Total Maximum Daily Load Determination for the Waccamaw River and the Atlantic Intracoastal Water Way Near Myrtle Beach, SC
INDEX

State of South Carolina Administrative Record
TMDL Submittal for Waccamaw River and Atlantic Intracoastal Waterway
Biochemical Oxygen Demand

Basis for 303(d) Listing                      Page 1
TMDL Technical Basis                        Page 2
TMDL                                         Page 7
References                                   Page 8
Appendix A - EPA/ Tetra Tech, Inc. Report    Page 9
Appendix B - Input Files for BRANCH/BLTM Models Page 23
Appendix C - Model Predicted Spacially Evaluated Instream DO Page 54
Appendix D - Public Notice                   Page 60
Appendix E - State of South Carolina 303(d) List June 1998 Page 63
BASIS FOR 303(d) LISTING

Introduction:

Section 303(d) of the Clean Water Act and EPA’s Water Quality Planning and Management Regulations (40 CFR Part 130) require states to develop total maximum daily loads (TMDLs) for their water bodies that are not meeting designated uses under technology-based controls for pollution. The TMDL process establishes the allowable loading of pollutants or other quantifiable parameters for a water body based on the relationship between pollution sources and instream water quality conditions, so that the states can establish water-quality based controls to reduce pollution from both point and nonpoint sources and restore and maintain the quality of their water resources (USEPA, 1991).

Problem Definition:

Waterbodies Impaired: Waccamaw River & Atlantic Intracoastal Waterway Watersheds 03040206-140, 03040206-150 and 03040207-030

Water Quality Standard Being Violated: Dissolved Oxygen

Pollutant of Concern: Biochemical Oxygen Demand (Carbonaceous and Nitrogenous)

Water Classification: Freshwater

Atlantic Intracoastal Waterway and the Waccamaw River are classified freshwater with the Waccamaw River having a site specific criteria for dissolved oxygen (DO). Waters of this class are to be:

“Freshwater suitable for primary and secondary contact recreation and as a source for drinking water supply after conventional treatment in accordance with the requirements of the Department. Suitable for fishing and the survival and propagation of a balanced indigenous aquatic community of fauna and flora. Suitable also for industrial and agricultural uses.”(R.61-68)

Dissolved Oxygen Criteria:

Waccamaw River: A minimum DO concentration of 4 mg/l.
Atlantic Intracoastal Waterway: Daily average DO concentration of 5 mg/l with a minimum of 4 mg/l.

The Waccamaw River and the AIWW are tidally influenced fresh waters located along the
northern coastal region of the state. The referenced portion of the AIWW is the man made canal from Little River to Waccamaw River. Net flow through this section is northward and enters the Atlantic Ocean through Little River. The referenced portion of the Waccamaw River runs from Conway, SC to south of the convergence with the AIWW. The predominate direction of flow for this section is southward towards Winyah Bay, although a portion of the Waccamaw enters the AIWW and flows north. Low velocities and low re-aeration are found throughout this system. These waterbodies, located in watersheds 03040206-140, 03040206-150 and 03040207-030, are listed as Primary Priority Waterbodies on the 1996 303(d) list and the 1998 South Carolina Waters of Concern for violations of DO. South Carolina Department of Health and Environmental Control (SCDHEC) has data from seven ambient STORET monitoring stations on the Intracoastal Waterway and Waccamaw River, MD-088, MD-085, MD-127, MD-087, MD-125, MD-089, MD-091 that document periods in the late summer during which DO concentrations fail to meet numeric standards. These periods are considered naturally occurring phenomenon. Antidegradation rules of South Carolina Regulation 61-68 allow a maximum DO deficit of 0.1 mg/l from point sources (“0.1 rule”) under these conditions. The “0.1 rule” will be the standard applicable in the development of these TMDLs.

**TMDL TECHNICAL BASIS**

**Target Identification:**

Antidegradation rules of South Carolina Regulation 61-68 state:

> “4. Certain natural conditions may cause a depression of dissolved oxygen in surface waters while existing and classified uses are still maintained. The Department shall allow a dissolved oxygen depression in these low dissolved oxygen waterbodies as prescribed below:
> 
> a. Under these conditions the quality of the surface waters shall not be cummulatively lowered more then 0.1 mg/l for dissolved oxygen from point sources and other activities .....”

This rule’s focus is the cumulative 0.1 mg/l point source impact on DO and will be the standard applicable in the development of these TMDLs.

**Point Sources by Area in Waccamaw/ AIWW Watershed:**

The four areas where point source TMDLs are being established are: the Conway area of the Waccamaw River; the North Myrtle Beach area of the AIWW; the area at the confluence of the AIWW and the Waccamaw River near Bucksport; and the southern area of the Waccamaw River, north of Hagley Landing. The pollutant of concern is biochemical oxygen demand, both carbonaceous and nitrogenous, which is expressed in ultimate oxygen demand (UOD). The TMDLs will be expressed in terms of UOD, based on the water bodies’ assimilative capacity for oxygen-demanding substances.
Permitted Dischargers in Areas of Concern

<table>
<thead>
<tr>
<th>Location</th>
<th>Dischargers</th>
<th>NPDES Permit #</th>
<th>Q (MGD)</th>
<th>UOD (#/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conway</td>
<td>City of Conway</td>
<td>SC0021733</td>
<td>3.2</td>
<td>522</td>
</tr>
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<td></td>
<td>GSW&amp;SA Central</td>
<td>SC0040410</td>
<td>1.2</td>
<td>1,351</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td>4.4</td>
<td>1,873</td>
</tr>
<tr>
<td>Bucksport</td>
<td>GSW&amp;SA Bucksport</td>
<td>SC0040886</td>
<td>0.2</td>
<td>228</td>
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<tr>
<td>Hagley</td>
<td>GSW&amp;SA Schwartz Plant</td>
<td>SC0037753</td>
<td>12</td>
<td>7,871</td>
</tr>
<tr>
<td></td>
<td>Myrtle Beach WWTP</td>
<td>SC0039039</td>
<td>17</td>
<td>13,507</td>
</tr>
<tr>
<td></td>
<td>GCW&amp;SD Murrells Inlet</td>
<td>SC0040959</td>
<td>1</td>
<td>567</td>
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<tr>
<td></td>
<td>GCW&amp;SD Pawley’s Area</td>
<td>SC0039951</td>
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<td>2,275</td>
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<td></td>
<td>Total</td>
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<td>24,220</td>
</tr>
<tr>
<td>North Myrtle</td>
<td>NMB Ocean Drive</td>
<td>SC0022152</td>
<td>3.4</td>
<td>685</td>
</tr>
<tr>
<td>Beach</td>
<td>NMB Crescent Beach</td>
<td>SC0022161</td>
<td>2.1</td>
<td>743</td>
</tr>
<tr>
<td></td>
<td>GSW&amp;SA Vereen Plant</td>
<td>SC0041696</td>
<td>2.5</td>
<td>481</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td>8.0</td>
<td>1,908</td>
</tr>
</tbody>
</table>

