulted in a good match of measured PO4-P to modeled values, respectively for the August 1982 and 1984 data sets (figure 21).

Since the uptake of PO4-P is quite variable, some conservatism must be used when assigning this rate in the model prediction runs. If phosphorus is reduced through point source controls, the population of bottom attached plants will be reduced and P-uptake will subsequently also be reduced. Hence the rates assigned in the model prediction runs are as follows:

**Table 3 – PO4-P Uptake Rates for Qual2EU Model**

| Model Run | PO4-P Uptake $mg/ft^2$-day | Explanation of Assumed Rate |
|---|---|---|
| Point Sources Licensed Flow | .25 | Low end of calibration (1982) |
| Point Sources Actual Flow | .20 | Low flow predicted PO4-P (28 ppb) consistent with typical observed PO4-P |
| Point Sources at 67% of Actual P | .15 | In-between actual P-loading and zero P-loading uptake rates |
| Point Sources at 40% of Actual P | .10 | |
| Point Sources at Zero Discharge | .05 | Predicted PO4-P (<1 ppb) consistent with clean riverine systems without completely depleting PO4-P |

In the WASP model, the uptake of PO4-P in Gulf Island Pond is modeled in the transport as settling. As explained earlier, two different rates resulted in the calibration, 0.50 m/day for Aug-00 and 2.0 m/day for Aug-84. The rate of 0.50 m/day is considered to be more reliable, since 0.50 m/day is the calibrated settling rate for all other chemical parameters (chlorophyll a, OP, ON, and UBOD). Hence a settling rate of 0.50 m/day for PO4-P was used in the model prediction runs.

## Analysis of Origin of Sediment Oxygen Demand

Another important consideration in the model prediction runs is the assignment of the sediment oxygen demand (SOD) rate. The input of more or less pollutant loads into Gulf Island Pond should also proportionally affect the SOD rate. As discussed later in the report, the SOD is the most significant cause to dissolved oxygen depletion in the deeper portion of the pond. How the SOD rate changes with different pollutant load inputs was not addressed in the initial modeling effort of the 1980's. Although the calculation of the expected changes of the SOD rate is inexact, it was determined that not addressing this factor results in introducing more error into the modeling analysis.

An analysis was undertaken to determine the sources of SOD and best actions to reduce SOD. This analysis shows that a majority of the SOD (85%) can be accounted for by current inputs. Current point source inputs are estimated to be responsible for about 46% of the measured SOD. About 65% of the SOD can be accounted for by the settling and decay of algae. Reduction of algae through point source phosphorus controls appears to be the most promising action to reduce SOD. Point sources are responsible for about 90% of the phosphorus entering the pond.

The SOD rate is typically assigned using two considerations; measurement and the model calibration of dissolved oxygen. Direct measurement is difficult. The SOD test involves collecting sediment cores in a number of locations. Oxygen depletion over time is observed at the laboratory in a water column over the sediment. There are many issues that make direct measurement an unprecise process. Some of these include: obtaining as undisturbed a sample as possible, the highly variable conditions of the sediment substrate, and the relatively small sample size of the pond bottom that the sediment cores represent.

The SOD measurement is regarded as a rough estimate of the actual SOD rate. It is a starting point in the calibration / verification process. The model rate of SOD that is needed to obtain a match of modeled to observed DO should not be largely different than the measured rate, but some variation is considered acceptable.

In the past, it has always been assumed that given the prior severe polluted state of the Androscoggin River, the sediment oxygen demand was largely related to historic accumulations of sediment. However, more than two decades have passed since the initiation of secondary treatment at all point source discharges on the Androscoggin River. In this time period, if all SOD was of historic origin, there should have been a significant reduction over time. Both the trend of the DO data taken in the pond over the 1990's together with limited SOD data taken in 1998 indicate that SOD has probably reached an equilibrium with current pollution sources. As discussed earlier, the DO data taken after the installation of GIPOP (1992), and the initial immediate improvements observed, indicate a trend of no significant subsequent improvement. The SOD rate measured in 1998 was actually 50% higher than an average of data taken in the early 1980's.

The apparent higher present day SOD could possibly be explained by data scatter that is expected in the SOD measurements.

Historic accumulations may not be the most important source of SOD anymore, and an analysis of how current pollution source may influence SOD is necessary. An analysis considered the settling of pollutants in Gulf Island Pond as both total suspended solids (TSS) annually, and phytoplanktonic algae seasonally. It is well documented that lakes with algae blooms typically have low DO in their deeper areas due to SOD and respiration and die-off of settling algae. The seasonality of the exertion of the SOD rate must also be considered.

This analysis must be done both within and outside the WASP modeling framework. Model runs are made to determine the portions of algae and TSS that settle to the pond bottom. Then a spreadsheet is set up that calculates the SOD that should result from the settled pollutants.

<u>SOD from TSS</u>

The modeling of TSS requires accounting for several seasonal considerations. A higher removal rate in Gulf Island Pond would be expected during the summer. A portion of TSS is particulate BOD and similarly has a BOD decay rate (Kd) associated with its biodegradation. Hence in the summer, a greater loss of TSS occurs in the upper Androscogggin above Gulf Island Pond than in non-summer. In the non-summer, loss of TSS in the upper Androscoggin is minimal, resulting in higher TSS concentrations entering at the pond inlet. Paper mill discharges, a large source of TSS (35% of total), typically discharge more solids in the non-summer than summer. There is also the issue of how river flow and water temperature vary seasonally.

