Characterization of the Dissolved Oxygen Environment of the Lower Savannah River Estuary

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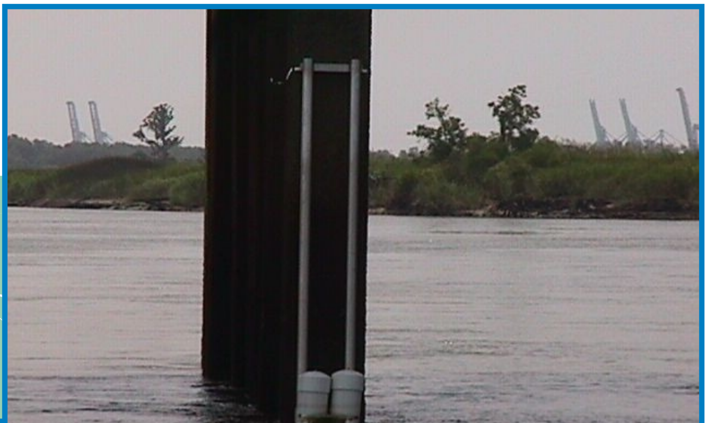

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1.0 INTRODUCTION

In support of an Environmental Impact Statement (EIS) for a proposed harbor expansion project, an extensive hydrographic and water chemistry data set was collected in the Savannah Estuary. The primary intended uses of the data set are to characterize the present conditions in the estuary and to calibrate a complex hydrodynamic and water quality modeling system. The field monitoring program and the hydrodynamic and salinity model calibration have been reported in detail in *Hydrodynamic and Water Quality Monitoring of the Lower Savannah River Estuary, August 2 through October 9, 1999* (ATM, October 5, 2000) and *Hydrodynamic and Salinity Model Approval Package* (ATM, August 2, 2002), respectively.

This report is a description, analysis and characterization of the dissolved oxygen (DO) environment as described in the data set found in the data report. The data report includes numerous figures and tables describing the study and summarizing the study results. Some of these tables and figures are repeated here for consistency and flow of the text, though additional information may be found in the original report. As such, this report may be considered an appendix to the main data report. The focus of this analysis and characterization, however, is to understand the DO environment in the Lower Savannah River in the context of the water quality model application. The goal of this study is to identify and understand the relevant processes and their interrelationships, with a focus on what the implications are for modeling of the processed affecting DO in the Harbor.

In the following report, a number of the sections correspond to components of the original 1999 field study. Elements of that study that do not relate directly to water quality issues and the planned water quality modeling effort, such as the chloride and bromide data, are not considered. Some of these data provide important underlying support for the modeling work, but will not generally be examined in detail during the model development unless model results suggest conditions that might be explained by reference to these data. The focus here is on the dissolved oxygen data and the measured conditions that contribute to changes in water column DO.

In a typical estuarine water body, instream dissolved oxygen has the potential to be affected by a variety of factors including:

- Instream concentration of oxygen demanding material;
- Primary productivity;
- Oxygen demand through the benthos; and
- Physical characteristics of the system, including currents and wind (through reaeration and mixing) salinity intrusion (stratification), and the degree of freshwater inflow (salinity effects on saturation).

This report first presents the measured DO conditions in the system and discusses the spatial and temporal variations measured. Within the DO presentation and the sections following, the factors listed previously are isolated and discussed in relation to the measured instream DO. The goal is to provide the basis for the development of the water quality model through as complete an understanding as possible of the key processes in the system from the measured data.

The report is structured into the following sections. Section 2 presents the measured continuous instream DO data. Section 3 examines the effects of primary productivity in the system through evaluation of chlorophyll a and light data. Section 4 quantifies the instream concentrations of biochemical oxygen demand (BOD). Sections 5, 6, 7, and 8 present special studies that evaluated the following:

- Section 5 examines the characteristics of the marshes throughout the system and their potential as a source or sink of nutrients, biochemical oxygen demand, and dissolved oxygen.
- Sections 6 and 7 present discussions of the temporal and spatial dissolved oxygen characteristics in the system based upon special snapshot study events.
- Section 8 presents sediment oxygen demand (SOD) measurements taken by other agencies including the U.S. Environmental Protection Agency (EPA) and Georgia Environmental Protection Division (GAEPD) as well as quantification of the potential for benthic flux of ammonium.

In general it is appropriate to first consider those parameters which impact DO before examining their affect on DO. In this report the measured dissolved oxygen is presented first to provide some knowledge of its temporal and spatial variations prior to examination of the in stream chemistry and other factors. Anthropogenic loadings of oxygen demanding material are presented under a separate loading analysis that will be presented and discussed independently from this report. This report simply discusses the measured instream concentrations that may have resulted from these loadings.

2.0 INSTREAM DISSOLVED OXYGEN

The primary data set for quantifying dissolved oxygen in the river consists of continuous monitoring records from 29 YSI data sondes deployed at 21 stations between the mouth of the Savannah River and the freshwater reach at river mile 43. Locations of these monitoring stations, with the deployment types and station names, are shown in Figures 2-1a and 2-1b. Eight of the stations, those in the navigation channel on the Front River, each consist of two sondes, placed about 1 meter above the bottom and 1 meter below the surface of the water. At other stations, sondes are placed near the bottom, below the surface, or at mid-water depth, depending on location and conditions. This is discussed in more detail in Section 5 of the 1999 data report, which should be referred to for relevant details.

Table 2-1 shows the deployment schedule for the instruments together with timing for the other studies undertaken, giving both dates and Julian days. This should help coordinate the various sampling events in this study with the events in the continuous data record.

The DO record at each station is a unique signal that is the result of a variety of conditions that occur over a range of time scales. These conditions include the location of the station and the sensor depth, as well as conditions at some distance from the station that are within the range of tidal excursions. In addition, short-term and long-term tide range differences, changes in the local current regime, solar and meteorological influences, and the history and condition of the instrument deployment may all have varying levels of influence on the resulting DO concentrations recorded.

2.1 ANALYSIS OF DISSOLVED OXYGEN TIME SERIES DATA

To help provide additional insight into the sources of DO changes along the river, the hydrodynamic model was used to estimate the tidal excursion at each station. Sources were introduced into the model at a station in the surface or bottom layer, and the model was run for two tidal cycles during a period of mean tidal range. The resulting distribution of effluent from the source was then examined and the upstream and downstream extent of the effluent over the first full tidal cycle was characterized and plotted. This was repeated for each station at the surface and at the bottom. The result is a series of bar plots (Figures 2-2a through 2-2f), showing the extent of tidal excursion at each station relative to river mile and adjacent stations.