**TMDL Development:**

The Branched Lagrangian Transport Model (BLTM), a dynamic, one dimensional water quality model, was applied by the United States Geological Survey (USGS) for the Waccamaw Regional Planning and Development Council (WRP&DC). BLTM utilizes hydrodynamic data generated by USGS’s BRANCH model. These models were submitted to SC Department of Health and Environmental Control (SCDHEC) in the fall of 1995 for use in determining the assimilative capacity for oxygen demanding substances of the Waccamaw/AIWW system.

The BRANCH/BLTM model developed by USGS for the Waccamaw River and AIWW has undergone internal USGS review as well as external review by SCDHEC and Jordan, Jones & Goulding, Inc. These entities have confirmed the model’s calibration and verification. Information concerning development, calibration and verification of BRANCH/BLTM can be found in the USGS Water-Resources Investigations Report 95-4111 titled *Assimilative Capacity of the Waccamaw River and the Atlantic Intracoastal Waterway near Myrtle Beach, South Carolina 1989-92.*

As a result of public comment, a second review of the model was conducted. This included an external review of the Department’s application of dynamic models by both the U.S. Environmental Protection Agency (EPA) and Tetra Tech, Inc. (an EPA contractor). This review offered specific recommendations for selection of critical conditions (App. A) which were
followed by SCDHEC.

BRANCH/BLTM, as with some other water quality models, handles point sources as loads without adding the corresponding flow to the hydrodynamic portion of the model. This approach was changed by USGS in order to utilize the model for evaluation of water withdrawal impacts on the system’s assimilative capacity. The BRANCH/BLTM model specific for the Waccamaw / Atlantic Intracoastal Waterway was re-schematized (Fig.1) and re-configured to accomplish this. The drinking water withdrawal on the AIWW was entered into the model as the difference between permitted and June through July 1994 average withdrawal. Other drinking water withdrawals were entered as permitted withdrawals. AIW1.CTL (App. B) contains discharge flow and drinking water withdrawal information. An internal boundary (an artifact from original model development) was also removed.

Critical conditions for wasteload allocation application were determined using data from USGS water quality stations and SCDHEC STORET stations for the month of July from 1988 to 1998. For all water quality parameters except DO, the 75th percentile was considered as being representative of critical conditions. For DO, the 25th percentile was considered as being representative of critical conditions. Values greater than plus or minus two standard deviations of the mean of the raw data were considered anomalies and discarded. Because the data used for critical conditions were actual water quality measurements, loads attributable to non-point and natural sources are indirectly included. Meteorological effects were derived from National Oceanic and Atmospheric Administration data. Average wind speed and average monthly maximum and minimum temperatures were determined for July 1990. Flow conditions for the model runs were actual stage data (June 1 - July 15, 1994) as required by the model. Sensitivity analysis shows changes in boundary conditions have little impact when predicting the relative difference between model predicted instream DO with and without the dischargers’ contributions. Boundary conditions for the critical condition model run are listed in Table 1. Model input files may be found in Appendix B.

Wasteload allocation models typically used throughout the state, for non-tidal rivers, are developed using a stream flow representing the lowest seven day average with a ten year recurrence (7Q10). A 7Q10 low flow is not applicable for the Waccamaw / AIWW system due to it’s complexity and tidal influence. There are four boundaries: two fresh water boundaries, representing four large river systems each with headwaters in different geographical regions, and two tidally influenced boundaries. In an effort to identify a critical flow period analogous to a 7Q10, USGS supplied analysis of seven day mean stream flow, daily average specific conductance and daily average minimum specific conductance for various stations near the model’s boundaries.
Review of supplied data identified numerous periods with low freshwater flow in the Waccamaw River as well as periods of high specific conductance at the tidally influenced boundaries throughout the period of record. To maintain continuity, to apply a watershed approach, and to reduce human error within the permitting process, one specific flow period, rather than different flow periods for each general area of the model, was selected to be the representative low flow critical condition. The chosen flow period was June 1 - July 15, 1994. This selection was based on the period’s low variability in flow, best approximation of a critical low flow with a ten year recurrence and lack of bias towards any specific region within the model.

Table 1 - Boundary Conditions for the Critical Condition Model Run with concentrations in mg/l

<table>
<thead>
<tr>
<th>Location</th>
<th>Temperature</th>
<th>Ammonia</th>
<th>NO₃</th>
<th>BOD₅</th>
<th>DO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pee Dee River</td>
<td>28 °C</td>
<td>0.06</td>
<td>0.23</td>
<td>2.3</td>
<td>5.0</td>
</tr>
<tr>
<td>Waccamaw River -at Conway</td>
<td>30 °C</td>
<td>0.07</td>
<td>0.22</td>
<td>1.3</td>
<td>4.5</td>
</tr>
<tr>
<td>Waccamaw River -at Hagley River</td>
<td>28 °C</td>
<td>0.09</td>
<td>0.36</td>
<td>1.2</td>
<td>5.0</td>
</tr>
<tr>
<td>AIWW -at Hwy 9</td>
<td>30 °C</td>
<td>0.10</td>
<td>0.39</td>
<td>2.3</td>
<td>4.5</td>
</tr>
</tbody>
</table>