It was decided that an annual analysis accounting for the mentioned seasonal variations must be undertaken to properly account for the TSS contribution to the pond's SOD rate. TSS that settles to the pond bottom in the winter, although it would not exert a significant sediment oxygen demand immediately, would remain intact to contribute to the SOD the following summer. The similarity of monthly average historic temperature (Gulf Island dam monitor) and flow (USGS Gage Rumford) data resulted in the following groupings by months: Dec-March; June; July-Sept, Oct-Nov. (Table 7). For the months of April and May, the average flow at Rumford is 7700 cfs, more than double that of the other ten months. It was decided that settling would be minimal under spring high flow conditions and could be neglected.

A critical step in this process is determining an appropriate settling rate to assign to TSS. Historic data taken in 1989 as part of a study on color, odor, and foam (COF) were used to calibrate a settling rate. In the COF study, the Androscoggin River was typically sampled once a week for TSS at many locations. Point source TSS inputs and non-point source TSS inputs as tributaries were also measured. The sampling began in early June and continued into mid-September, so both low flow and runoff periods were included. A TSS removal rate (Kr) of 0.10 per day was calibrated from a summer average of all this data (Figure 22). (Kr = Kd + Ks, where Kd is the rate of decay and Ks is the rate of settling.) The removal rate is used to determine the amount of TSS lost from the point of input to the inlet of Gulf Island Pond. A run with QUAL2eu is done to determine TSS removal above Gulf Island Pond. Point sources were input at the average amount discharged from 1998 to 2000 and specific to the four time periods.

Once pollutants enter Gulf Island Pond, the difference between the decay and settling of TSS must be determined. Temperature correction factors need to be applied to the rates of removal, decay, and settling. Default temperature corrections (θ) were applied to the calibrated rates of Kr = .10 and Kd = .03, which resulted in θ"s of 1.047 and 1.024 for decay and settling, respectively, as summarized in the following equation.

$X_t = X_{20} * \theta^{(t-20)}$ where $X_t$ is the corrected rate at the local temperature, t
$X_{20}$ is the calibrated rate at 20°C

The settling rate is determined by the difference of the temperature-corrected removal and decay rates. This resulted in settling rates from about 0.05 and 0.07 per day in the summer and non-summer, respectively (Table 7).

**Table 4 Model Runs For TSS Analysis**

| | Ave Flow (cfs) | | Ave Temp | Temp Corrected Rates | | |
|---|---|---|---|---|---|---|
| | Gorham | Rumford | | Qual Kr | WASP Kd | Wasp Ks |
| Dec-Mar | 2201 | 3057 | 0.6 | 0.063 | 0.012 | 0.051 |
| April-May | 4100 | 7710 | 9.5 | No Settling Assumed | | |
| June | 2816 | 3947 | 19.1 | 0.098 | 0.029 | 0.069 |
| July- Sept | 1984 | 2420 | 22 | 0.104 | 0.032 | 0.072 |
| Oct-Nov | 2050 | 3049 | 8.5 | 0.076 | 0.018 | 0.058 |

A series of model runs were made to determine the amount of setting that occurs in the pond in each time period. The portion of TSS that settles can be determined by a comparison of the pond inlet and outlet TSS in the model run (the decay is set at zero). The amount of SOD that occurs can than be calculated by the following equation:

SOD ($gm/m^2$-day) = ($T_c$) x ($TSS_s$) x (BOD/TSS) x (Unit) / (BA)
Where
$T_c$ =Temperature Correction Factor = 1.77 = Normalized annual average water temperature (10.2 °C to 20 °C). using θ = 1.06.
$TSS_s$ =TSS that has settled in ppd.
BOD/TSS = 0.4 Determined by field data Dec 2001 (Table 5).
Unit = Unit Conversion (lb to gm) = 454
= 0.4 Determined by field data Dec 2001 (Table 5).
BA = Bottom area in $m^2$

Field investigations were made in December of 2001 to estimate the amount of TSS that is BOD, i.e. biodegradable, and hence can cause SOD. The findings were as follows:

**Table 5 – Field Investigations of BOD / TSS Ratio Dec 2001***

| Date | Dissolved CBODu ppm | Particulate CBODu ppm | % CBODu Particulate | TSS ppm | Part. BOD / TSS |
|---|---|---|---|---|---|
| 12-6 | 4.2 | 1.4 | 25 | 2.3 | .6 |
| 12-7 | 4.9 | 0.7 | 13 | 2.3 | .3 |
| 12-10 | 5.2 | 0.9 | 15 | 2.7 | .3 |
| | | | | | **Ave = .4** |

* Sampled at Twin Bridges sampling location at the entrance to Gulf Island Pond

The model runs were made with and without point source inputs to determine the point source and non-point source (NPS) contribution of TSS discharges to SOD. Model runs were also made at licensed conditions for TSS to determine the potential for SOD, since current licensed point source TSS are about 10 times the actual discharge rates. The historic data shows a trend of higher SOD in the middle of the pond (Turner Bridge to Lower Narrows) and lower SOD at the beginning and end of the pond. This resulted in breaking the pond into three reaches longitudinally for calculation purposes. The following results were obtained (Table 7).