Figures 2-3 through 2-31 present separate figures for the DO data recovered from each of the sondes, together with salinity and temperature data records. Figure 2-3 shows the DO data recovered from the sensor at GPA-26B, near the bottom at the mouth of the river. This record is only about 60 percent complete, but there are many telling features in this figure about the levels and variations in DO concentrations here. This figure also includes temperature and salinity data from the sensor. The rise and fall in salinity is a clear indicator of the rise and fall of the tide as high-salinity seawater from offshore enters the estuary on the rising tide and mixes with the freshwater coming down from upstream. Over much of the record, there is a strong correlation of DO concentration to salinity. The ocean waters seaward of this site are better oxygenated than the river waters coming out from the lower estuary, so that as the tide floods and ebbs, there is this pattern of increasing and decreasing dissolved oxygen. This pattern is striking in its tidal component, and there is no discernable diurnal component to the signal such as would be expected in a system in which primary productivity plays a major role in controlling DO concentrations. Of course, any such effect would be more in evidence at the surface than at a bottom sensor. This does not preclude the presence of some small diurnal component, as surely some effects from primary productivity can be expected here. There could be a diurnal meteorological effect, but it is too small to be teased out of the overwhelming tidal signal in a visual examination of the data. The daily range of DO varies considerably from less than 1 to more than 3 mg-O_2/L. This reflects changes in the concentrations in the source waters that are transported through this region over a tidal cycle, as well as changes in the tidal excursion (the extent of travel of a water parcel between consecutive low and high tides) and differences in tidally generated mixing between spring and neap tide cycles, i.e., the degree of stratification.

Data from the surface sensor at this station, GPA-26S, is shown in Figure 2-4. The record is about 40 percent complete and does not overlap with the bottom sensor in many places. However, it is apparent from this data that the DO concentrations here increase and decrease with salinity much the same as at the bottom. No clear diurnal effect can be detected visually.

Moving up the river to GPA-02, shown in Figures 2-6 and 2-7, there was virtually no data from the bottom sensor, due to a number of issues, but the surface sensor has the same strong positive correlation of DO to salinity that is evident further seaward.

At these two lower river stations, there is a fairly clear pattern of DO increasing and falling with salinity, an indication that the ocean is a major source of higher DO to the lower estuary. Moving further upstream and into other branches of the river, the pattern shifts, and areas are encountered in which patterns are not as clear. Moving up the Front River to Station GPA-04 (Fort Jackson; Figures 2-11 and 2-12), DO changes with the tides at the bottom sensor are quite small compared to those at GPA-02 and GPA-26, but these changes still are clearly positively correlated to salinity changes. This might indicate that the areas of low dissolved oxygen extend upstream and downstream of GPA-04 a sufficient distance that the tidal excursions brings similar water past the sensor through each tidal cycle. At the surface, there are periods of much larger DO changes than are seen at the bottom, but there are also long periods in the record here when DO changes are smaller, and it is difficult to provide a simple characterization of the patterns.

At GPA-21 (Corps Depot; Figures 2-13 and 2-14), the pattern at the bottom is much the same as at GPA-04B, with small DO changes correlating to changes in salinity. At the surface, however, a new pattern emerges. This may be a transitional zone between what is seen downstream and the pattern that we will see upstream. In many parts of this record, the DO pattern appears more nearly diurnal than semidiurnal, driven, presumably, by the inequality in the two daily tide curves. No overall pattern of correlation of DO changes to salinity changes is clearly evident. GPA-06 (Figures 2-16 and 2-17) is also in the transitional zone between upstream and downstream patterns. At the bottom, at times, salinity and DO appear positively correlated (e.g., Days 230-236 and 257-268), and at other times negatively correlated (e.g., Days 254-256 and 270-274), with periods separating these times in which no correlation is visually apparent. For most of the record, tidal DO changes remain relatively small, as seen at GPA-21B and GPA-04B. At the surface, when a clear pattern can be discerned, the correlation is negative: DO falls as salinity rises. But much of this record resembles what is seen at GPA-21S, in which no clear pattern is evident.

The record at GPA-22 (Figures 2-18 and 2-19) represents a clear change from the downstream stations. Here, large regular changes in DO with changes in salinity, i.e., the tides are apparent, but the correlation is clearly and persistently negative. The changes in DO are much more regular at the bottom than at the surface, corresponding closely to the greater regularity in salinity changes near the bottom. At this station, it is the freshwater upstream waters that have become the important source of increased DO. Further upstream, at GPA-08 (Figures 2-21 and 2-22) and GPA-09 (Figures 2-23 and 2-24), this pattern remains the same. This indicates that at these stations the tidal excursion is sufficient to bring the areas of high DO gradient change (i.e., from upstream freshwater) across the sensors. The biggest tidal ranges of DO appear now to be found at the bottom, and this range is greatest at GPA-08B, which appears to be sampling the greatest range of salinity and DO gradients. During the neap tide period around Day 232, the tidal salinity range extends from 1 to nearly 20 parts per thousand, and the corresponding DO range extends over more than 4 mg/L during a single tidal cycle. At GPA-11RB (Figure 2-27), the negative DO/salinity pattern persists and is very clear. The water here is nearly fresh much of the time. The largest drops in DO occur during the largest salinity intrusions, seen during the major neap tide periods. At other times, the tidal DO range is reduced, and the mean overall DO level is increased. Traveling further upstream to stations GPA-14B (Figure 2-29), GPA-16M (Figure 2-30), and GPA-17M (Figure 2-31), the water is consistently fresh and the DO levels become almost uniform, with only a small remnant semidiurnal cycle at GPA-14B, suggesting a small impact from downstream and sometimes a small diurnal cycle at the stations further upstream due to uncertain causes. The limited available chlorophyll data indicate very low concentrations, but the small diurnal pulses may indicate daily primary production.

Patterns on the other stems and tributaries reflect some of the patterns already observed along with other local factors not already considered. At GPA-03B (Figure 2-5) in the South Channel, and at GPA-25M (Figure 2-8), GPA-24M (Figure 2-9), and GPA-23M (Figure 2-10) in the cuts or tributary mouths in the lower river, the DO patterns are not easily characterized, presumably due to the complex interactions of the various sources that comprise them. At GPA-05B (Figure 2-15), above the tide gate on the Back River, the DO/salinity correlation appears clearly negative, unlike GPA-21 and GPA-06, which bracket it (in distance from the river mouth) on the Front River. Above here, at GPA-07S (Figure 2-20) on the Little Back River, the relationship of DO changes to salinity changes appears to vary over time between positive, negative and no observable relationship is evident. Further upstream, at GPA 15S (Figure 2-26) (at the Houlihan Bridge), DO changes seem to be positively correlated to salinity changes, when there is salt present at this predominantly freshwater station. Note that this is quite different from what is seen at the Houlihan Bridge in the Front River, at GPA-09, where the correlation is clearly negative. At GPA-10S (Figure 2-25) on the Middle River at Houlihan Bridge, and further upstream at GPA-12RS (Figure 2-28), the correlation is negative when there is a clear pattern, but frequently the pattern is not clear.

The overall pattern of the harbor area appears to be a DO sink with increased DO concentrations in freshwaters upstream and in the saline waters seaward. As the tides carry water back and forth across each sensor, in a sense, a record of the conditions is created along the length of the tidal excursion above and below that station. Because the tidal excursion varies considerably with tidal conditions - the transition between neap and spring tides - the patterns of tidally driven DO change vary over the month. This tidally-driven component, of course, is only a part of the complex processes generating the patterns of DO seen in the Savannah River estuary.

