Methods to Determine Critical Period

Total Maximum Daily Loads (TMDLs) must be developed to attain applicable water quality standards and account for critical conditions. Critical conditions often represent the combination of loading, waterbody conditions and other environmental conditions that result in impairment and violation of water quality standards. They can represent times of increased loading (e.g., wet weather, seasons of increased source activity) as well as times when waterbody impairment is exacerbated due to environmental or waterbody conditions or processes (e.g., times of higher temperatures or low flow). Critical conditions for individual TMDLs typically depend on the water quality standards, characteristics of the observed impairments, source type and behavior, pollutant, and waterbody type. Critical conditions not only affect the evaluating timeframe of the TMDL analysis for representing source loading and waterbody response but also how allocations are expressed. When TMDLs are developed using supporting watershed models, such as the Chesapeake Bay TMDL, selecting a "critical period" for model simulation is essential for capturing critical conditions and providing the necessary information for calculating appropriate TMDL allocations. To aid in the selection of a critical modeling period for the Chesapeake Bay TMDL, previously completed TMDLs were reviewed, and the approaches used to determine critical period were documented.

Approaches Used in Previous TMDLs to Select the Critical Period

To determine if there is a consistent approach to establishing a critical period among the Chesapeake Bay states, EPA staff explored each state's water quality standards, polled the states and referenced previously completed TMDLs. Generally, the states' water quality standards do not address a method for establishing the critical hydrologic period. Further, EPA does not have specific guidance or regulations on how to determine critical period. EPA only requires that critical conditions and seasonal variations are considered (40 CFR §130.7 (c)(1)). EPA Region 3's approach has been that states may use any method for determining critical conditions and seasonal variations as long as the approach is supported by sound science.

In polling the Chesapeake Bay states regarding their approaches to determining the hydrology critical period, all states reported that the determination is dependent on the pollutant, the water quality standards, the TMDL endpoint and the amount of flow data available. All states reported that the critical period was determined using a representative data set capturing a range of high, low and average flows. Maryland, the District of Columbia and Virginia reported selecting the critical period based on using a dry year, an average year and a wet year. Maryland also indicated that in some TMDLs time-variable models use the worst condition in the calibration period. Although, nutrient TMDLs with steady state models use 7Q10 flows as the critical period. Delaware reported using the 7Q10 for free flowing streams and using the monthly or seasonal average flow as the critical condition for the calibration period for tidal streams. Pennsylvania reported recently beginning to use the growing season average flow as the critical period for nutrient TMDLs. West Virginia watershed TMDLs use representative precipitation induced flow data over a 6-year period with high, low and average conditions.

A review of TMDLs completed for tidally influenced streams and estuaries along the Atlantic and Gulf Coasts revealed that there is not one consistent method for determining the critical period. This review was not intended to be exhaustive, but to reveal general patterns of methodology across the country. Most TMDLs used a critical period that was protective during low flows, rather than high flows, which are of equal or greater interest for the Chesapeake Bay TMDL. The methodologies in the reviewed TMDLs typically were one of the following:

- Use of the 7Q10 or other defined low flow to represent times of worst impairment (lowest DO)
- Selection of a multi-year modeling period to capture the varying hydrologic conditions (e.g., wet year, dry year and average year)
- Selection of a specific timeframe to simulate conditions during the worst documented impairment (e.g., lowest DO)
- Selection of a modeling time period that corresponds to available data

The most commonly identified method for establishing the critical period was the use of 7Q10 flows. Frequently, 7Q10 flows are used to establish the "worst case" conditions within the waterbody. This also serves as an implicit margin of safety in many TMDLs. The Louisiana Standard Operating Procedures for Louisiana TMDL Technical Procedures (LDEQ 2009) specifically outlines the summer critical conditions for use in TMDL model projections as 7Q10 or 0.1 cfs, whichever is greater, or for tidal streams one-third of the average or typical flow averaged over one tidal cycle. Similarly winter critical conditions in model projections should be 7Q10 of 1 cfs, whichever is greater, or for tidal streams one-third of the average or typical flow averaged over one tidal cycle. There are some exceptions to the use of 7Q10 as the critical condition. Critical conditions for waterbodies heavily impacted by nonpoint source pollutants may differ from 7Q10, but must be technically justified in the TMDL report.