**Table 6– SOD Origins from Non-Algal TSS**

All SOD in units of $gm/m^2$-day

| River Mile | Current NPS | Current PS | Current Total | Licensed PS |
|---|---|---|---|---|
| 41-33 | 0 | 0.18 | 0.18 | 0.74 |
| 33-28 | 0.17 | 0.17 | 0.34 | 0.44 |
| 28-26.7 | 0.43 | 0.15 | 0.58 | 0.66 |

This analysis shows that non-algal TSS do not appear to be a large source of current SOD, but account for an average of 20% of the current SOD of which point sources contribute to about ½ (10% of total current SOD).

<u>SOD from Algae</u>

For the calculation of SOD that originates from the settling of algae, a seasonal analysis considering summer conditions was undertaken. Since the formation of SOD is a long-term phenomenon, the model is run at average summer flow of three dry summers (95,99,01) rather than 7Q10, which resulted in a flow of about 1930 cfs at Rumford. The model is run with and without algae settling and the difference of the two model runs is that portion of the algae which has settled to the pond bottom. SOD is then calculated in spreadsheet format by the following equation:

SOD (gm/$m^2$-day) = (0.55) x (Chl a) x (C/Chl) x (O/C) x (Unit) / (BA)

Where

0.55 = That portion of algal SOD exerted in the summer based upon temperature correction considerations

Chl a = *Chlorophyll a* that has settled (ppd)

C/Chl = Carbon to *chlorophyll a* ratio = 40

O/C = Oxygen/ Carbon Ratio = 2.67

Unit = Unit Conversion (lb to gm) = 454

BA = Bottom Area in $m^2$

The model runs and the calculations for the three reaches with and without point source inputs. Point source inputs were varied by both licensed flow and actual flow conditions. In addition, SOD reductions resulting from point source abatement of phosphorus were investigated. This resulted in the following:

**Table 7 - SOD Origins from Algae**

All SOD in units of gm/$m^2$-day

| River Mile | Current NPS | Current PS | Current Total | Licensed PS | PS With TP 67% Actual | PS With TP 40% Actual |
|---|---|---|---|---|---|---|
| 41-33 | 0.63 | 0.37 | 1.00 | 0.38 | 0.35 | 0.27 |
| 33-28 | 0.68 | 1.12 | 1.80 | 1.27 | 1.48 | 0.43 |
| 28-26.7 | 0.28 | 0.55 | 0.83 | 0.66 | 0.33 | 0.16 |

The sum of SOD from the settling of TSS and algae can now be summed and compared to the historic (baseline) rates assigned to the model.

**Table 8 – SOD Origins TSS + Algae**

All SOD in units of gm/$m^2$-day

| River Mile | Current NPS | Current PS | Current Total | Historic Baseline | Unknown* | License PS | Total @ License** |
|---|---|---|---|---|---|---|---|
| 41-33 | 0.63 | 0.55 | 1.18 | 1.6 | 0.42 | 1.12 | 2.17 |
| 33-28 | 0.85 | 1.29 | 2.14 | 2.5 | 0.36 | 1.71 | 2.92 |
| 28-26.7 | 0.71 | 0.70 | 1.41 | 1.4 | -0.01 | 1.32 | 2.02 |

*Unknown = The difference between historic baseline SOD and the calculated current total SOD.

** The total SOD rate for point sources, NPS, and unknown inputs, assuming point sources are discharging at licensed conditions.

It can be seen (table 9) that the calculations for SOD origins are within 0.4 gm/$m^2$-day of baseline values, or on the average within 15% of baseline values. The difference between the calculations and baseline conditions are probably attributable to the inexact methodology of the SOD measurement or calculations. They may also be other factors contributing to the SOD that weren't accounted for such as contributions during large storm events.

In summary, when the origins of SOD are considered by source type, about 46% of the SOD can be accounted for by point sources; 39% by non-point and/or natural sources, and 15% by unknown sources (Figure 23). If point sources were continuously discharging at maximum licensed conditions, the current SOD could potentially increase by 27% (Figure 23). When the origins of SOD are considered by pollutant parameters, about 65% can be accounted for by the settling of algae, 20% by non-algal TSS, and 15% by unknown sources (figure 24).

When assigning the SOD rate for the model prediction runs (figure 25), unknown sources were grouped with NPS/ natural sources to derive a zero discharge condition of point sources. The SOD rate assigned at these conditions averaged about 54% of baseline conditions. With point sources at licensed conditions, the SOD rate averaged about 27% higher than baseline conditions. Finally for the phosphorus abatement conditions investigated, the SOD rate averaged about 79% and 90% of baseline conditions for 40% and 67% of actual point TP, respectively.