2.2 24-HOUR AVERAGED DO DATA ANALYSES AND LONGITUDINAL VALUES

Figures 2-32 through 2-52 show the same DO data reviewed above, but with the values reprocessed with a 24.84-hour moving average. The chosen period corresponds to two cycles of the M2 tide, the major tidal harmonic driving the tides here. Two cycles were chosen because there is frequently a tidal inequality, due to other harmonics, that is manifested as major and minor high and low tides each day. As a result of the averaging, much of the day-to-day tidal component of the DO signal is removed and it is easier to characterize the mean DO conditions that are experienced at a particular station and different stations are more easily compared. Each of these plots also shows the saturation DO concentration at each sensor calculated from its salinity and temperature data. The difference between the saturation value and the measured DO value at each point reflects oxygen used up by water column and sediment processes since the water was fully reaerated, or what could be called a DO “deficit.”

Differences in the fully saturated levels at any given point in time are primarily driven by salinity as would be expected. Thus, at the eight Front River stations at which there are surface and bottom stations, surface saturation is always greater than or equal to bottom saturation. Also, there is a general trend of increasing saturation values from the more saline stations near the mouth to the freshwater reaches upstream. In addition, in every case, there is a general trend of increasing saturation concentration over the 2 months of the deployments. This pattern reflects the effect of falling water temperatures during the study.

At Station GPA-26, shown in Figure 2-32, there is almost no data overlap between the two sensors. At GPA-02 (Figure 2-33), there is no data overlap between surface and bottom records and just a short period of overlap of the surface sensor record with bottom data from GPA-26. For these stations, circumstances and the QA/QC process have eliminated most of the data. It is interesting to note that mean DO at the surface at GPA-02 is lower than it is at the bottom downstream at GPA-26. This is a strong indication of the pattern already described, suggesting a greater proportion of more oxygenated and more saline ocean water coming into the lower estuary from offshore near the bottom, and the fresher, more DO-depleted water from the upper harbor coming down from upstream.

At GPA-04 (Figure 2-34), bottom DO concentrations are normally less than or equal to surface values. Where data overlaps exist, DO is lower here than at both of the stations further downstream. At GPA-21 (Figure 2-35), surface DO is higher than at the bottom in the small overlapping periods. The brief periods of concurrent data with GPA-04 suggest very similar DO levels at these two stations. At GPA-06 (Figure 2-36) and at the three other stations further upstream in the harbor channel (GPA-08, GPA-22) fairly consistently higher DO exist at the surface than at the bottom. This indicates the influence of stratification increasing moving upstream into the upper harbor area and the bottom deficit due to stratification overwhelming the influx of the higher DO bottom waters near the mouth.

DO concentrations at GPA-06 are quite similar to those seen at GPA-21 and GPA-04. This is the region of transition that was noted in the patterns of DO and salinity correlations seen in the raw data, so the similar DO values along this stretch of the Front River are not unexpected. Traveling further upstream to GPA-22 (Figure 2-37), there is a marked increase in mean surface DO values and small increases at the bottom. At

GPA-08 (Figure 2-38), surface values are similar but bottom values are higher than seen at GPA-22. Values continue to rise at the surface (much less so at the bottom) at GPA-09 (Figure 2-39), and continue to rise further upstream at GPA-11, GPA-14, and GPA-16, but not at GPA-17 (Figures 2-40 through 2-43).

The overall spatial pattern of mean DO is largely consistent with the patterns of changing DO seen in the raw data at each station, with tidal transport moving the higher and lower values seen upstream or downstream past each sensor. Regions with large changes in the mean DO from one station to the next are where the sensors with the largest tidal swings in DO are located, and the image of low DO in the harbor area with higher values coming in from the offshore and upstream areas is reinforced.

The details of the records at GPA-03, GPA-23, GPA-24, and GPA-25, the stations in the South Channel and cuts of the lower river will not be discussed in this report, but they are presented here in Figures 2-44 through 2-47.

Traveling up the Back and Little Back Rivers, mean DO levels rise from GPA-04 to GPA-05, continue to rise at GPA-07, but then fall somewhat at GPA-15 (Figures 2-48 through 2-50). Along the Middle River, levels rise from GPA-10 to GPA-12 (Figures 2-51 and 2-52), and on up to GPA-14 on the main stem of the river. These are not unexpected results from what has already been observed in the raw data for these stations, but the complex flows in this part of the river system have a strong influence on the dissolved oxygen conditions.

In order to try and summarize the longitudinal characteristics of the system along the main area of interest, the Front River, the full data sets were analyzed and the 10th, 50th, and 90th percentile values of the dissolved oxygen were calculated for each of the deployment locations. Figure 2-54 presents a longitudinal plot of the 10th, 50th, and 90th percentiles for each of the stations. Where surface and bottom sondes were present both are presented on the plot. This plot identifies many of the key features of the dissolved oxygen characteristics of the system on an average basis for the critical summer months. The most evident characteristic is the location of the dissolved oxygen sag in the bottom waters as well as the surface waters. Mean dissolved oxygen conditions in the bottom waters show their lowest levels between mile 15 and 20. With

50th percentile values as low as 3.2 mg/L and 90th percentile values as low as 2.0 mg/L. The dissolved oxygen sag is further upstream for the bottom waters as would be expected, the sag in the surface waters is located between mile 10 and 15. The dissolved oxygen conditions rise rapidly between river mile 20 and 25 and are above 6.0 mg/L in the upstream freshwater portions. Another key feature is the higher bottom water dissolved oxygen seen at the mouth of the river as the fresher low DO waters coming from the upper Harbor flow over the higher DO offshore waters moving in along the bottom.

2.3 EFFECTS OF NEAP/SPRING TIDE STRATIFICATION ON DO CONDITIONS

Another critical feature of the Savannah River Estuary is the stratification and destratification cycle that occurs from neap to spring tides. This has a dramatic effect on the gradient of surface to bottom water salinities which in turn affects the degree of reaeration from the surface waters to the bottom waters. This creates a situation where the dissolved oxygen in the surface and bottom waters stratify. Figure 2-55 presents a plot showing the surface and bottom dissolved oxygen at GPA-06 through a spring-neap cycle. The degree of DO stratification goes from near zero up to near 3.0 mg/L and then back down below 1.0 mg/L.

2.4 DISCUSSION OF DO DATA SPIKES

Returning to the original raw data plots, in Figure 2-3, there is another feature of the DO record that requires some examination and explanation: sharp negative spikes in the DO concentration. Some of these are evident in the short record from Days 232 to 235, and even more so in the period from Days 244 to 250. Many more of these are evident in records from other sensors. These spikes are quite sharp, no wider than the line of points used to display the data, implying a very rapid change in DO. They are largely restricted to the periods of slack tide, whether high or low. It is proposed that these “slack tide spikes” are artifacts of the instrument deployments and should be largely ignored in any attempt to understand the DO dynamics of the estuary.

