DEVELOPMENT OF A DISSOLVED OXYGEN TMDL FOR BRUNSWICK RIVER USING A 2-D HYDRODYNAMIC AND WATER QUALITY MODEL

Hugo N. Rodriguez[1] and Steven J. Peene[2]

AUTHORS: [1]Water Resources Engineer and [2]Director, Tetra Tech Inc., 2110 Powers Ferry Road, Suite 460, Atlanta, GA 30339.
REFERENCE: Proceedings of the 2001 Georgia Water Resources Conference, held March 26-27, 2001, at the University of Georgia. Kathryn J. Hatcher, editor, Institute of Ecology, the University of Georgia, Athens, Georgia.

Abstract. St. Simons Sound and Brunswick River are located in an estuary along the Atlantic Coast approximately 80 miles south of Savannah, Georgia, and 70 miles north of Jacksonville, Florida. They were placed on the 303(d) list for dissolved oxygen. As prescribed under the Clean Water Act, a Total Maximum Daily Load (TMDL) has been determined for these listed reaches.

In order to determine the allowable TMDL for oxygen demanding material considering the potential impacts of ongoing point source, non-point source, marsh loadings, and benthic conditions, a two-dimensional hydrodynamic, transport, and water quality model was developed. The primary point source discharge to the system is a paper mill along the Brunswick River. The Environmental Fluid Dynamics Code (EFDC) hydrodynamic model was utilized along with the Water Quality Analysis Simulation Program (WASP). The model system provides accurate simulations of the circulation and transport within the system, this was verified through simulation of salinity. The model projected an allowable TMDL and referenced that allowable loading to natural and anthropogenic sources.

INTRODUCTION

Brunswick Harbor is located in an estuary along the Atlantic Coast approximately 80 miles south of Savannah, Georgia, and 70 miles north of Jacksonville, Florida. The upper portions of the estuary are made up of the Brunswick, Turtle and East Rivers. The lower portions are made up of St. Simons Sound, which empties into the Atlantic Ocean, and a series of small tidal tributaries extending north. In addition to these main rivers, the estuary is composed of a complex network of small streams, creeks, tidal sloughs and vast expanses of tidal salt marsh. The MacKay and Frederick Rivers flow into St. Simons Sound from the north, connecting this estuary to the Altamaha River, and Jekyll Creek from the south connecting St. Simons Sound to Jekyll Sound.

The drainage basin of the Turtle and South Brunswick Rivers, which are primarily tidal channels, is quite small. There are no major rivers that flow directly into the harbor area. However, because of the high tidal fluctuations, the water is well mixed and there is relatively uniform salinity. The tides at Brunswick Harbor are semidiurnal (a tidal period of 12.4 hours). The mean tide range is 6.5 feet at the entrance and 7.3 feet in the East River. For mean tide conditions, maximum ebb velocities throughout Brunswick River and the lower reach of the Turtle River are about 1.5 to 3.0 feet per second (fps), while maximum flood velocities are about 1.5 fps to 2.5 fps.

Brunswick Harbor is located in an area that has a temperate coastal climate. Average seasonal temperatures range from 55 to 61 degrees F in winter, 68 to 81 degrees F in the spring, 79 to 82 degrees F in the summer, and 56 to 71 degrees F in the fall.

The prevailing winds are from the southwest during May to August, and from the northeast from September to December.

Specific reaches of the Brunswick Harbor Estuary have been listed as impaired for dissolved oxygen on the State of Georgia 303(d) list. Under the Clean Water Act, a Total Maximum Daily Load (TMDL) must be determined for the parameter of concern. The TMDL is the total amount of anthropogenic point and nonpoint source load, plus natural background, plus a margin of safety, where the waterbody meets water quality standards. The goal was to develop a hydrodynamic and water quality model suitable for the determination of the TMDL for dissolved oxygen within the Brunswick Harbor Estuary. A two-dimensional, vertically averaged, hydrodynamic model using the Environmental Fluid Dynamic Code (EFDC) was coupled with a water quality model using the Water Quality Analysis Simulation Program (WASP).

FIELD DATA

During August and September 1982 data were collected at 20 stations throughout the system by Georgia Environmental Protection Department (GAEPD, 1983), to be used in conjunction with a tidally-averaged model.