## Water Quality Model Prediction Runs

The summary of the model predictions indicate that if point sources were to discharge at current licensed limits and with GIPOP at full capacity, DO non-attainment of the monthly average criteria (6.5 ppm) would occur throughout the Androscoggin River from Jay to Gulf Island Dam, a distance of 28 miles. Monthly average DO criteria would not be met in 72% of the volume of Gulf Island Pond and daily minimum DO criteria in 55% of the pond volume. Model predictions with BOD and TSS of point source discharges at actual levels indicate that DO non-attainment of the monthly average criteria and daily minimum criteria would occur in about 20% and 11% of the pond volume, respectively, and could be limited to a distance of 4 miles. If all point sources were at zero discharge, the DO non-attainment of both the monthly average criteria (6.5 ppm) and daily minimum criteria (5 ppm) would be limited to 1% of the total pond volume. Finally it can also be concluded that GIPOP makes a large difference in improving the pond's DO levels.

After the water quality model is calibrated to observed data, worst case conditions are simulated to assure dissolved oxygen criteria will be achieved at all locations. Worse case conditions are defined by:

1. low river flows, when dilution of wastewater inputs is at a minimum;
2. high water temperatures, when the saturation of dissolved oxygen is lower and BOD decay and oxygen demand from the sediment are higher; and
3. maximum inputs (point sources discharging at licensed limits).

Two tests are run with the water quality model to check dissolved oxygen compliance with statutory criteria; one to test compliance of class C minimum dissolved oxygen criteria (5 ppm and 60% of saturation) and a second to test compliance with the monthly average criteria of 6.5 ppm.

When considering the daily minimum DO criteria, the water quality model's prediction of dissolved oxygen is a daily average and must be adjusted outside the model framework to obtain a daily minimum DO. A regression equation was derived from the *chlorophyll a* data and the continuous monitor data (figure 21). There are two considerations for a diurnal fluctuation of DO; one related to algae photosynthesis and respiration and another due to variability not related to algae. The algal component of daily DO variation should result in the daily minimum DO occurring in the early AM (after an evening of limited light results in respiration and net oxygen depletion), and maximum DO occurring in the afternoon (after extended daylight results in photosynthesis and net oxygen production).

The continuous monitor diurnal fluctuation of the minimum and maximum DO did not always occur in the early AM and mid-afternoon, respectively, indicating other non-algal factors are effecting the diurnal variation in addition to the algae. The monitor readings in the early AM and mid afternoon were considered as the algal component of daily DO variation. The difference between the actual monitor daily minimum and maximum DO and the algal component of daily DO variation is the component of non-algal daily DO variation. This can be summarized as follows:

DO (Total) = DO (algae) + DO (Non-algae)
where
DO (Total) = The difference between the daily maximum and minimum monitor DO
DO (Algae) = The difference between the early morning and mid afternoon daily monitor DO

The regression equation calculates the algal component of daily DO variation as a function of *chlorophyll a*. The regression is as follows:

DO (Algae) = .03 x (*chl a)* + 0.22    where *chl a* is in ppb and DO in ppm.

In addition, a non-algal diurnal component was calculated from the median difference of DO (Total) and DO (Algae). This diurnal variation due to causes other than algae is estimated to be 0.8 ppm.

DO (Non-Algae) = 0.8 ppm

The diurnal adjustment applied to the model output of daily average DO is one-half the diurnal range and the following equation is applied to the model prediction of *chl a* :

**Diurnal DO Adjustment = ½ x DO (Total) = 0.015 x (chl a) + 0.51**

This equation is applied to the surface model segments (top 10 feet of depth) only, where algal photosynthesis is significant. Since the model predictions and available data always show adequate DO occurs in surface segments, the diurnal adjustment applied here is generally not a factor in making regulatory decisions.

In the subsurface segments the median monitor diurnal range at 20, 35, and 50 foot depths was consistently around 0.8 ppm in the summers from 1998 to 2000. Hence a diurnal adjustment of 0.4 ppm (DO Non-Algae) was applied to subsurface segments.

Point source inputs used in the model prediction runs are summarized as licensed (Table 10) and actual discharge conditions (Table 11). The actual discharge conditions were calculated for paper mills as a 95% confidence interval of a log-normal distribution from three years (98-00) of discharge monitoring reports (DMR's). This is a representation of the upper limit of what the treatment plants are actually discharging and is usually quite a bit less than license values (what the plants are currently allowed to discharge). ). For municipal discharges, which represent a very small portion of the TSS and BOD, actual discharge conditions were calculated as an average discharge over 98-00. The design conditions used for the model prediction runs and numeric class C DO criteria, which must be met are summarized in Table 12. A representation of licensed, actual, and average values of BOD and TSS for the three paper mill discharges for the summer and non-summer is summarized in Table 13.

The model prediction runs are first made at three different assumed conditions. The first (Run 1) examines the predicted dissolved oxygen in Gulf Island Pond with all point sources at licensed flow and BOD. This run is used to check compliance with the class C statutory requirements and gives potential worse case DO levels. The second (Run 2) examines point sources at actual discharge levels. This predicts what the actual dissolved oxygen levels in the pond currently are and how much of the pond is achieving class C criteria. The third (Run 0) examines a model prediction of dissolved oxygen levels in the pond assuming no point sources are discharging to the Androscoggin River above Gulf Island Pond. Finally, the model runs are made without the oxygenation diffuser, GIPOP (suffix a is with GIPOP; suffix b is without GIPOP).