To better illustrate this feature, short records from the surface and bottom sensors at station GPA-04 have been expanded and are shown in Figures 2-53a and 2-53b. This shows how, even at this expanded scale, the spikes are quite short-lived, but not instantaneous. They correspond very closely in time to the maximum and minimum salinity peaks, presumably the period of slack tide currents.

As soon as a data sonde is put in the water, the surfaces become settling substrate for plants and sessile animals. The extent to which this becomes a problem varies considerably with temperature, season, and salinity range. These organisms respire, consuming oxygen, and under appropriate conditions this activity can be reflected in the response of the DO sensor. During normal ebb or flood tide, water currents rapidly flush the sensor field of the sonde and minimize any effects from the fouling organisms. But when the currents cease, it then becomes possible for the localized effects to become apparent.

The slack tide spikes observed at GPA-26, or something like them, were observed at many stations, and it may be useful to review the extent of their occurrence. It should not be assumed that the cause of these data spikes is clearly understood, or that there is a unique explanation for their occurrence. The explanation offered here is tentative, and other observations regarding conditions of deployment, instrument servicing and data processing, among other things, could alter the proposed explanation.

3.0 PRIMARY PRODUCTIVITY

A critical feature of the overall DO records that were presented in Section 2.0 is the apparent lack of any truly diurnal element to the variations in DO such as would be expected where primary productivity was an important local contributor to the DO dynamics. True, there are places in which there are patterns of DO change that occur on a nearly daily basis, due most likely to the tidal inequality in which alternating tides are larger and smaller. The DO signal appears to be very sensitive to these inequalities in some places, e.g., GPA-03 and GPA-21S. But it does appear to be the tides that are driving the DO changes at any fixed station on a daily basis. These observations are based on a visual examination of the data and do not exclude the likelihood, as already discussed, that primary productivity and other factors such as meteorology may contribute small diurnal changes to the DO. It also appears that there may be very small true diurnal variations at the two stations furthest upstream, GPA-16 and GPA-17.

In earlier studies, chlorophyll concentrations were found to be routinely quite low in the lower Savannah River. For example, in three surveys in the 1997 monitoring study (Hydrodynamic and Water Quality Monitoring of the Lower Savannah River Estuary, July to September 1997, ATM, May 1998) concentrations very rarely were measured to exceed 1 µg/L. In developing the protocols for the present study, the review and evaluation process concluded that primary productivity could be excluded as an important factor in the DO balance in the lower river. Chlorophyll measurements were made in the 1999 study to justify this decision, but only a minimal set was collected.

Three sets of chlorophyll a data were collected. During the Week 1 water chemistry sampling (August 4-8, Days 216-220), all samples were analyzed for chlorophyll in addition to nutrients and BOD. Samples were once again collected on both September 22 and 23 (Days 265 and 266), for chlorophyll analysis only, along with the in situ measurement of Secchi disk depth.

The results of the chlorophyll analyses for the Week 1 water chemistry sampling are shown in Figure 3-1. These data were presented in the data tables in Appendix J of the data report, but were not otherwise shown in the report. The values shown here are remarkably high for a system in which primary productivity is assumed to be insignificant. But on closer examination, some important features of the data set emerge. Overwhelmingly, values are higher at high tide than at low tide, and values are higher at the bottom than at the surface. There are only a few exceptions, and for these, the comparative values are close together. Broadly speaking, there is an overall trend of decreasing values in an upstream direction. The high concentrations of chlorophyll at the bottom stations in deep water clearly could not have grown there, there simply is not enough light. It would appear that there is a source of moderate chlorophyll concentrations at the mouth of the river that is imported to the river on the rising tide. Seawater has been shown to enter the river flows below the fresher surface waters. Some of the imported chlorophyll will mix up into the surface layer, but much of it dies and settles out, because it cannot grow in the light-limiting waters of the Savannah River.

It appears that the Week 1 chlorophyll analyses were performed without any correction. Normally, when chlorophyll is analyzed, after measuring the overall chlorophyll concentration, the sample is modified to make a second measurement that allows the evaluation of the phaeopigments or dead component of the chlorophyll. Without this correction, it cannot be determined how much of the “chlorophyll” in these samples is live material and how much is detritus. It is very likely that much or all of the high concentrations of chlorophyll measured in the bottom samples in the Week 1 data are detrital and represent material that is accumulating near the bottom as it settles out. This also means that there is no reliable measure of chlorophyll in the surface layer either, but some unknown portion of it can be assumed to be living material and the rest of it is detritus. The data is useful, however, it does provide a measure of how much of the water column particulate matter is due to phytoplankton, living or dead, and this may be a significant component of the particulate BOD.

The results of the second and third chlorophyll sample surveys are summarized, in part, in Figure 3-2. These plots only show data from the Front River, but give a good sense of chlorophyll distribution along the river. Methodology for these analyses called for a phaeopigment correction, and so it can be assumed that these results represent living phytoplankton. On both of these days, there is a pattern of moderate chlorophyll concentrations at the seaward end, falling off to low concentrations, around 2 µg/L, by river mile 14 (Corps Depot, station GPA-21), and very low concentrations, around

1 µg/L, by river mile 20 (near the head of the channel, GPA-08). There is little evidence of stratification, although the value at river mile 4.5 (GPA-02) is highest at the deepest sample on both days. This is consistent with the ocean as source of high chlorophyll concentrations and salinity stratification at this station.

Overall, these datasets from the second and third sample surveys support the notion that primary productivity is likely to be of very limited consequence in most of the Savannah River estuary. This is consistent with a light-limited system resulting from high water turbidity, Secchi depths being of the order of only 1 meter. Because light does appear to be the principal growth-limiting factor, the potential contribution of excess nutrient additions to the system, or eutrophication, does not need to be considered. This does not exclude the possibility that there could be contributions to nutrient-related problems offshore of the Savannah River, but that is not the issue being discussed. No analysis of nutrient concentrations in the Savannah River, as they relate to eutrophication, will be presented.

4.0 BIOCHEMICAL OXYGEN DEMAND

Oxygen consuming substances in the water column are typically characterized as biochemical oxygen demand, or BOD. Normally it consists of two major components, carbonaceous, or CBOD, due to the oxidation of carbon compounds, and nitrogenous, or NBOD, due to the oxidation of the nitrogen in organic nitrogen and ammonium. The standard approach to quantifying BOD is a five-day assay or BOD5, which quantifies the amount of oxidation that occurs under standard conditions in the first five days after the sample is collected. A variation on this analysis is the CBOD5 analysis, in which a nitrification inhibitor (nitrification is the oxidation of ammonium to nitrite and nitrate) is added at the start of the analysis. The resulting five-day oxidation is presumed to be due exclusively to carbonaceous materials (and, by implication, the difference between BOD5 and CBOD5 is taken to be NBOD). An alternative approach, when time and budget allow, is to perform a long-term BOD analysis, or LTBOD. Oxygen consumption in a water sample is measured over the period of several months, until it approaches an asymptote, and at the same time, the increase in nitrite plus nitrate is measured. The asymptote values for oxygen uptake and nitrate production are calculated and are a direct measure of total, or ultimate, BOD (UBOD) and NBOD, with the difference being CBOD.