Antidegradation rules of South Carolina Regulation 61-68 allow a maximum DO deficit of 0.1 mg/l attributable to point sources (“0.1 rule”) where waters do not meet the numeric DO standard due to natural conditions. The “0.1 rule” was applied to determine the point source TMDL for oxygen consuming constituents. The “background” condition was identified by removing the permitted dischargers from the critical condition model and used as a baseline. The second step was to run each area’s permitted loadings separately, and identify the corresponding areas of impact. The third step was to reduce the area loadings, until a change of 0.1 mg/l below the “background” DO was identified. The loadings were then run concurrently and adjusted to compensate for interaction between areas. The dischargers’ impacts were determined as the difference between the “background” run’s and the “load” run’s twenty-four hour daily averages as required by R.61-68. Appendix C contains five graphs representing the predicted instream DO with and without the discharges at a given point in time. These graphs illustrate the dynamic nature of discharges’ impact on the system. Table 2 lists the current NPDES permit limits and corresponding loads by area. Table 3 lists the identified TMDL UOD load by area.
Table 2 - Current limits for Waccamaw/ AIWW permits

<table>
<thead>
<tr>
<th>Location</th>
<th>Dischargers</th>
<th>Limits (BOD/NH3/DO)</th>
<th>Q (MGD)</th>
<th>UOD (#/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conway</td>
<td>City of Conway</td>
<td>10/1/6</td>
<td>3.2</td>
<td>522</td>
</tr>
<tr>
<td></td>
<td>GSW&amp;SA Central</td>
<td>*</td>
<td>1.2</td>
<td>1,351</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td>4.4</td>
<td><strong>1,873</strong></td>
</tr>
<tr>
<td>Bucksport</td>
<td>GSW&amp;SA Bucksport</td>
<td>30/-/-/1</td>
<td>0.2</td>
<td><strong>228</strong></td>
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<td>Hagley</td>
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</tr>
<tr>
<td></td>
<td>Myrtle Beach WWTP</td>
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<tr>
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<td>GCW&amp;SD Murrells Inlet</td>
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<td>567</td>
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<tr>
<td></td>
<td>GCW&amp;SD Pawley’s Area</td>
<td>*</td>
<td>2.75</td>
<td>2,275</td>
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<tr>
<td></td>
<td>Total</td>
<td></td>
<td>32.75</td>
<td><strong>24,220</strong></td>
</tr>
<tr>
<td>North Myrtle Beach</td>
<td>NMB Ocean Drive</td>
<td>10/2/6</td>
<td>3.4</td>
<td>685</td>
</tr>
<tr>
<td></td>
<td>NMB Crescent Beach</td>
<td>10/6/6</td>
<td>2.1</td>
<td>743</td>
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<tr>
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<td>GSW&amp;SA Vereen Plant</td>
<td>*</td>
<td>2.5</td>
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<td></td>
<td>Total</td>
<td></td>
<td>8.0</td>
<td><strong>1,908</strong></td>
</tr>
</tbody>
</table>

*Currently limited by UOD load

Table 3 - Proposed TMDLs for Waccamaw/ AIWW System with effluent DO of 6 mg/l

<table>
<thead>
<tr>
<th>Location</th>
<th>Dischargers</th>
<th>UOD (#/d)</th>
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<tbody>
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<td>Conway</td>
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</tr>
<tr>
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<td>GSW&amp;SA Central</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>303 #/d</td>
</tr>
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<td>Bucksport</td>
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<tr>
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<td></td>
<td>Myrtle Beach WWTP</td>
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</tr>
<tr>
<td></td>
<td>GCW&amp;SD Murrells Inlet</td>
<td></td>
</tr>
<tr>
<td></td>
<td>GCW&amp;SD Pawley’s Area</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>8,643 #/d</td>
</tr>
<tr>
<td>Location</td>
<td>Dischargers</td>
<td>UOD (#/d)</td>
</tr>
<tr>
<td>-------------------</td>
<td>--------------------------------------------</td>
<td>-----------</td>
</tr>
<tr>
<td>North Myrtle Beach</td>
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<tr>
<td></td>
<td>NMB Crescent Beach</td>
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<tr>
<td>Total</td>
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<td>1,638 #/d</td>
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</tbody>
</table>

References


Appendix A

EPA/Tetra Tech, Inc. Report
EPA SWAT Team Modeling Assistance

Review of South Carolina Dynamic Modeling Applications for Dissolved Oxygen

Jonathan B. Butcher, Ph.D., P.H.
Tetra Tech, Inc.
May 6, 1998

1. Summary

Through the EPA SWAT program, the South Carolina Department of Health and Environmental Control (DHEC) requested a review of their application of dynamic modeling to wastewater allocation development for biochemical oxygen demand (BOD) and ammonia loading in terms of their impacts on dissolved oxygen (DO). This report is based on a review of two draft wastewater allocation model applications to the Waccamaw River/Intracoastal Waterway system and to the Cooper/Wando River system.

DHEC specifically requested an assessment of (1) the appropriateness of using dynamic models to determine wastewater allocations, (2) the methodology used to determine critical conditions, (3) the averaging period used to evaluate model output for compliance with standards, and (4) the methodology used to determine permit limits from model output. In general these applications are of high quality and relevant to establishing appropriate wastewater allocations. The following summarizes the results of the review:

- Dynamic models of the type used by DHEC are appropriate for wastewater allocations in tidal systems.

- Critical conditions used in the existing wastewater allocation applications might be overly stringent. Additional analysis of critical conditions for determination of wastewater allocations might hold excursions of the DO standard to an acceptably low frequency.

- Consideration might be given to the use of a fixed daily period (rather than running a twenty-four hour average) for evaluation of the daily average instead of 7-day average concentrations. In addition, evaluation of dynamic model output both in terms of instantaneous concentrations (for compliance with the instantaneous DO standard) and daily average concentrations (for compliance with the daily average standard) would coordinate with the state water quality standards.

- A statistical method can be used to evaluate the consistency of permit limits with the wastewater allocations.
2. Relevant Standards

In wasteload allocations, models are applied to determine and predict attainment of water quality standards. Therefore, appropriate model application and interpretation of model output is consistent with the applicable state standards. South Carolina standards are summarized in this section.