Model prediction runs are also made for four major alternatives explored to improve the pond's DO levels. Run 3 examines the predicted DO with point source TP reduced to 67% of actual levels and with point source BOD and TSS at actual levels. Run 4 examines the predicted DO with point source total phosphorus (TP) reduced to 40% of actual levels and with point source BOD and TSS at actual levels. Runs 5a, b, and c investigates additional point source BOD and TSS discharges levels of 10%, 25%, and 50% of actual discharge in addition to reducing point source TP to 40% of actual. Run 6 investigates adding an additional oxygen diffuser at Lower Narrows (see schematics) at the two point source TP discharge levels investigated (40% and 67% of actual).

The runs are summarized in tabular form (Table 14) and as plotted in schematic representations of Gulf Island Pond. The areas of non-attainment are shaded in light gray and the corresponding model predicted dissolved oxygen (ppm) is displayed in all portions of the pond. The total volume of the pond not meeting dissolved oxygen criteria is calculated.

In order to simplify the modeling process and the interpretation of the model results, the simulation was done as steady state. In all model runs the thermocline was assumed to occur at 60 feet of depth. Hence a moderately low level of vertical mixing was used that could potentially occur over a longer period of time (several days). This resulted in model vertical dispersion inputs of 0.35 $cm^2$/sec for most reaches and .10 $cm^2$/sec for the poorer mixed reaches. As mention previously, the SOD rates and PO4-P uptake rates were assigned as suggested earlier in this report. For the BOD decay rate, a rate of 0.05 was assigned for licensed point source conditions and a rate of 0.03 per day for conditions of actual point source BOD or less. The BOD decay rate generally decreases with decreasing discharge and these two assigned rates are consistent with the 1984 and 2000 calibrations. Assigning rates lower than 0.03 was not considered appropriate, since a rate lower than 0.03 per day has never been experienced in any of Maine's waters. The results obtained with the model are as follows.

<u>Run 0a - Point sources at levels of zero discharge with GIPOP at full capacity</u>

- Daily minimum DO criteria (5 ppm) are met in entire pond volume (Figure 27).
- Monthly average DO criteria (6.5 ppm) is met everywhere except in areas hydraulically isolated by thermal stratification (length of 1 river miles and 1% pond volume) (Figure 28).
- Maximum chlorophyll a of 2 ppb and the entire length of the pond is under the algae bloom threshold of 8 ppb (Figure 41).

Run 0b - Point sources at levels of zero discharge without GIPOP

- Daily minimum DO criteria (5 ppm) not met for a length of 3 river miles and 10% of pond volume (Figure 29).
- Monthly average DO criteria (6.5 ppm) not met for a length of 4 river miles and 29% of pond volume (Figure 30).
- Maximum chlorophyll a of 2 ppb and the entire length of the pond is under the algae bloom threshold of 8 ppb (Figure 41).

Run 0d – Paper Mills at levels of zero discharge, municipal WWTP at actual levels with GIPOP at full capacity

- Daily minimum DO criteria (5 ppm) not met for a length of 1 river mile and 1% of pond volume. This result is similar to Run 0a (zero discharge all point sources).
- Maximum chlorophyll a of 7 ppb and the entire length of the pond is under the algae bloom threshold of 8 ppb (Figure 41). However no phosphorus allocation is available for paper mill discharges.

Run 1a - Point sources at licensed limits with GIPOP at full capacity

- Daily minimum DO criteria (5 ppm) not met for a length of 13 river miles and 55% of pond volume (Figure 31).
- Monthly average DO criteria (6.5 ppm) not met for a length of 38 river miles and 72% of pond volume (Figure 32).
- Maximum chlorophyll a of 19 ppb and length of 8 miles exceeds the algae bloom threshold of 8 ppb (Figure 41).

Run 1b - Point sources at licensed limits without GIPOP

- Daily minimum DO criteria (5 ppm) not met for a length of 14 river miles and 64 % of pond volume.
- Monthly average DO criteria (6.5 ppm) not met for a length of 38 river miles and 86% of pond volume.
- Maximum chlorophyll a of 19 ppb and length of 8 miles exceeds the algae bloom threshold of 8 ppb (Figure 41).

Run 2a - Point sources at actual discharge levels with GIPOP at full capacity

- Daily minimum DO criteria (5 ppm) not met for a length of 4 river miles and 11% of pond volume (Figure 33).
- Monthly average DO criteria (6.5 ppm) not met for a length of 4 river miles and 20% of pond volume (Figure 34).
- Maximum chlorophyll a of 17 ppb and length of 7 miles exceeds the algae bloom threshold of 8 ppb (Figure 41).

Run 2b - Point sources at actual discharge levels without GIPOP

- Daily minimum DO criteria (5 ppm) not met for a length of 6 river miles and 20% of pond volume (Figure 33).
- Monthly average DO criteria (6.5 ppm) not met for a length of 6 river miles and 54% of pond volume (Figure 34).

- Maximum chlorophyll a of 17 ppb and length of 7 miles exceeds the algae bloom threshold of 8 ppb (Figure 41).

Run 3a - Point sources at actual levels except TP at 67% of actual levels with GIPOP at full capacity

- Daily minimum DO criteria (5 ppm) not met for a length of 4 river miles and 7% of pond volume (Figure 35).
- Monthly average DO criteria (6.5 ppm) not met for a length of 5 river miles and 15% pond volume (figure 36).
- Maximum chlorophyll a of 12 ppb and length of 4.5 miles exceeds the algae bloom threshold of 8 ppb (Figure 41).