As part of the water chemistry sampling program, samples were collected at each of the 32 instrument locations of the continuous instream water quality monitoring program – 24 stations with surface and bottom instruments at eight of them. Station locations are shown in Figures 4-1a and 4-1b. Samples were collected at each station at high slack and at low slack tide. An additional single sample was collected at the gauging station at Clyo. This sample set was collected once per week for seven weeks over the period August 4 to October 9, 1999. Among other parameters, analyses included BOD5, CBOD5, ammonium and total Kjeldahl nitrogen (TKN; ammonium plus organic nitrogen).

In a separate sampling program, samples were collected for LTBOD analysis during Weeks 2, 4, and 6 of the weekly water chemistry sampling program. Samples were collected at low slack and high slack tides from six sites in the lower river and were also collected at the Clyo site. Sample locations for this sampling program are shown in Figure 4-2. The LTBOD analyses were performed to provide a more detailed characterization of the BOD in the river and to help in setting up the water quality model for calibration. The analysis of the LTBOD samples provides a better measure of both total CBOD and NBOD, it allows proper quantification of K_d and K_n, the rates at which the oxidations of carbon and nitrogenous materials occur, and it provides factors by which to quantify total BOD (UBOD) given BOD5.

4.1 BOD5 AND CBOD5 MEASUREMENTS

Summaries of the BOD5 and CBOD5 analyses are given in Figures 4-3 and 4-4. The overall mean BOD5 value for all samples is 1.50 mg-O_2/L, and the mean CBOD5 value is 1.05 mg/L. This gives a difference of 0.45 mg/L, which is assumed to be attributable to NBOD. LTBOD results are presented in Figures 4-5 through 4-11. These show representations of the total DO consumption and the DO consumption attributable to nitrate production over time. A review of these figures strongly suggests that during the first five days of these analyses, very little nitrate production occurs, and that 0.45 mg-O_2/L of NBOD over this period is an overestimate. In fact, for the LTBOD samples for which an NBOD sample was taken on the fifth day of the analysis, the measured value averaged about 0.07 mg-O_2/L associated with nitrification. There is an issue here of which is the more credible result. The use of a nitrification inhibitor in the CBOD5 analyses is a standard method and is widely used, but additional research into the use of the effects of this poison is needed to see whether it might have unintended side effects on the CBOD measurements. Unless facts can be demonstrated to the contrary, this study will continue to use the CBOD5 data (with corrections calculated from the LTBOD data to calculate UCBOD) as acceptable in the modeling analysis.

BOD5 distributions in the river during the seven weeks of the water chemistry sampling program are shown in Figures 4-12 through 4-18, one representing each week's samples. High and low tide samples are represented separately, and each sample is represented on the horizontal axis by its distance from the river mouth. The Front River stations data is separated out from the stations off of the Front River. Overall, values are mostly in the range of 0 to 2 mg/L, with occasional higher values. During Weeks 1 and 6 there is a greater frequency of these higher values. For the final data set, the distribution is totally different (see also Figure 4-3), and it may be necessary to set aside the final data, as it was collected 1 month after the Week 6 data. Because of the timing, there is a real possibility that these differences are accurate, but it is difficult to be comfortable with such a large change in BOD between Weeks 1 through 6 and the final collection. The differences are so large, though, that the model calibration process should readily reveal whether or not these differences are realistic.

Viewed in this way, week by week, it is difficult to see clear patterns in BOD5 along the length of the river. Where in some cases a “pattern” may be evident (e.g., higher BOD in certain reaches at one tide or the other), this pattern does not carry through to the other weeks or to the data for the other slack tide in a way that is consistent with the ebb and flow of the tides. It is important to note that the measured BOD5 data are very close to the method detection limit, i.e. very low values; therefore, it is hard to know how much of the differences might be noise and how much is real.

These differences may accurately reflect week-to-week differences in the distribution of BOD along the river as the loads from the various sources change. However, to see what the mean condition would look like, average values over the first 6 weeks for each sample location and time were calculated and have been plotted in Figure 4-19. These results suggest that, on the average, there is higher BOD in the bottom water than at the surface, there is higher BOD in the lower part of the estuary at high tide than at low tide, and, traveling in a downstream direction, there seems to be an increase in BOD concentrations from about river mile 22 to river mile 15, an increase which may be shifted somewhat seaward between high tide and low tide. Below river mile 15, the trend in BOD concentration varies between surface and bottom and between high tide and low tide.

4.2 AMMONIUM AND TKN MEASUREMENTS

A summary of ammonium concentrations from the 7-week sampling program is given as scatter plots and a cumulative distribution in Figure 4-20, and as weekly data in Figures 4-21 through 4-27. Ammonium concentrations are plotted against river mile. Results show a considerable week-to-week variation in ammonium concentrations along the estuary, with values rarely exceeding 0.06 mg NH4-N/L during three of the weeks, whereas on two of the other weeks, values near or exceeding 0.1 mg/L were common. For several of the weeks, the data are strongly suggestive of a large ammonium source in the region of river mile 20. Concentrations generally rise suddenly between river miles 25 and 20 and then slowly fall as the ammonium is consumed or diluted as it is carried to the river mouth. This pattern is much more evident during the weeks when the higher levels of ammonium were measured. On these occasions, at the point where the ammonium increases, the added loads result in significant river concentrations of 0.05 to 0.15 mg-N/L. Data from Weeks 3, 4 and 5 either do not show this pattern or show it only indistinctly. It is tempting to try to relate these changes to known loads, however, the model will provide a better tool for calculating mass balance and scaling loads to concentrations in the water column. Distribution during Week 7 is also quite different. This data set is subject to the same qualifications as the Week 7 BOD5 data: samples were collected 1 month after the Week 6 samples. It will prove interesting to see, during the modeling process, whether this alternate distribution of ammonium is consistent with loading during this period.

The mean ammonium results, averaged by sampling location and tide, for the first 6 weeks of the sampling program, are shown in Figure 4-28. This reinforces the impression of ammonium sources, which may extend downstream to about river mile 15. The difference between high tide and low tide distributions leaves this point unclear in a visual examination of the data. Clearly, these sources are within the river, as concentrations below about river mile 10 are routinely higher at low tide than at high tide.

Ammonium is the immediate source of NBOD and ammonium levels probably reflect the short-term NBOD that might be measured at any given point. However, total NBOD is more accurately measured as total Kjeldahl nitrogen, or TKN, which quantifies the sum of ammonium and organic nitrogen. TKN data for the 7 weeks of the sampling program are shown as scatter plots and a cumulative distribution in Figures 4-29 and as weekly data in Figures 4-30 through 4-36. Values vary mostly around the range of 0.2 to 0.6 mg TKN-N/L.