**DO Standards**

Dynamic models of the DO balance are proposed by DHEC for analysis of waterbodies in which steady state and tidally averaged models may lead to an incomplete or incorrect evaluation of the impacts of loads of oxygen demanding waste. This includes estuarine and tidally-influenced freshwater rivers, as well as rivers controlled by hydroelectric power plants. The most relevant South Carolina water use classifications in which dynamic models are likely to be applied for wasteload allocations are Freshwaters ("freshwaters suitable for primary and secondary contact recreation and as a source for drinking water supply after conventional treatment..."), Class SA ("tidal saltwaters suitable for primary and secondary contact recreation"), and Class SB ("tidal saltwaters suitable for primary and secondary contact recreation, crabbing and fishing, except harvesting of clams, mussels, or oysters for market purposes or human consumption"). Within Freshwaters and Class SA waters, the following quality standard is established for DO: "Daily average not less than 5.0 mg/l with a low of 4.0 mg/l." Within Class SB waters the standard for DO oxygen is "not less than 4.0 mg/l."

**Applicability of Standards**

These standards are not applied under extreme low flow conditions. The general statement on applicability at C(2)(a) and (b) states:

(a) With the exception of human health criteria...the numeric standards...are applicable to any flowing waters when the flow rate is equal to or greater than the minimum seven day average flow rate that occurs with an average frequency of once in ten years (7Q10).
(b) The Department will consider flows other than 7Q10 where appropriate to protect classified and existing uses.

In addition, South Carolina's antidegradation statement at D(4) provides for water bodies in which the DO concentration will naturally contravene the standards (the "point one" rule):

Under certain conditions, the quality of some free flowing surface waters and lakes...does not meet numeric standards for dissolved oxygen due to natural conditions, even though classified uses in these waters are achieved. Under these conditions, the quality of the free flowing surface waters or lakes...shall not be cumulatively lowered more than 0.10
mg/l for dissolved oxygen from impacts by point sources and other activities, unless a site-specific standard is established.

Comments

The regulations state that 4 mg/l is an instantaneous minimum standard for DO and the 5 mg/l standard (applicable to Freshwaters and Class SA waters) is defined as a daily average.

The applicability statement recognizes that appropriate DO standards are likely to be contravened under rare conditions of extreme low dilution. The intent of the standard is not to ensure that instantaneous DO concentrations less than 4 mg/l (and daily average concentrations less than 5 mg/l) never occur; rather, it is to ensure that excursions of the standard are held to an acceptably low frequency. In flowing streams this goal is achieved by specifying that the standards are applicable only when flow is equal to or greater than the 7Q10 flow; it is expected that a low (but non-zero) frequency of excursions will occur during those infrequent time periods when flow is less than 7Q10.

The 7Q10 flow is established as a cutoff value of flow rate for applicability of the standards. Even though this flow rate is estimated as a 7-day average, no averaging period for applicability of the standard is necessarily implied by use of the 7Q10 calculation. For instance, analysis of historical flow records might establish that the 7Q10 flow for a given river is 100 cfs. Instantaneous standards (e.g., 4 mg/l DO) should then be achieved whenever the instantaneous flow is greater than 100 cfs. Two interpretations appear possible for daily average standards (e.g., 5 mg/l DO): (1) the standard should be achieved as a daily average whenever the daily average flow is greater than 100 cfs; or (2) the standard should be achieved as the daily average of all times in which the instantaneous flow is greater than 100 cfs. These two interpretations can yield different results when continuous observations or model predictions of DO are available. The first alternative is more stringent, as DO concentrations at flows less than 7Q10 may be included in a daily average, as long as the daily average flow is greater than or equal to the 7Q10 flow. For instance, consider a river with a 7Q10 of 100 cfs and 24-hour period in which 12 hours of flow are at 50 cfs and a DO of 3 mg/l and 12 hours of flow are at 150 cfs and a DO of 5 mg/l. The daily average flow is equal to the 7Q10 flow. The first interpretation of applicability yields a daily average DO concentration of 4 mg/l. The second interpretation, which allows exclusion of the 12 hour period with flow less than 7Q10, yields a daily average concentration of 5 mg/l for purposes of application of the standard. The issue is not, however, relevant to the “critical condition” model applications submitted by DHEC as long as boundary flows are held at appropriate design conditions.

The “point one” rule in the antidegradation statement does not contain a specific note as to applicable flow conditions. However, since the “point one” rule refers to conditions in which standards are not achieved, and standards are only applicable at flows greater than or equal to the
7Q10 flow, the “point one” rule also can be inferred to be applicable at flows greater than or equal to the 7Q10 flow.

The applicability clause is written for uni-directional flowing streams in which the 7Q10 flow is readily determined. In tidal systems, 7Q10 may not be readily measured, and the interpretation is much less clear. The intent of the standards appears clear, however, that allocations for these types of waterbodies should be designed to restrict excursions of the DO standard to an acceptably low frequency, rather than prohibiting excursions under all extreme low dilution conditions. Potential minimum dilution design conditions for tidal systems are discussed further in Section 5.

3. Use of Dynamic Models for Wasteload Allocations

Applicability of Dynamic Models to DO Analysis in Tidal Systems

In wasteload allocations, models are applied to determine and predict attainment of water quality standards. Therefore, appropriate model application and interpretation of model output should be consistent with the applicable state standards. Traditionally, most wasteload allocations have relied on steady state modeling at design conditions representative of a rare event with a specified probability of occurrence. Where appropriate, steady state models are recommended for wasteload allocations because they are simpler to apply and easier to interpret. In certain situations, however, steady state modeling does not provide an accurate estimate of the probability of excursions of a standard resulting from a wasteload allocation. The steady state approach yields only the probability of standard excursions at design conditions, and does not yield the full distribution of environmental outcomes. This is appropriate when a design condition associated with an acceptable low probability of excursion of the standard is identifiable—for instance, when an effluent discharges oxygen-demanding waste into a uni-directional flowing stream, such that impact on DO is at a maximum when dilution capacity is lowest, temperature-dependent oxygen saturation is lowest, and temperature-dependent reaction rates are highest. To determine design or critical conditions, a suitably rare combination of low dilution flow, high water temperature, and other relevant factors is selected. A steady state wasteload allocation at such design conditions then ensures that excursions of the standard will not occur at more common higher flow and lower temperature combinations. If, however, a design condition is not identifiable, steady state wasteload allocations under a particular set of conditions cannot ensure a specific low frequency of excursions of the standard under other conditions. Use of steady state models also does not explicitly consider the effects of correlation between dilution capacity and variable effluent loads. For instance, precipitation-driven nonpoint loads are associated with higher instream dilution flows, and analysis at steady state 7Q10 design conditions can lead to overly-stringent results.
For tidal waterbodies, flow is not uni-directional, but changes in magnitude and oscillates with the tidal cycle. It is still possible to define critical, minimum dilution conditions within a tidal system (see Section 4); however, a steady state analysis at the minimum dilution condition is not sufficient to provide an accurate time course prediction of DO concentrations, because DO will depend on the extent of mixing of oxygen-demanding waste in the period leading up to the minimum dilution condition, and critical DO concentrations may not coincide in time with minimum dilution.