Run 3b - Point sources at actual levels except TP at 67% of actual levels without GIPOP

- Daily minimum DO criteria (5 ppm) not met for a length of 6 river miles and 40% of pond volume.
- Monthly average DO criteria (6.5 ppm) not met for a length of 6 river miles and 54% pond volume.
- Maximum chlorophyll a of 12 ppb and length of 4.5 miles exceeds the algae bloom threshold of 8 ppb (Figure 41).

Run 4a - Point sources at actual levels except TP at 40% of actual levels with GIPOP at full capacity

- Daily minimum DO criteria (5 ppm) not met for a length of 4 river miles and 6% of pond volume (Figure 37).
- Monthly average DO criteria (6.5 ppm) not met for a length of 4 river miles and 9% pond volume (Figure 38).
- Maximum chlorophyll a approaching 8 ppb and the entire length of the pond is under the algae bloom threshold of 8 ppb (Figure 41).

Run 4b - Point sources at actual levels except TP at 40% of actual levels without GIPOP

- Daily minimum DO criteria (5 ppm) not met for a length of 6 river miles and 37% of pond volume.
- Monthly average DO criteria (6.5 ppm) not met for a length of 6 river miles and 54% pond volume.
- Maximum chlorophyll a approaching 8 ppb and the entire length of the pond is under the algae bloom threshold of 8 ppb (Figure 41).

Run 5a - Point Sources at 40% of actual TP and 10% of actual BOD/TSS with GIPOP at full capacity

- Daily minimum DO criteria (5 ppm) not met for a length of 1 river mile and 1% of pond volume (Figure 39).
- Monthly average DO criteria (6.5 ppm) not met for a length of 4 river miles and 4% pond volume (Figure 40).
- Maximum chlorophyll a approaching 8 ppb and the entire length of the pond is under the algae bloom threshold of 8 ppb (Figure 41).

Run 5b - Point Sources at 40% of actual TP and 25% of actual BOD/TSS with GIPOP at full capacity

- Daily minimum DO criteria (5 ppm) not met for a length of 2 river mile and 2% of pond volume (Figure 39).
- Monthly average DO criteria (6.5 ppm) not met for a length of 4 river miles and 4% pond volume (Figure 40).
- Maximum chlorophyll a approaching 8 ppb and the entire length of the pond is under the algae bloom threshold of 8 ppb (Figure 41).

Run 5c - Point Sources at 40% of actual TP and 50% of actual BOD/TSS with GIPOP at full capacity

- Daily minimum DO criteria (5 ppm) not met for a length of 3 river miles and 4% of pond volume (Figure 39).
- Monthly average DO criteria (6.5 ppm) not met for a length of 3 river miles and 6% pond volume (Figure 40).
- Maximum chlorophyll a approaching 8 ppb and the entire length of the pond is under the algae bloom threshold of 8 ppb (Figure 41).

Run 6a - Point sources at actual levels except TP at 67% of actual levels. Oxygen injection rates of 45000 and 90000 PPD, respectively, at Upper and Lower Narrows.

- Daily minimum DO criteria (5 ppm) not met for a length of 1 river mile and 1% of pond volume.
- Monthly average DO criteria (6.5 ppm) not met for a length of 1 river mile and 1% pond volume.
- Maximum chlorophyll a of 12 ppb and length of 4.5 miles exceeding the algae bloom threshold of 8 ppb (Figure 41).

Run 6b - Point sources at actual levels except TP at 40% of actual levels. Oxygen injection rates of 35000 and 70000 PPD, respectively, at Upper and Lower Narrows.

- Daily minimum DO criteria (5 ppm) not met for a length of 1 river mile and 1% of pond volume.
- Monthly average DO criteria (6.5 ppm) not met for a length of 1 river mile and 1% pond volume.
- Maximum chlorophyll a approaching 8 ppb and the entire length of the pond is under the algae bloom threshold of 8 ppb (Figure 41).

Data taken in the summer of 1999 can be compared to the model predictions of point sources at actual discharge levels (Run 2a). This can be regarded as another calibration check of the water quality model. The model's prediction of DO non-attainment of minimum criteria (11% of the volume of the pond) compares well to the measured DO non-attainment of the 1999 data (10% of pond volume, figure 42). The model's prediction of DO non-attainment of monthly average criteria (20% of the volume of the pond) also compares well to the measured DO non-attainment of the 1999 data (23% of pond volume, figure 43).

## Model Component Analysis of Impacts to Gulf Island Pond

In a modeling component analysis, different potential factors are tested to determine the most significant pollutants that contribute to dissolved oxygen depletion. The component analysis reveals that sediment oxygen demand and point source discharges continue to be the most significant factors affecting dissolved oxygen levels on Gulf Island Pond. Since current point source discharges are also contributing to sediment oxygen demand, point source controls should be an effective strategy for improving the water quality of Gulf Island Pond. GIPOP is an effective mechanism for obtaining compliance with dissolved oxygen criteria in the upper half of the water column near the dam. In the deeper half of the water column, the effectiveness of GIPOP becomes diminished due to the difficulty of transferring the benefits of GIPOP to deeper waters.