Since TKN is usually mostly organic matter, and that is the case here (ammonia is only about 10 percent of the total), it might be expected that TKN distribution might resemble that of BOD, which is also primarily organic matter. As with the BOD data, the week-to-week variation in TKN distributions is so great that it is difficult to characterize. The 6-week mean values by station and tide for TKN are shown in Figure 4-37. As with BOD, there appears to be an increase in TKN concentrations between river miles 22 and 15, but the distribution as it flows out to the river mouth is different. There is no clear preference for distribution in the surface or bottom layer and high tide values are similar to or lower than values at low tide.

4.3 ANALYSIS OF LTBOD DATA

As discussed, LTBOD data are to be used to provide initial estimates of K_d and K_n, the BOD decay factors in the model, and to calculate values for the f-ratio, the factor by which long-term CBOD exceeds the corresponding CBOD5 value. Table 4-1 presents the results from the LTBOD measurements along with the K_d values and the f-ratios. Values for K_d generally fall in the range of 0.03 to 0.1 per day (i.e., oxidation of about 3 to 10 percent of the BOD each day), with a mean of about 0.06. Values for the f-ratio generally fall in the range of 2 to 8, with a mean of about 4.6.

The LTBOD samples were not collected simultaneously with the BOD5 samples, nor at the identical set of stations. However, they were collected close in time (a few days) and close in space to a subset of the BOD5 samples, and it seems appropriate to compare the results of the five-day and long term BOD analyses to see if they give similar results. For most of the LTBOD samples, the laboratory took measurements on the fifth day of the analysis, so in principle, these should resemble the final analysis for the BOD5 and CBOD5 samples. For LTBOD, these measurements usually included both DO and nitrate analyses.

Overall, the mean of the fifth-day LTBOD values (1.25 mg/L) compared more closely with the mean CBOD5 value (1.15) than the mean BOD5 value (1.51). The mean LTBOD nitrate produced by Day 5, however, accounted for DO consumption of only 0.07 mg-O_2/L compared to the BOD5 vs. CBOD5 difference of 0.35 mg/L. It is important to recognize the low levels of BOD5 and CBOD5 measured and that these measurements are close to the method detection limit. This would indicate the potential for some of the variance to be a function of proximity to method detection and expected levels of noise.

Since ultimate NBOD is derived from TKN, it would be expected that these values might also be comparable in these water samples. The mean TKN value for this subset of water chemistry sampling program samples was 0.38 mg-N/L, which, if all oxidized to NO_3, would consume 1.73 mg-O_2/L. The mean ultimate NBOD from the LTBOD samples was 1.41 mg-O_2/L, which is in the range of measured values of TKN assuming complete oxidation.

5.0 EFFECTS OF MARSHES ON INSTREAM CONDITIONS

The Marsh Exchange Event was one of the Special Events of the 1999 water quality monitoring study. The purpose of this marsh study was to quantify the exchange of nutrients, DO and BOD between selected marshes and the adjacent river water column. This was accomplished by monitoring water chemistry in feeder creeks that flood and drain the marsh systems. Two creeks off the Little Back River (Transects 2 and 5) and three creeks off the Middle River (Transects 1, 3 and 4) were sampled, all within the Savannah National Wildlife Refuge. Transect locations are shown in Figure 5-1. At each creek, hourly samples were collected during a single flood-ebb cycle and analyzed for a suite of parameters, including BOD5, CBOD5, nitrite plus nitrate, ammonia, and TKN. In addition, hourly measurements of temperature, salinity, and DO were taken. Two marshes were sampled on September 9 (Day 252) and the other three marshes were sampled on September 21 (Day 264). This study is discussed in more detail in Section 9.3 of the main data report. Each of these systems was also sampled for LTBOD in a separate sample collection. One sample on the flood tide and one sample on the ebb tide were collected at each of the five creeks on September 22 and analyzed for LTBOD.

Chemistry sampling results are shown in Figures 5-2a and b through 5-6a and b. DO data are shown in Figures 5-7 through 5-9. Long term BOD data results are shown in Figures 5-10 through 5-14. Based on a visual examination of the plots, for each transect it appears that ammonium concentration increased on the ebb tide to a maximum about the time of slack low, then fell as the tide started to flood, so they were all exporting ammonium. For some of the transects, this interpretation is based on values at only one or two points, without which the ammonium concentrations would appear essentially flat.

There seems to be little doubt that these systems all imported nitrate. There was routinely about 0.15 to 0.25 mg-nitrate-N/L entering the creeks and 0.05 mg/L or less leaving them. At Transects 1, 2, and 3, TKN appeared to be unchanged or gave an ambiguous result that could not be characterized as import or export. At both Transects 4 and 5, it appears that TKN was being exported. Interestingly, total phosphate (TP) and orthophosphate behaved very similarly to TKN at transects 4 and 5, and were also ambiguous at the other three transects. Orthophosphate, which the analyses suggest is most of the TP, for some reason appears more variable than TP, especially at Transects 1 and 2.

DO data for Transects 1 and 3 are not presented due to instrument problems. The other three are presented in Figures 5-7 through 5-9. Examination of the data shows a clear pattern of oxygen update in the marshes with very consistent differences on incoming and outgoing flows from 2.0 to 3.0 mg/L. This will provide an overall net oxygen deficit to the system occurring directly from marsh effects.

Generally, in all five marsh transects, BOD5 is higher at low tide than at other points during the tidal cycle, so they are exporting BOD. Overall, however, the BOD values are quite low, below the standard method detection limit, and, thus, there is much noise in the data, and the noted pattern is not always clear.

There is also LTBOD data from these transects which can be used to supplement this interpretation. These are single flood tide and ebb tide LTBOD samples. In all five systems, UBOD during ebb tide was greater than during flood tide implying that the marshes were all exporting BOD. For Transects 1 and 2, the differences were small enough to give a low level of confidence in this conclusion. For the other three transects, the differences were large enough to give some confidence that they are real. Note that this pattern is generally consistent with the pattern of TKN export, as would be expected. Table 4-1 presents the UBOD values for each of the ebbing and flooding samples at each of the transects. It is interesting to note that moving downstream to areas where freshwater marshes are less prevalent, the overall values of differences in inflowing and outflowing LTBOD increase.

The mean value of K for the marsh samples during the ebbing tide is 0.04 and the mean f-ratio is 6.3. The results of the LTBOD of the outgoing marsh waters indicates that the oxidation rates of this material are slightly slower than those measured along the main stem of the Front River.

6.0 LONGITUDINAL PROFILES AT GAEPD STATIONS

The Longitudinal Profiles at Pre-Established GAEPD Stations study was another Special Event of the program. The goal of this event was to look at longitudinal and vertical salinity and DO structure in the lower estuary, repeating a similar sampling survey, undertaken by the GAEPD in 1988, which identified transient areas of low DO within the system. Station locations are shown in Figure 6-1.