In contrast to a steady state analysis, dynamic modeling approaches attempt to reproduce the actual time series or distribution of instream concentrations and explicitly include the effects of variability in dilution capacity and effluent load over time. A full dynamic modeling analysis can predict the entire effluent concentration frequency distribution, thus allowing wasteload allocations to be set to produce an expected frequency of excursions of the standard.

Steady state analyses are still useful for tidal systems, particularly for initial scoping analyses. They are particularly useful for approximating concentrations averaged over a tidal cycle. For DO problems a steady state analysis cannot, however, provide accurate estimates of intra-tidal instantaneous concentrations. South Carolina water quality standards specify both daily average and instantaneous DO concentrations. Thus, a dynamic, intra-tidal modeling analysis is appropriate for accurate determination of a wasteload allocation.

**DHEC Dynamic Model Applications**

For two waterbodies—the Waccamaw/Intracoastal Waterway and the Cooper River—DHEC, in conjunction with USGS, has conducted dynamic DO modeling using the BRANCH/BLTM model (Drewes and Conrads 1995, Conrads and Smith 1997). BRANCH/BLTM is a USGS one-dimensional, unsteady-flow model coupled with an unsteady water-quality transport model which is applicable to tidal systems lacking significant stratification. Both models have a credible record of application by USGS and others. DO and nutrient kinetics of the BLTM model are the same as those included in EPA’s QUAL2E model.

A technical review of model application was not specifically requested for this SWAT response; however, a cursory review of the model set-up and calibration did not uncover any unreasonable assumptions. Synoptic water quality data available for calibration were, however, limited. The Waccamaw/Intracoastal Waterway model was calibrated to data for April 10-25, 1990, while the Cooper/Wando model was calibrated to data for August 23-25, 1993 and validated on data from May 4-5, 1993. For the Waccamaw/Intracoastal Waterway system, USGS developed assimilative capacity curves that show assimilative capacity conditional on seven-day average influent streamflows. For the Cooper/Wando model, the primary freshwater input is controlled by Pinopolis Dam, and USGS reported simulations for several different assumptions of flow over this dam.
One significant difference between the Cooper and Waccamaw models is that the Cooper model includes algae in the simulation, while the Waccamaw model does not. This is typically a difficult issue for DO wasteload allocation modeling. Algae can have a significant effect on the DO balance, but are difficult to represent accurately in dynamic models. Under many conditions algae lead to a net increase in DO; however, at a saltwater/freshwater interface the die-off of freshwater algae can sometimes result in a high oxygen demand. It is often necessary to include algae in a DO model to obtain calibration to synoptic data, unless the effect of algae on the DO balance can be shown to be insignificant. Inclusion of algae in a wasteload allocation model is a different matter. While algae may increase DO during calibration observations, algal populations are highly variable, and may not always mitigate effects of oxygen-demanding waste. An available option to account for the effects of algae but still ensure the highest possible accuracy, is to calibrate and validate the model including the algal component, but then run the model with and without algae, using the more stringent result for the wasteload allocation.

4. Interpretation of Dynamic Modeling Output: Averaging Periods

DHEC extended the USGS model applications for the Waccamaw and Cooper Rivers by adjusting the calibrated, validated BRANCH model to a critical conditions model. First, assumptions were made for design conditions of flow and other relevant parameters (see Section 5 for a review of design condition assumptions). For the Waccamaw, the analysis was based on examination of the June to September flow records for the year of calibration, with the most critical month selected for each permitted facility (September for some, July for others). For the Cooper river the model uses an observed late summer month of flow conditions, except that some synthesized flows are used for the dam. The last two weeks of the simulation period is at dam releases equal to the limiting flow specified in the dam operation agreement (personal communication from Nancy Sullins, SC DHEC, 1/12/98). In both water bodies the DO standards are not expected to be attained due to natural conditions at low flow conditions, so the “point one” rule is applied to analysis of wasteload allocations. DHEC then applied the model as follows:

DHEC has chosen to run the BRANCH/BLTM model for six weeks, two weeks for model warm up and four weeks of the critical month. First, a no load run is made without discharger inputs. Then the model is run with the dischargers permitted loads included. The outputs are compared, time step by time step, and twenty-four hour running averages of the differences between the two scenarios are determined. Adjustments are made in the “with load” scenario to determine the maximum loading that will not result in any twenty-four hour period having an average deficit greater than 0.1 mg/l. The load associated with this 0.1 mg/l change is then identified as the maximum allowable load for that reach of the water body. A twenty-four hour running average was chosen with the thought that any averaging period longer than twenty-four hours would reduce the variability of the predicted dissolved oxygen. This softening of the curve reduces the
effectiveness of the model to predict periods which may cause stress to the biological community.

The DHEC analysis of attainment of standards is based on running twenty-four hour averages calculated from a critical low flow month, with other design conditions held constant. Instantaneous predictions were not used to assess attainment.

Examination of issues surrounding the averaging period was included in review of the analysis. The water quality standards express an instantaneous DO standard (4 mg/l) and a “daily average” DO standard (5 mg/l). Therefore, for waters which would attain the standards under natural conditions, it would be appropriate to compare both each instantaneous prediction and the twenty-four hour averages in model output to the appropriate standard.

Similarly, in naturally non-attaining waters where the “point one” rule applies, both instantaneous and daily average values are appropriate for measurement to compare to the water quality standards. For any point in time when the instantaneous DO under natural conditions would be less than 4 mg/l the wasteload allocations allows no more than an 0.1 mg/l lowering of instantaneous concentration, and for any day in which the average DO under natural conditions would be less than 5 mg/l the wasteload allocations allows no more than an 0.1 mg/l lowering of the twenty-four hour average concentration.