Field measurement of DO, temperature, pH, conductivity, and secchi depth were conducted at two consecutive slack waters. Laboratory tests, including BOD, were conducted on water samples taken during the field campaign.

Mean tide values of Salinity, Ultimate Biochemical Oxygen Demand (BODu), and Dissolved Oxygen (DO) along the main channel were computed by GAEPD based on the measured values at high and low water.

A special studies program to determine non-point source loadings from marsh areas and direct measurement of Sediment Oxygen Demand (SOD) were also conducted.

HYDRODYNAMIC MODEL CALIBRATION

The Environmental Fluid Dynamics Code (EFDC) is a general purpose modeling package for simulating three-dimensional flows (Hamrick, 1992).

The EFDC hydrodynamic application for Brunswick Harbor is a two-dimensional vertically integrated simulation with tidal forcing at the ocean boundary, and freshwater inflow at the upstream boundaries. The shoreline and bathymetry are represented through the use of a curvilinear grid whose boundaries are based upon the digital NOAA shoreline data, and whose depths are interpolated from the NOAA digital depth data (Figure 1). The simulation period covers July and August of 1982 when data were collected. The hydrodynamic model was forced using astronomical tide projections for July and August of 1982 at the mouth of St. Simons Sound. Model comparisons for water surface elevation and currents also used astronomical tide and tidal current projections at interior points within the harbor and tributaries. Given the dominance in the system of the astronomical tides, with neap and spring tide ranges on the order of 6 to 9 feet respectively, the effects of local wind and atmospheric pressure on water surface elevation and currents were neglected. A constant freshwater inflow of 318 cfs comes in through the Turtle River. The final values of the bottom roughness coefficient and the horizontal dispersion were 0.001 m and 90 m^2/s and were uniform throughout the model.

Harmonic analysis for seven stations were performed. Table 1 presents the normalized RMS error of the amplitude for all the stations considered. The absolute errors are normalized to the local tide range in order to provide intercomparison between the stations. The results show normalized RMS errors all below 10 percent. Phase errors were all less than 20 minutes.

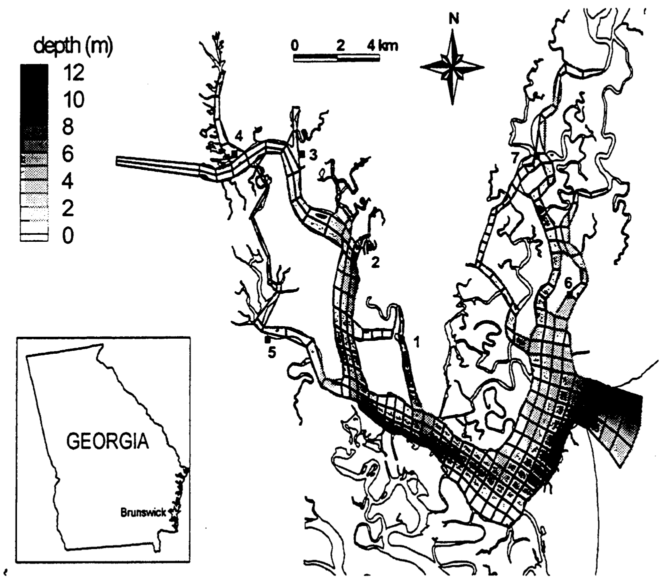

Figure 1. Location, model grid and bathymetry, and location of water surface elevation stations.

Current comparisons were also performed to provide an order of magnitude evaluation of the simulated tidal currents.

The simulated salinity at the stations longitudinally distributed over the Brunswick and Turtle Rivers were averaged over the period of measurement in order to compare with the measured data (Figure 2).

The results showed that the model was capturing the longitudinal distribution of the salinity and therefore the tidally averaged dispersion is reasonable for simulation of transport.