The longitudinal profiles were sampled three times, September 13, 1999, September 20, 1999, and September 27, 1999. During the first sampling event, it was desired to try to quantify the lateral distribution of dissolved oxygen as well as the longitudinal variations. Based upon this goal, four stations across the river were sampled at each longitudinal location. The time required to sample this many stations made it impossible to measure a true snapshot of the low and high slack tides and this method was not utilized in the remaining sampling events.

Figure 6-2 presents longitudinal contours of the measurements taken during the first sampling event. While these plots do not represent true synoptic high and low slack measurements, they do provide some quantification of the lateral variation in the system as well as isolating an area of low dissolved oxygen around River Mile 15.

For the second and third longitudinal sampling events, two boats were utilized which moved up the river from EPD-01 to EPD-10. These boats collected measurements on either side (Georgia or South Carolina) of the river within the navigation channel at low slack and high slack tide. During the sampling event on September 27, one of the instruments proved to be bad based upon post calibration and the data were discarded.

Figures 6-3 and 6-4 present the longitudinal dissolved oxygen measurements at the surface and bottom on September 20 and September 27. On the September 27th event, only one transect is shown for each of the high and low slack events because of the bad meter. Two key features are identified in these plots.

The first key feature is relative to the vertical distribution of DO. On September 20, the tidal range is low and near neap tide conditions, while on September 27, the tidal range is high and near spring tide conditions. The corresponding measurements on September 20 show the system as stratified relative to dissolved oxygen during both the high and low tide events. This is seen in both meters. On the September 27 sampling, the system is well mixed relative to DO and shows the effects of the spring/neap cycle on the vertical distribution of dissolved oxygen.

The second key feature reinforces findings on the horizontal distribution of DO in the system. At high tide on both sampling events (September 20 and 27), the longitudinal distribution of dissolved oxygen is one of higher dissolved oxygen at the lower reaches indicating the higher DO source waters in the offshore. At low tide, the influence of the higher DO freshwater is seen at the upstream stations as DO values rise moving upstream. An interesting side point is that during the neap tide conditions, the influence of the higher DO freshwater extends further downstream in the surface waters with the bottom waters only showing the influence at the uppermost station. This is not seen on September 27, when the system is well mixed.

The results of these surveys are largely consistent with the interpretation of DO conditions presented in a summary report believed to describe the original surveys on which this Special Event was based (Section 5. Savannah Harbor Centerline Monitoring Results in Savannah Harbor Dissolved Oxygen Monitoring Project, 1989 Summary Report, Georgia Environmental Protection Division). This earlier report describes the lower DO conditions at depth that move up and down the river with the flooding and ebbing tide much the same as are seen in the 1999 results, although, of course, there are differences in the details. This earlier report does not observe “transient behavior” in water column DO levels and specifically states this in an earlier section of the report.

The pattern that is seen here of a region of low DO in the harbor area that moves back and forth with the tides is fully consistent with the interpretations already given of the records from the continuous instruments. Indeed, this result could have been predicted from the continuous records. These longitudinal profile surveys serve to help fill in the gaps by providing more along-stream detail.

7.0 24-HOUR DYNAMIC SAMPLING

The 24-Hour Dynamic Sampling study was another of the Special Events. In order to quantify diurnal variations in water chemistry, samples were collected at 2-hour intervals over a 24-hour period at four sites within the study area. In addition, vertical profiles of temperature, salinity, and DO were taken hourly at each site. Sampling station locations are shown in Figure 7-1. Results of the chemical analyses and salinity and DO sampling are shown in Figures 7-2 through 7-9.

Results of this study do not reveal much about this system that has not already been discussed. At the mouth of the river, the water column was not strongly stratified during this period, and DO levels did not clearly show a regular pattern of increase and decrease with the tides as would be expected. The large swing in DO that is expected with the tides at this station is more typical of the deeper continuous station. Actual sampling took place closer to shore at a much shallower location. Some of the chemistry data are noisy enough that interpreting patterns is speculative. For instance, BOD5 may be increasing and decreasing with the rise and fall of the tide in the bottom layer but not at the surface, suggesting an offshore source. Nitrate, by contrast, is apparently higher up river and low offshore, with a very clear inverse relationship to the rise and fall of the tide. TKN may be somewhat like BOD5, but it is too variable to tell, and no pattern can be seen in the ammonium data.

Upstream of the Talmadge Bridge, the salinity is much more stratified, but any pattern of DO corresponding to tide changes is weak. This is consistent with what has already been observed. BOD5 seems to show no pattern except that it is routinely higher at the bottom and generally lower than further downstream. TKN falls through the entire period. Nitrate concentrations suddenly double about the time of the midnight high tide, for which no explanation can be provided here. Ammonium, which is generally much higher than at the station downstream, appears to be inversely related to salinity at the bottom but more positively related at the surface.

At Houlihan Bridge, salinity is uniform over depth. Rise and fall in DO concentrations correlates closely with the decrease and increase in salinity (i.e., an upstream source) at all depths. This pattern is clearly evident in records from the continuous instruments. No

BOD5 pattern is apparent. TKN is low throughout, with a possible pattern of increase with the rising tide. Ammonium more clearly shows a pattern of increasing and decreasing with the flood and ebb of the tide, and it is generally lower here, comparable in concentration to levels at the river mouth. Nitrate is generally high without a clear pattern.

At the US Fish and Wildlife dock on the Little Back River, there was no salinity signal. The DO pattern is not clearly related to any changes in the tide. BOD5, TKN, nitrate and ammonium are all mostly unchanging over time.

8.0 SEDIMENT OXYGEN DEMAND AND BENTHIC FLUX

Measurement of SOD was not part of this study. There was, however, an SOD study undertaken in support of this work in August of 1999 by scientists with the EPA laboratory in Athens, GA. Results are contained in a report: *Dissolved Oxygen Diffusion Study and Sediment Oxygen Demand Study, Savannah River, Savannah, Georgia* (August 2-14, 1999, EPA Science and Ecosystem Support Division, Ecological Assessment Branch, Athens, Georgia.

A series of measurements was made at each of four stations, corresponding to continuous monitoring stations GPA-02, GPA-21, GPA-22, and GPA-11 (Figure 2-1a), using diver-deployed chambers enclosing the sediment. Mean SOD rates varied from 0.86 to 2.58 g-O_2/m^2/day. Results at GPA-22, at 2.58 g-O_2/m^2/day, were substantially greater than at the other stations, which ranged from 0.86 to 1.3 g-O_2/m^2/day. This much greater value at GPA-22, in the Kings Island Turning Basin, was attributed to the "stilling zone" associated with the widening of the river at that location. The divers' observations for this site ("hardpak clay with sand & gravel in depressions") appear more characteristic of a scour zone rather than a settling basin. Given the natural variability of these measurements, the other three stations, which all had overlapping replicate values, are quite similar and reflect an average SOD of about 1.1 g-O_2/m^2/day. No temperature data were provided in the data report, so presumably the data indicate SOD rates at about 31ºC, the approximate bottom water temperature at most stations during this period. If these SOD values are corrected from 31ºC to 20ºC , then the three lower values have a mean of about 0.66 g-O_2/m^2/day, and the value at GPA-22 is about 1.56 g-O_2/m^2/day

Due to the difficulty and expense of carrying out SOD measurements, especially in the highly energetic tidal environment of the Savannah River estuary, the number of measurements that can be collected is limited. This limitation is all the more difficult when considering the variable distribution of SOD. Replicate measurements at a single site may differ by a factor of two or more. Thus, it is desirable to seek out other sources of SOD data for this system. In October 1985, GAEPD and EPA cooperatively undertook a series of SOD measurements at eight stations in the estuary. The results are reported in *Savannah River Classification Study – October 1985, Sediment Oxygen*

Demand Surveys, Summary. Sample sites are described in Table 8-1. Methodology was essentially the same as for the 1999 EPA study, using replicate experimental and control diver-deployed chambers.