Options for calculation of the twenty-four averages include use of a running average, or use of a discrete average concentration over a specified diurnal cycle (e.g., sunrise to sunrise). The two methods do not necessarily provide the same result under dynamic conditions, and the running average would be more stringent, as it can “seek out” and combine adjacent parts of two days in which concentration is abnormally low. However, the use of running twenty-four hour averages may overestimate the accuracy of the model. In general, DO models should be better at predicting the average over a diurnal cycle than instantaneous concentrations. Therefore, it might be more appropriate to evaluate daily averages on a fixed (rather than running) twenty-four hour period.

According to DHEC, “There has been concern expressed by the regulated community that the twenty-four hour running average is overly conservative and a seven day average is more appropriate for tidally influenced systems.” The South Carolina standards refer to the twenty-four hour average and minimum concentrations and not a 7-day average. The fact that the flow regime under which the standard is applicable is based on the 7Q10 flow is not relevant to the standard averaging period. Finally, it should be noted that the appropriate interpretation of dynamic model output is dependent on how the design conditions are specified. These issues are addressed in the following section.
5. Design Conditions for Dynamic Modeling

Dynamic versus Quasi-Dynamic State Applications

For tidal systems, dynamic modeling of DO is recommended to capture complex patterns induced by tidal mixing, particularly for prediction of instantaneous DO concentrations. DHEC adopted a dynamic modeling framework primarily because appropriate design conditions for flow in tidal systems were not readily identifiable. Model calibration to synoptic data also implicitly includes the effects of variability in nonpoint and background pollutant loads, although this is not explicitly addressed in the wasteload allocation applications.

As noted above, a full dynamic modeling analysis can predict the entire effluent concentration frequency distribution, thus allowing wasteload allocations to be set to produce an expected frequency of excursions of the standard. A full dynamic analysis, however, requires a substantial level of effort and data. For instance, if recurrence intervals of 10 or 20 years are desired, at least 30 years of continuous simulation is needed to provide a sufficient record to estimate the probability of such rare events (USEPA 1991).

While DHEC has employed a dynamic model, the wasteload allocation procedure is not a full dynamic analysis; sufficient flow data are not available to undertake long-term simulation. Instead, DHEC has used the dynamic model to represent internal flow and mixing processes, and to implicitly determine critical flow conditions. The wasteload allocation analysis was then performed with other critical conditions, such as temperature, held constant. This may be termed a quasi-dynamic model application. Although based on dynamic flows, it is still essentially a design condition analysis.

This section reviews the various components of the quasi-dynamic design condition specification.

Approximate Minimum Dilution Design Conditions for Tidal Systems

In typical steady state wasteload allocation modeling, a design low flow such as the 7Q10 is used. This design flow has a low dilution capacity for effluents, and is used to implicitly establish an acceptable frequency of excursions of the standard associated with a wasteload allocation for a steady source. Within tidal systems, the concept of 7Q10 flow does not directly apply, although a 7Q10 flow of freshwater influent to the tidal system can be estimated. More importantly, dilution capacity of a tidal system is a function of both the inflow of fresh water and tidal flushing.

DHEC has adopted a quasi-dynamic modeling approach to represent tidally-driven mass fluxes and intratidal variability of concentrations within the waterbody. Boundary conditions are held
constant in the quasi-dynamic application. Because simulation is not undertaken for the long period of time necessary to establish actual average excursion frequencies, it is important to ensure that the simulation design conditions represent a suitable level of criticality in dilution capacity. A steady-state analysis would be sufficient to establish wasteload allocations. Although more than one option might be appropriate, an example approach for tidal systems is to use an analysis based on a minimum dilution level which is analogous to the 7Q10 flow used for steady state wasteload allocations in streams. USEPA (1991, p.74) makes the following recommendation for estimating critical dilution conditions for toxics in estuaries:

In estuaries without stratification, the critical dilution condition includes a combination of low-water slack at spring tide for the estuary and design low flow for riverine inflow. In estuaries with stratification, a site-specific analysis of a period of minimum stratification and a period of maximum stratification, both at low-water slack, should be made to determine which one results in the lowest dilution... Recommendations for a critical design period for coastal bays are the same as for stratified estuaries.

This approach is most applicable to acute or instantaneous standards for toxics in which intratidal variability must be considered and maximum impact is expected at the point of discharge of an effluent. For BOD/DO problems, reactions and transport within the system must also be considered and maximum DO deficit may not coincide in time with minimum dilution; it would be advisable to examine a combination of design low flow (7Q10) in riverine inflow with both spring and neap tidal ranges, which determine the maximum and minimum values of tidal mixing. With this approach, it would be helpful to examine instantaneous DO concentrations and daily average conditions over a full lunar cycle.

**Physical and Chemical Components of Design Conditions**

A number of factors other than flow or dilution capacity affect the impact of BOD loads on DO concentrations. Most notable among these is temperature: higher temperatures decrease the saturation concentration of oxygen in water, and increase reaction rates which deplete DO. The DO balance is also affected by wind-driven reaeration and influent (freshwater or tidal) concentrations of DO, BOD, and nutrients (which affect algal growth and thus DO). Design conditions for DO/BOD analysis should specify a variety of other physical and chemical factors in addition to flow. This is done automatically in a full dynamic simulation; in the quasi-dynamic approach, fixed boundary values of these supplementary parameters are specified externally. While using a dynamic simulation of flows, DHEC has specified additional critical conditions as steady state at the boundaries using the following rule:

In-stream water temperature, DO, NH$_3$N, NO$_2$, NO$_3$, PO$_4$, and BOD$_2$ critical values are determined by identifying the 95th percentile of all parameters except for DO, where the 5th percentile was identified, for the given month from STORET station monthly
sampling data located within the model's domain. These percentiles were chosen with
the thought that since a 7Q10 critical flow period approximates a 95th percentile the other
parameters should approach the same criticality.

The 7Q10 critical flow does not specifically represent a "95th percentile." The 7Q10 is calculated
as a minimum annual 7-day average which recurs once every ten years on average—so, on
average, one or more 7-day flows at least this low will be seen in one out of ten years (10% of
years). The 7Q10 is based on annual minima, and is not simply related to the actual frequency of
7-day flows. In the terminology of USEPA (1986), the 7Q10 is a hydrologically-based
recurrence interval, whereas the actual recurrence of all low dilution flows (not just annual
minima) is called a "biologically-based" recurrence interval. Further, the South Carolina
standards are based on 1-day or instantaneous flows, not 7-day flows, even though the 7Q10 is
used to establish the critical flow. Based on the analysis in USEPA (1986), the 1-day
biologically-based dilution flow with a 3-year recurrence interval averages approximately 90% of
the 7Q10 flow. Therefore, a 1-day flow at the 7Q10 value should occur in at least one out of
three years, only 0.09% of days.