Other examples of using 7Q10 flows include:

- **Total Maximum Daily Load Analysis for Nanticoke River and Broad Creek, Delaware (DNREC 1998)** The model for this dissolved oxygen (DO), total nitrogen, and total phosphorus TMDL was developed and calibrated using hydrologic and hydrodynamic data from 1992, a dry year. The hydrodynamic model was run using 7Q10 flows, and the water quality model was run using 1992 pollutant loads.
- **Organic Enrichment/Dissolved Oxygen TMDL Rabbit Creek and Dog River, Alabama (ADEM 2005).** Hydrology in the LSPC watershed model was calibrated for the period of record, October 1, 1996 through September 30, 2000. Low dissolved oxygen conditions in the watershed correspond to summer periods of low flow, high temperature and salinity-induced density stratification. For the purposes of this TMDL the year 2000 was utilized as the critical low flow period. 2000 was a relatively dry year, with high temperatures and was one of the time periods over which the models were calibrated, lending confidence to the simulations. The time period of the model simulation was from 2000 to 2001. This time period was selected based on the availability and relevance of the observed data to the current conditions in the watershed. The model was calibrated for the year 2000, which represented both high and low flow periods. In 2000, flows were very low and near critical 7Q10 conditions, while in 2001 flows were higher.
- **TMDL Bayou Sara/Norton Creek – Mobile River Basin Organic Enrichment/DO (ADEM 1996).** Summer (May –November) TMDL critical conditions and MOS were established as 7Q10 flows and 30°C. The winter (December –April) TMDL critical conditions and MOS were established as 7Q2 and 20 °C.
- **Total Maximum Daily Load Cooper River, Wando River, Charleston Harbor System, South Carolina (SCDHEC 2002).** Critical conditions for this dissolved oxygen TMDL were determined in the model by setting water quality parameters to represent 75/25 percentiles. The average spring and neap tidal conditions were evaluated with fresh water inflow set to

approximate a 7Q10 recurrence, and algal processes were turned off. The model was calibrated to a three-day period and validated on a two-day period in 1993. The seasonal critical period was considered to be the low flow, high temperature conditions associated with summer and early fall because this is the timeframe with the greatest potential to reach worst case conditions.

- **Total Maximum Daily Load Ashley River, South Carolina. (SCDEHC 2003).** The recommended critical flow period includes setting uncontrolled freshwater inflows to 7Q10 flows and selecting the seaward tidal boundary to represent a full lunar month including both spring and neap tides. These conditions approach worst-case conditions for the impact of point sources on river DO levels. The wasteloads determined for these critical conditions are considered to be protective of the river DO standard when river flow is equal to or greater than 7Q10 since higher flows would provide greater dilution. Higher river flows are expected during wet weather, so the wasteloads should be protective under these conditions.

Another common method for determining the critical modeling period was the selection of a three-year time span based on precipitation, selected to include a wet year, a dry year and a normal year. Some examples of this approach include:

- **Total Maximum Daily Load Analysis for Indian River, Indian River Bay and Rehoboth Bay, Delaware (DNREC 1998).** In this nitrogen and phosphorus TMDL, the baseline period was established as 1988 through 1990. The hydrologic condition of the year 1988 was considered to represent a dry year, 1989 a wet year, and 1990 a normal year. No indication of the full data set from which the baseline period was established was given.

- **Total Maximum Daily Loads of Nitrogen and Phosphorus for Baltimore Harbor in Anne Arundel, Baltimore, Carroll, and Howard Counties and Baltimore City, Maryland (MDE 2006).** The baseline conditions scenario represents the observed conditions of the Harbor and its tributaries from 1995-1997. Simulating the system for three years accounts for various loading and hydrologic conditions, which represent possible critical conditions and seasonal variations of the system. For example, the 1995-1997 period includes an average year (1995), a wet year (1996) and a dry year (1997).