The author found the data to be satisfactory overall, using most of the data points as source data for a modeling study. Data from station B1 (too low) and 11A (too high) were considered suspect and were not used. In determining whether to use these data in the present study, and how, proper consideration will need to be given to changes that have taken place in the estuary in the intervening 14 years between the two studies. There are few sites that can be compared between the two studies. Only GPA-02 (1999) and station 1 (1985) are spatially close together and after correcting for temperature, they differ by a factor of three.

Table 8-1. SOD Measurement

Station ID	Approx. River Mile	Location	Closest "GPA" Station	Sampling Agency	Mean SOD g-O$_2$/m^2/day	Temp. C
S1A	5	South Channel	GPA-03 and GPA-24	GAEPD	2.08	23
1	6	Elba Island Cut	GPA-02 and GPA-25	EPA	1.88	*
4	11	Front River at Back River	GPA-04	GAEPD	1.58	24
B1	13	Back River below tide gate	GPA-04 and GPA-05	EPA	0.57**	*
B2	15	Back River above Rte 17	GPA-05	GAEPD	0.76	24
B4	21	Little Back River at Houlihan Bridge	GPA-15	GAEPD	3.50	22
11A	26	Below Rte I-95	GPA-14	GAEPD	4.82	23
16	45	Ebenezer Landing	GPA-17	EPA	0.55	*

* EPA results are at the ambient temperature of 21-24 ºC.

**Results for station B1 considered suspect due to site location and substrate qualities.

A third data set, collected October 1-5, 1980, comes from *Application of CE-QUAL-W2 to the Savannah River Estuary," Technical Report EL-87-4, US Army Engineer Waterways Experiment Station, Vicksburg, MS* (Hall, Ross W., 1987).. The three data points were taken in the Front River. At river mile 5.9 (near GPA-02) = 1.2 g/m^2/day, RM 16.3 (~GP-06) = 2.9, and RM 21.5 (~GPA-09) = 1.7. Temperature data were not provided. U.S. Geological Survey (USGS) records indicate a temperature of 20ºC at Clyo about this time. On a temperature-corrected basis, this study suggests values overall that may be comparable to the 1985 study, but higher than the 1999 study. The changes that have taken place in the river since 1980 may make this earlier data irrelevant.

It would be desirable to be able to correlate SOD measurements to sediment types in order, perhaps, to arrive at some objective measure of how to map the small amount of existing data to the whole model domain. Present efforts have failed to find suitable maps of sediment properties in the Savannah River estuary.

The 1985 GAEPD/EPA study provided one additional data component of value that has not been available elsewhere from this study. They were able to sample water from most of the SOD chambers at the end of the sample interval and have these samples analyzed for ammonia. As a result of this, they determined that sediments at the six sites successfully analyzed released a mean of 0.159 g/m^2/day of ammonia (presumably ammonia-N). The mean SOD at these sites was 2.22 g-O$_2$/m^2/day. This ratio of SOD to ammonia release is reasonably consistent with a Redfield ratio of carbon to nitrogen and should be useful for quantifying ammonia release from the sediment in the present water quality model.

9.0 SUMMARY AND CONCLUSIONS

The critical variables in the present water quality modeling effort, given a well-calibrated hydrodynamic model on which to base it, will be dissolved oxygen, BOD in its various forms, SOD, and reaeration, plus, of course, the various model parameter settings. It has already been observed that primary productivity is only a minor component of DO dynamics in this system, so algal growth and eutrophication will not be a significant component the modeling effort. There are other chemical components that were measured that may prove useful in adjusting mass balance in the model, but will have no effect on dissolved oxygen.

The continuous records of dissolved oxygen at some stations throughout the system had fouling issues or other problems that left some data gaps, however, there were so many instruments, with such rich spatial coverage, that the complete data set should provide an excellent tool to which to calibrate the model.

Reaeration at the surface, BOD in the water column and SOD on the bottom will collectively account for the distributions of DO that is seen in the estuary. Control of the values and loads for these variables, along with the parameters that control them in the model will define how the model can be made to simulate the recorded DO distributions.

Reaeration is to be simulated through use of a formula, as a function of water depth and velocity, and was not considered in the forgoing discussion. Data on which to base SOD in the model is somewhat limited. For the present, it may be necessary to assign one lower value to the greater part of the estuary, and a second, greater value to areas of high settling such as the turning basin and the sediment basin. Consideration needs to be given to the relevance of older SOD studies to the present-day Savannah River estuary.

BOD actually constitutes components from several sources, including the upstream and ocean boundaries, the marshes, the sediments, point sources, and non-point sources such as runoff from developed areas (e.g., stormwater). Data supporting quantification of BOD in the estuary include analyses of BOD5, CBOD5, ammonium and TKN in the water column at numerous stations for seven weekly sample runs; similar sets of analyses for point source effluents, and for water at the upstream boundary at Clyo, but not for the open boundary; a single set of the same analyses for water exiting marsh creeks; and long term BOD analyses at subsets of the water column and marsh stations.

While the BOD5 and CBOD5 data do not fully correlate with the LTBOD data, they do correlate with each other, suggesting that the analyses are, at least, consistent. The CBOD5 data should be suitable for use in setting up and calibrating the model. The consistency should carry through for the sources for the first 6 weeks.

From this study some key physical processes were characterized, the following list summarizes the key processes identified and the findings;

- The temporal and spatial distribution of dissolved oxygen was well quantified throughout the system and in particular the conditions along the Front River. This included the effects of stratification/destratification, the horizontal transport and extent of low dissolved oxygen.
- The higher DO source waters in the offshore and upstream were quantified as well as the intrusion of higher DO waters along the bottom at the mouth of the estuary.
- Primary productivity was found not to be a significant component of the DO cycle in the Savannah River Estuary
- LTBOD samples identified potential ranges of K_d and the f-ratios to apply to the BOD5 and CBOD5 data for model set-up and calibration.
- The relative effects of carbonaceous versus nitrogenous BOD were identified.
- The import and export of nutrients and BOD were identified for the marshes
- The potential ranges of SOD in the system were identified and the potential locations of settling areas where higher SOD resides.

The knowledge gained through the identification of these processes will greatly aid in the calibration of the dissolved oxygen model and will help to put realistic boundaries on parameter values and tuning of those parameters for calibration.