Table 1. RMS Errors for Water Surface Elevation Stations

Station Number	RMS Error (m)	Tidal Range (m)	Normalized RMS Error (%)
1	0.06	2.09	3.1
2	0.11	2.19	5.0
3	0.15	2.30	6.3
4	0.17	2.31	7.2
5	0.17	2.19	7.8
6	0.05	2.00	2.4
7	0.08	2.05	3.8

WATER QUALITY MODEL CALIBRATION

The water quality application for Brunswick Harbor utilized the WASP component model within EFDC in a dynamic two-dimensional vertically integrated simulation. The hydrodynamic conditions, including the temporal and spatial variations in the cell volumes, depths, flows, and dispersion coefficients are imported as an external forcing file generated by the EFDC 2-D hydrodynamic model. The advective and dispersive transport solutions within the WASP simulation were performed on the identical model grid used to simulate the hydrodynamics.

The primary state variable simulated was Dissolved Oxygen. The kinetic processes, sources, and sinks considered within the WASP simulations that impact the mass balance of dissolved oxygen were: combined nitrogenous and carbonaceous BODu, reaeration, SOD, headwater and offshore boundary fluxes of BODu and DO, adjacent marsh sources of BODu, point source discharges of BODu, and temporal and spatial variations in temperature based upon ambient measurements.

The model was calibrated to the longitudinal distribution of mean DO concentrations, temporal variations in DO concentrations, and longitudinal distribution of mean BODu concentrations (Figure 2).

Based upon the field measurements collected in 1982, an initial distribution of CBODu marsh loadings throughout the system was computed. As the marsh contribution was the least known source of CBODu to the system, the base values were manipulated in the model calibration to achieve the best fit of the longitudinal CBODu distribution.

Two point source discharges are considered in the water quality model calibration, these are the Georgia Pacific Paper Company and the City of Brunswick Academy Creek Plant. For the paper mill a time series of daily average CBODu was utilized. The daily average load from this facility varies from 5000 lbs/day up to 30,000 lbs/day during this period. For the City of Brunswick Academy Creek facility, a constant load was utilized based upon reported monthly average flows.