A second concern is that if a 95th (or other) percentile level is desired, this is not properly
obtained by taking the 95th percentile value of each of seven observed parameters, unless the
distributions of these parameters are perfectly correlated. For example, assume that each of the
parameters is independent. For each parameter, a value equal to or greater than the 95th
percentile occurs 5% of the time. The probability of all seven parameters exceeding the 95th
percentile at the same time (if independently distributed) would be 0.05^7 = 7.81 \times 10^{-10}, or the
99.99999999th percentile. Even for three parameters (e.g., temperature, DO, and BOD, as
required for the Waccamaw model), the probability of all parameters exceeding the 95th
percentile (if independently distributed) is equal to the 99.9875th percentile. Although, some of
these parameters will be strongly correlated (e.g., the nitrogen series), increasing the probability
of co-occurrence. Others, however, (such as temperature and BOD) may be negatively
correlated, which decreases the probability of co-occurrence. Further, the analysis assumes that
the 95th percentile of these parameters is uncorrelated to the occurrence of minimum flow,
whereas nonpoint washoff processes may result in a positive relationship between flow and
pollutant concentrations, and perhaps a negative correlation between flow and temperature.

Determining appropriate critical conditions for multiple parameters is a difficult issue. It is
possible, however, that choosing the 95th percentile (5th percentile for DO) of each of these
parameters could lead to an analysis which is more stringent than is intended. Indeed, if analysis
with the 7Q10 dilution flow is assumed to implicitly establish an allowed frequency of excursion
of the standard, selection of extreme values for other design conditions would result in holding
the allocations to a lower allowed frequency of excursions than is implied in the regulation.
Unfortunately, the fact that the distributions are likely to be non-normal and correlated means
that an analysis with the other design conditions simply set to monthly mean values may under-estimate the actual frequency of excursions.

There are various approaches which can be taken here. One is to impose a protective, but more conservative assumption. For instance, the State of North Carolina sets each of these auxiliary design parameters at the outer edge of the interquartile range (75th or 25th percentile) of the observed summer distribution in a wasteload allocation. This is essentially an ad hoc compromise designed to avoid highly stringent results while retaining a (likely) conservative approach. This percentile was selected based on non-parametric analysis which suggested it provided a good representation of the actual frequency of excursions of standards (personal communication from Trevor Clements, former Chief, Technical Support Branch, Water Quality Section, NC Division of Environmental Management, now with Tetra Tech, 1/13/98).

A more rigorous alternative to specifying steady design boundary conditions is to undertake a multivariate analysis. This is the approach used in EPA’s (1988, 1991) DESCON model. While DESCON is not directly applicable to tidal systems, the general approach is relevant. DESCON estimates design conditions based on maintaining a specified desired limit on the frequency of water quality excursions in a receiving water. DESCON considers the effects that daily fluctuations in stream flow and other water quality conditions have on the capability of a receiving water to accept pollutant loadings, while explicitly accounting for the correlation present among design variables. The general approach is as follows (USEPA 1991):

1. A long-term record of observed stream flows and pertinent water quality data are assembled or synthesized.

2. The maximum allowable pollutant load that the receiving water can accept without causing a water quality excursion is computed for each day of this record.

3. This synthesized record of allowable loads is searched for the critical load, i.e., the load whose frequency of not being exceeded matches the desired water quality excursion frequency.

4. Design conditions are then derived from receiving water conditions realized during the period of record when the computed allowable load was closest to the critical load.

Unfortunately, this type of approach would be difficult to implement for the complicated tidal flow patterns of the Waccamaw and Cooper Rivers. Further, available data might not be sufficient to support such an approach. Therefore, a simpler ad hoc approach (such as choosing 75th percentile values) is a more viable option.
However, a full long-term dynamic simulation would avoid these issues by directly representing the interactions between all parameters.

Based on the discussion on the previous pages, the following options for additional design or critical condition analysis are provided:

- Set upstream uncontrolled freshwater inflows to 7Q10 flows, consistent with state regulations to represent minimum dilution design conditions while keeping a dynamic seaward boundary condition. For Pinopolis Dam, set overflows to minimum specified in operational agreement.

- Select seaward tidal boundary conditions to represent the range of spring to neap tides. This is probably best done by simulating a lunar month (from first quarter to subsequent first quarter) with the addition of a sufficient model spin-up period.

- Set seaward boundary temperature and constituent concentrations to 75th percentile values (25th percentile for DO).

- Set freshwater inflow temperature and concentration to either median observed at low flow conditions, or 75th percentile values for summer months.

- Test sensitivity of model to boundary conditions.

6. Permit Limits

The procedure set out by DHEC yields wasteload allocations to result in compliance with the “point one” antidegradation rule. Appropriate statistical methods are discussed in EPA’s (1991) TSD for Toxics. This approach to statistically-based permit limits is included as a point of discussion. It is not often applied to DO/BOD problems, but does represent a way to obtain sophisticated and accurate permit limits appropriate to dynamic model output. Other options are available that are appropriate for determining permit limits.