This analysis is accomplished by individually subtracting each component of impact, and observing the difference from a base case in the model's prediction of higher dissolved oxygen. Point sources were inputted at actual discharge levels for the base case at 7Q10 river flow. The components of impact that were tested for the modeling of dissolved oxygen on Gulf Island Pond are as follows: sediment oxygen demand, algal photosynthesis and respiration, point source carbonaceous biochemical oxygen demand (CBOD), and non-point and natural CBOD. Although not an impact, the addition of oxygen with GIPOP is also tested by observing the difference in the model's prediction of lower dissolved oxygen without its input. Components of impact are computed at different depths in 10-foot increments and averaged over the river from Lower Narrows to Gulf Island Dam, a distance of about 3 river miles. This length is significant in that most of the DO non-attainment occurs here.

The results of the component analysis are plotted for each individual component both as dissolved oxygen impacts in ppm (Figure 44) and percentage comparisons (Figure 45). The two most significant contributors to dissolved oxygen depletion in Gulf Island Pond are sediment oxygen demand and point source inputs. SOD and point source inputs are responsible for about 60% to 70% and 20% to 40%, respectively, of the DO depletion.

As would be expected, the impact from SOD results in an increasing DO depletion as water depth increases. The DO depletion due to SOD ranges from 1 ppm five feet from the water surface to 6.8 ppm five feet from the bottom (65-foot depth). The DO depletion due to point source CBOD inputs ranges from 0.7 ppm five feet from the water surface to 1.9 ppm five feet from the bottom (65-foot depth).

The contribution of DO due to GIPOP is most efficient at depths of 25 to 45 feet ranging from 2.6 to 3.2 ppm. At a depth of 5 feet the contribution of DO from GIPOP is reduced to 1.1 ppm, probably due to atmospheric losses. At a depth of 65 feet, there is negligible contribution from GIPOP, due to thermal stratification. It is interesting to note that where GIPOP can offset the impact due to SOD, DO criteria are usually met (surface to 35 foot depth), and where it cannot (45 foot depth to bottom), DO criteria are not met.

The relative contribution of pollutant loads entering Gulf Island Pond are compared in pie chart diagrams (Figure 46). In this analysis, point sources were inputted at actual discharge levels. It can be observed that the majority of total suspended solids (TSS) originate from non-point and natural sources (64%), followed by paper mill point sources (35%), and municipal point sources (1%). When considering CBOD loads entering Gulf Island Pond, paper mill point source discharges account for about 83%; non-point and natural inputs account for about 15%, and municipal point source discharges account for about 2%. When considering total phosphorus loads entering the pond, the paper mill point source discharges account for about 77%; municipal point source discharges account for about 13%, and non-point and natural sources account for about 10%.

## Model Sensitivity Analysis

In a model sensitivity analysis, different parameter rates are tested to determine which ones are the most important. A model sensitivity analysis was undertaken on the SOD rate, mill BOD inputs, and GIPOP oxygen injection rates. The results indicate that the SOD rate is the most important parameter, and oxygen injection is second. Mill BOD inputs are less important, but still significant when assessing the impact of oxygen depletion in Gulf Island Pond.

The results of the sensitivity analysis are plotted on graphical representations of Gulf Island Pond (Figures 47 to 49). The change that results in the predicted model DO by reducing the calibrated rate in 50% increments can be observed. The magnitude of the change determines the parameter's sensitivity or importance when making regulatory decisions.

The results indicate that sediment oxygen demand is the most sensitive parameter tested, especially in the deeper reaches where the non-attainment of DO criteria most frequently occurs. At the bottom reach of Lower Narrows (RM 29.5), for example, the model response of predicted DO is as much as 4 ppm for each 50% incremental reduction in SOD.

The model response in predicted DO is less sensitive to mill BOD inputs. The predicted DO change for each 50% reduction of mill BOD was slightly over 1 ppm in the more sensitive model reaches where the DO non-attainment occurs.

Finally, the sensitivity of the model to varying inputs of oxygen injection at GIPOP was tested. The model response to reductions of oxygen injection was in-between that of SOD and mill BOD reductions. (Lower response than SOD but higher response than mill BOD). In the deeper reaches immediately below GIPOP where the DO non-attainment occurs, the model response of predicted DO typically ranged from 1 to 2 ppm for each 50% reduction of oxygen injection.

## Analysis of Hydropower Operation at Gulf Island Dam

An analysis was undertaken to determine whether or not the mode of operation of the hydropower facility at Gulf Island dam is contributing to the low dissolved oxygen of bottom waters in the pond. Through both modeling and an examination of data, it was determined that the hydropower operation is not having a significant impact.

River flow from the hydropower facility at Gulf Island dam is currently controlled in a store and release mode. This means that during the release mode, generation flows or outflow from Gulf Island Pond often exceeds inflow resulting in a lowering of the water level. The storing mode is needed to re-fill the pond while still maintaining an adequate minimum flow to support water quality standards in the Androscoggin River below Gulf Island Pond. In the storing mode, no power generation typically occurs.

A non-generating minimum flow of 1450 cfs (to be exceeded in the storing mode) is proposed for the FERC re-licensing. This minimum flow has recently been maintained from Gulf Island dam, even though it is not yet required. Another issue that is examined is whether or not operating the hydropower project in a store and release mode rather than run of river mode is negatively impacting the pond's dissolved oxygen levels during the storing period. There are two possibilities that should be examined.