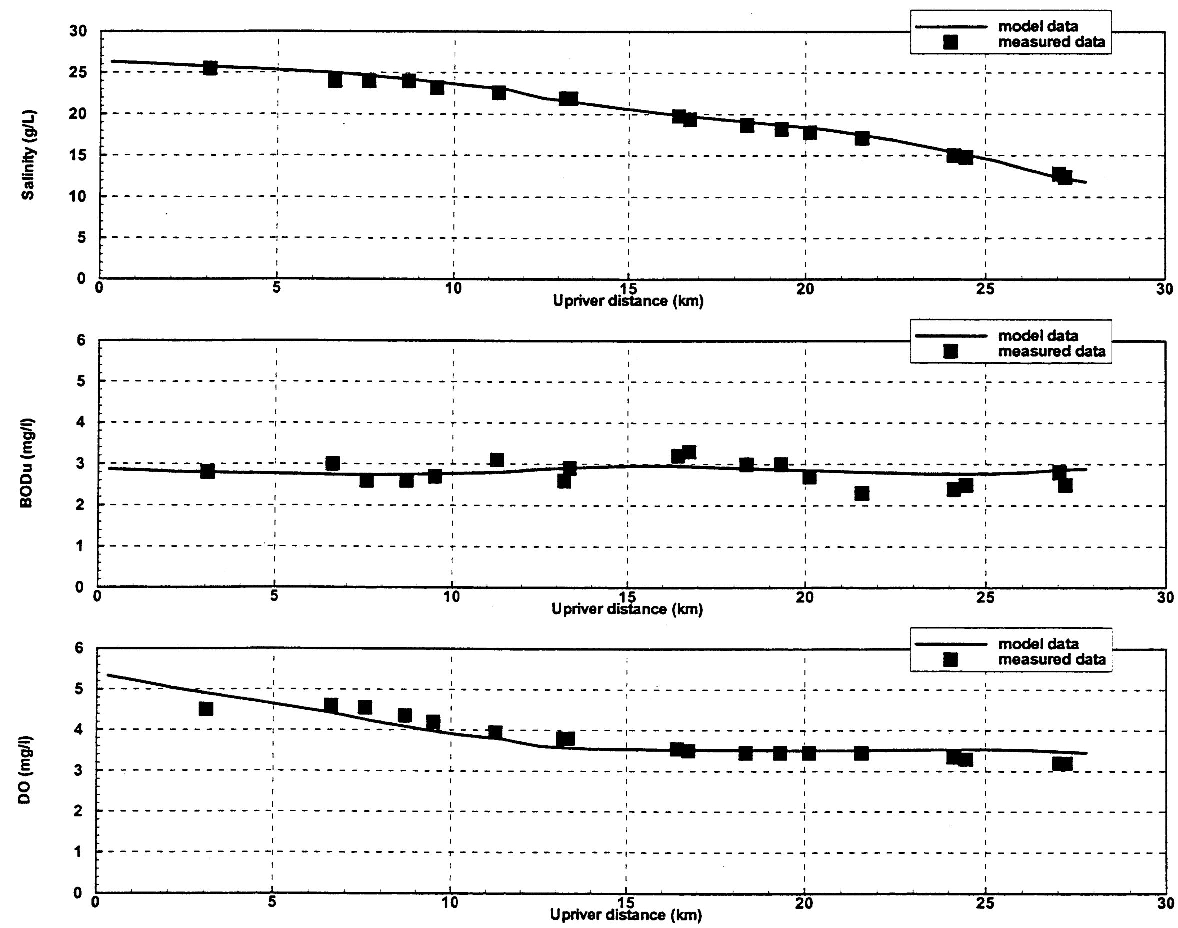

Figure 2. Comparison between simulated and measured longitudinal mean tide salinity, BODu, and DO.

For the EFDC WASP calibration, the Covar Method was utilized to define the spatial and time varying reaeration rate over the period of the simulation. The data from each model grid was output and processed to determine the maximum and minimum re-aeration value on August 12 and 13th. Reaeration rates ranged up to 0.20 day^{-1} throughout the simulation.

Figure 2 presents the longitudinal distribution of the mean tide Salinity, BODu, and DO concentrations with the model simulated mean concentrations values over the 24 hour period from the first mean tide condition on August 12th through two tidal cycles. This coincides with the period of measurements in the GAEPD study.

The longitudinal results presented in Figure 2 represent simulated conditions along the main Brunswick and Turtle Rivers.

TMDL DETERMINATION

The TMDL represents the total mass of oxygen demanding material that can be discharged to the system under a prescribed set of critical conditions, and the water body meet its designated use. The critical condition was defined as the summer/fall, low flow, high temperature period. All inputs to the model do not change from the calibration except for: theoretical water surface elevation time function at the ocean boundary over a 15 day period that includes a mean spring and a mean neap tide, low flow at the headwaters based upon critical conditions previously determined (GAEPD, 1983), temperatures set at the 75 percentile of historic available data for the month of August, and Georgia Pacific Pulp and Paper Facility and City of Brunswick Academy Creek Facility at their permitted discharge. The naturally occurring dissolved oxygen within the listed reaches of St. Simons Sound and Brunswick River was determined to be between 3.3 mg/L and 4.0 mg/L. Accordingly, the allowable anthropogenic impact on dissolved oxygen is 0.3 mg/L. The total allowable load for anthropogenic discharges was determined to be 47,307 lbs/day of BODu including the influence of Carbonaceous Biochemical Oxygen Demand (CBOD) and Nitrogenous Biochemical Oxygen Demand (NBOD).

The partial contribution of the different sources of BODu to the system are the marshes 66%, boundaries 6%, Municipal discharge 6% and Paper Mill discharge 22%.

An implicit margin of safety was considered in the TMDL development process due to conservative modeling assumptions.

CONCLUSIONS

The hydrodynamic and water quality calibrations show that the models are sufficient for evaluation of the TMDL for dissolved oxygen relative to loads of oxygen demanding material and the resultant impacts to dissolved oxygen concentrations. This model is applicable within the listed segments and accounts for the dynamic nature of the system.

ACKNOWLEDGMENT

The authors wish to thank Roy Burke III and the Georgia Environmental Protection Division for their invaluable support.

LITERATURE CITED

GAEPD, 1983. *Final Report Brunswick Estuary Modeling Project.* Environmental Protection Division. Atlanta, GA.

Hamrick, J. 1992. *A Three-Dimensional Environmental Fluid Dynamics Computer Code: Theoretical and Computational Aspects.* Virginia Institute of Marine Science. The College of William and Mary. Gloucester Point, VA.