References


Appendix B

Input Files for BRANCH/BLTM Models
<table>
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<th>VARIABLE</th>
<th>RECOMMENDED RANGE</th>
<th>MODELED RANGE</th>
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**QUAL2E.IN**

AIW Nutrient Model June 1 94 to July 15 94 Up-dated PRODUCTION RUN NRS 4/26/99

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LABEL 3 NH3 3
LABEL 4 NO2 4
LABEL 5 NO3 5
LABEL 6 P 6
LABEL 7 BOD 7
LABEL 8 DO 8
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GRID 12  9.640  0  0.03  28.00  0.00  0.06  0.00  0.20  0.00  1.77
GRID 13 10.470  0  0.03  27.80  0.00  0.06  0.00  0.20  0.00  1.74
GRID 14 11.330  0  0.03  27.70  0.00  0.06  0.00  0.20  0.00  1.71
GRID 15 12.030  0  0.03  27.90  0.00  0.06  0.00  0.21  0.00  1.65
GRID 16 12.820  0  0.03  28.00  0.00  0.06  0.00  0.21  0.00  1.65
GRID 17 13.430  0  0.03  28.00  0.00  0.05  0.00  0.22  0.00  1.65
GRID 18 13.670  0  0.03  28.00  0.00  0.05  0.00  0.22  0.00  1.65
GRID 19 14.670  0
TIME 1   8
B  1 G 1 27.90  0.00  0.06  0.00  0.23  0.00  3.45  5.05
B 17 G 1 30.00  0.00  0.07  0.00  0.22  0.00  2.00  4.45
B 16 G 20 30.00  0.00  0.10  0.00  0.39  0.00  3.50  4.50
B 10 G 3 28.00  0.00  0.09  0.00  0.36  0.00  1.80  5.00
B 17 G 5 30.00  0.00  0.50  0.00  0.00  0.00  6.00  6.00
B 16 G 17 29.00  0.00  1.00  0.00  0.00  0.00  20.00  6.00
B 15 G 4 27.90  0.00  5.00  0.00  0.00  0.00  30.00  6.00
B  5 G 2 28.00  0.00  2.00  0.00  0.00  0.00  25.00  6.00

AIW1.CTL

BRANCH MODEL OF AIWW NETWORK FROM HWY 9 TO 501 TO 701 TO HAGLEY. Sullins w/ withdrawals
EN2421 4  0EN10950000001 0 0 15100 10000.050 1.00.00261961710010170.00210001
1.00.0000.0000.0000.00 15 0.0 0.0 0.00.002338 0.0068.000 0.0000
 0.0 0.0 -40.3  0.0  0.0 46.9  0.0 -6.2  0.0  0.0
 0.3 6.8  0.0  0.0  0.0 -17.6 12.4  0.0  0.0  0.0
 0.0  0.0  0.0
Z18  02110705 FROM= 94.06.01 24:00 TO= 94.07.15 24:00  96 -2.16   I2
Z21  02135190
Z19  02110777  96 -11.72
Z20  02110815  96 -13.95
Appendix C

Model Predicted Spatially Evaluated Instream DO
at
Five Different Time Periods
DO delta at timestep 469.5

DO in mg/l

- no load
- load

AIWWm26.77 AIWWm20.71 AIWWm15.68 AIWWm10.55 AIWWm7.53 AIWWm2.5 WACm13.43 WACm12.5 WACm11.2 b4m0.8 b5m7.2 b6m1.5 b10m1.5

56
DO delta at timestep 726.5

DO in mg/l

AIWWm26.77
AIWWm20.71
AIWWm15.68
AIWWm10.55
AIWWm5.5
AIWWm0.5
WACm13.43
WACm12.5
WACm11.2
b4m0.8
b5m7.2
b5m5.2
b10m1.5

Load

No load
Appendix D

Public Notices
NOTICE OF AVAILABILITY OF PROPOSED TMDL
FOR WATERS AND POLLUTANTS OF CONCERN IN SC

The South Carolina Department of Health and Environmental Control (DHEC) has developed a proposed total maximum daily load (TMDL) for biochemical oxygen demand for the Waccamaw River and the Atlantic Intracoastal Waterway in South Carolina and is proposing to establish this as a final TMDL. This TMDL has been developed in accordance with Section 303(d) of the Clean Water Act.

Persons wishing to offer comments or new data regarding the proposed TMDL may submit data and comments in writing no later than June 18, 1999 to Nancy Sullins, DHEC, Bureau of Water, 2600 Bull Street, Columbia, SC 29201. For more information, please contact Ms. Sullins at (803) 898-4244 or visit our website at www.state.sc.us/dhec/eqpubnot.htm.

May 17, 1999
PUBLIC NOTICE

NOTICE OF AVAILABILITY OF PROPOSED TOTAL MAXIMUM DAILY LOAD
FOR WATERS AND POLLUTANTS OF CONCERN IN THE STATE OF SOUTH CAROLINA

May 17, 1999

Section 303(d)(1)(C) of the Clean Water Act (CWA), 33 U.S.C. §1313(d)(1)(C), and EPA’s implementing regulation, 40 C.F.R. §130.7(c)(1), require the establishment of total maximum daily loads (TMDLs) for waters identified as impaired pursuant to §303(d)(1)(A) of the CWA. Each of these TMDLs is to be established at a level necessary to implement applicable water quality standards with seasonal variations and a margin of safety, accounting for lack of knowledge concerning the relationship between effluent limitations and water quality. At this time, the South Carolina Department of Health and Environmental Control (SC DHEC) has developed a proposed TMDL for the Waccamaw River and the Atlantic Intracoastal Waterway, §303(d)(1)(A) waters in watershed units 03040206-140, 03040206-150 and 03040207-030 in Horry and Georgetown Counties, South Carolina. The pollutant of concern is biochemical oxygen demand, (carbonaceous and nitrogenous), the combination of which is expressed as ultimate oxygen demand (UOD). The TMDL suggests reductions in UOD as great as 64% to meet the dissolved oxygen standard. SC DHEC is proposing to establish this as a final TMDL.

Persons wishing to comment on the proposed TMDL or to offer new data regarding the proposed TMDL are invited to submit the same in writing no later than June 18, 1999 to the South Carolina Department of Health and Environmental Control, Bureau of Water, 2600 Bull Street, Columbia, South Carolina 29201, ATTN.: Ms. Nancy Sullins. Ms. Sullins’ telephone number is 803-898-4244. Her E-Mail is sullinnr@columb32.dhec.state.sc.us.

The proposed TMDL and the administrative record, including technical information, data, and analysis supporting the proposed TMDL, may be reviewed and copied at 2600 Bull Street, Columbia, South Carolina between the hours of 8:00 a.m. and 4:30 p.m., Monday through Friday. Copies can be obtained by contacting Ms. Brenda Williams at the above address, by calling her at 803-898-4173 or by e-mail at williabb@columb32.dhec.state.sc.us. Copies will be provided at a minimal cost per page.

Following review and consideration of comments, the proposed TMDL will be sent to EPA for approval shortly after June 25, 1999.

Please bring the foregoing to the attention of persons whom you believe will be interested in this matter.
Appendix E

State of South Carolina 303(d) List for 1998