1. Does the cycling of river flow result in a hydraulic isolation of bottom waters of the pond?
2. Is the dissolved oxygen impacted due to factors such as increased river time of travel through the pond?

To answer the first question, plots of inflow, outflow, and the monitored dissolved oxygen at the dam were compared at the deeper pond areas (35 and 50 foot depth). There did not appear to be any consistent pattern of lower DO during extended periods of minimum flow. At times, the DO decreased, but at other times it increased. Since the expected response would be a consistent decrease of DO during extended minimum flow periods, the conclusion reached was that minimum flow releases of 1450 cfs did not appear to affect dissolved oxygen of bottom waters.

A model run was made to help answer the second question. A run was made assuming 5.5 hours of generation outflow of 3300 cfs and a minimum flow release of 1450 cfs for up to three days. This operation appears to be consistent with how the hydropower plant is operated during low flow periods. A difference in DO of only 0.1 ppm lower was predicted by the model as compared to a base case in which a steady state flow of 1700 cfs is maintained. It is concluded that since the minimum flow is already similar to 7Q10 flow (1700 cfs), the impact from dissolved oxygen due to the cycling of flow is negligible.

## Analysis of GIPOP Operation

The summer requirement (since 1992) for a single oxygen injection rate of 73000 lb/day at GIPOP was recently re-evaluated to allow more flexibility. The new operational plan was started in the summer of 1999. Less oxygen is injected at times when it isn't needed and more injected when it is needed. This results in an earlier startup date; an earlier shutdown date; a lower injection rate during periods of higher river flow; and a higher injection rate during periods of higher water temperature. The revised operational plan for GIPOP allows for a greater operational efficiency, and appears to be working, except DO non-attainment continues to occur at low flow conditions. It should be recognized that DO non-attainment at low flow conditions might not be entirely fixable by management regimes utilizing a single oxygen injection point.

The requirement for the quantity of oxygen injected at GIPOP has historically been connected to the modeling undertaken in 1985. A rate of 73000 lb/day has been injected at Upper Narrows, five miles upstream from the dam starting July 1 and ending September 30. The injection system has an efficiency of about 37% resulting in about 27000 lb/day oxygen being transferred to the water column. In 1998, this requirement was re-evaluated. There is recognition by DEP and the GIPOP cooperative that there may be situations (i.e., higher flow, lower temperature) when less oxygen injection could be acceptable, and other situations (higher temperature) when more oxygen injection is needed. The following revised operational plan was agreed upon by DEP and the GIPOP cooperative and became effective starting the summer of 1999.

**Table 14 – Revised GIPOP Operational Plan – Effective June 1999**

Begin GIPOP operation when the 3-day average temperature[(1)] at Turner Bridge is greater than 18 $^{o}$C in June.

| Oxygen Injection Thresholds | % Normal Capacity | Oxygen Injection (ppd) |
|---|---|---|
| Q[(2)] > 3500 cfs | Idle | 8000 |
| T < 24 $^{o}$C & $3000 < Q \le 3500$ | 50% | 36500 |
| T < 24 $^{o}$C & $2500 < Q \le 3000$ | 75% | 54750 |
| T < 24 $^{o}$C & $Q \le 2500$ | 100% | 73000 |
| $T \ge 24$ $^{o}$C & $Q \le 3500$ | 125% | 91000 |

End GIPOP operation when the 3-day average temperature at Turner Bridge is less than 21 $^{o}$C in September.

Footnotes

(1) All temperature measurements shall be obtained from the continuous temperature monitor at Turner Bridge and shall be expressed as a 3-day rolling average. The 3-

day rolling average is defined as the arithmetic mean of the daily maximum and minimum temperatures over any given consecutive three-day period.

(2) All flow measurements shall be obtained from the USGS gage at Rumford and shall be expressed as a consecutive 3-day rolling average of daily average flow values.

The revised operational plan results in both an earlier startup and also an earlier shutdown of GIPOP by two to three weeks. The earlier startup is needed to improve late June and early July DO. After the first to second week in September, the pond is typically mixed and water temperature is cooler, so that the oxygen from GIPOP is not needed. The data taken at the dam continuous monitor has shown that the most severe DO non-attainment typically occurs when water temperature exceeds 24 $^{o}$C. Periods of higher water temperature are also more likely to result in pond chemical stratification, which results in low DO in the deeper waters.

The relaxation of injection requirements at higher river flows is being tried on an experimental basis. The data at the dam monitor is being used to determine whether or not the lower injection rates are adequate. DO readings at the monitor indicate that class C criteria can be met down to a depth of 35 feet but at a depth of 50 feet some non-attainment is still experienced. The modeling indicates that the effectiveness of the current oxygen injection system becomes greatly diminished at depths of greater than 45 feet. Hence the relaxation of injection requirements at higher flows does not appear to be the cause of this non-attainment. The non-attainment of DO in the deeper areas of the pond will be addressed in the TMDL.

# Appendix
# Graphical Representations of 1999 DO Non-Attainment

# Hydropower Inflow / Outflow Plots Compared to Dissolved Oxygen