- **Total Maximum Daily Load Organic Enrichment/Dissolved Oxygen Threemile Creek, Alabama (ADEM 2006).** Hydrology in the LSPC model was calibrated for the period of available flow data, October 1, 1996 through September 30, 2000. The time period of the model simulation was from 2000 to 2001, selected based on the availability and relevance of the observed data to the current conditions in the watershed. The model was calibrated for the year 2000, which represented both high and low flow periods. The model was simulated from May 2000 through April 2001 to account for both summer (May through November) and winter (December through April) conditions. In the natural conditions model, two critical periods were selected to establish seasonal TMDLs. A period during June 2000 was simulated under natural conditions which resulted in a minimum DO concentration of 1.91 mg/L at a 5 ft depth. This June event defines critical conditions in Threemile Creek during the summer season. A period during April of 2001, the model simulated natural condition is 2.26 mg/L at a 5 ft depth and defines the winter critical period. A low flow period with high temperatures for both summer and winter seasons was utilized to represent the worst-case conditions for in-stream DO.

- **Total Maximum Daily Loads of Nutrients/Biochemical Oxygen Demand for the Anacostia River Basin, Montgomery and Prince George’s Counties, Maryland and The District of Columbia. (MDE and District of Columbia Department of the Environment 2008).** The critical condition and seasonality was accounted for in the TMDL analysis by the choice of simulation period, 1995-1997. This three-year time period represents a relatively dry year (1995), a wet year (1996), and an average year (1997), based on precipitation data, and accounts for various hydrological conditions including the critical condition.

Two of the reviewed TMDLs used the period of the worst hypoxia as the critical period. Dissolved oxygen exceedances for Long Island Sound were dominated by point sources. Further details regarding the TMDLs include:

- **A Total Maximum Daily Load Analysis to Achieve Water Quality Standards for Dissolved Oxygen in Long Island Sound (NYSDEC and CTDEP 2000)**. Annual surveys from 1986-1998 and a review of historical data indicated that the 1988-1989 modeling time frame was the most severe period of hypoxia on record. As a result, model simulations of reduced nitrogen inputs were used to predict water quality conditions that would result during the same physical conditions that exist during the 1988-89 period. The use of 1988-89 worst case scenario was considered an implicit margin of safety.

- **Total Maximum Daily Load for Nitrogen in the Peconic Estuary Program Study Area Including Waterbodies Currently Impaired Due to Low Dissolved Oxygen: the Lower Peconic River and Tidal Tributaries; Western Flanders Bay and Lower Sawmill Creek; and Meetinghouse Creek, Terrys Creek and Tributaries (Peconic Estuary Program 2007)**. The Environmental Fluid Dynamics Code (EFDC) model was calibrated using an eight-year period from October 1, 1988 to September 30, 1996 and validated using the six-year period from October 1, 196 through September 30, 2002. Model calibration and verification included all seasons of the year, as well as extreme wet and dry years. Monitoring data indicated that the October 2000 to September 2002 time frame was the most severe period of hypoxia on record from 1988-2002. October 1, 2000 to September 30, 2002 was selected as the critical period for the TMDL model runs.

In some cases, the data set either does not contain a critical year or several years are included to capture a range of temperature and flow concentrations. The *TMDLs for The Little Assawoman Bay and Tributaries and Ponds of the Indian River, Indian River Bay, and Rehoboth Bay* (DNREC 2004) is an example of the former. There was no "worst" year for dissolved oxygen, nitrogen and phosphorus during the three-year period in question, so the average over the three summers was used as the critical (design) condition. The *TMDL for Nutrients in the Lower Charles River Basin, Massachusetts* (MassDEP and USEPA 2007) is an example of the latter. A continuous five-year simulation was run. The 1998-2002 period was selected because it represented some of the lowest summer flows throughout the 23 period of record. Low flows at or near the 7Q10 flow value were observed during three of the summers during the selected critical period.

Two of the TMDLs reviewed had limited data sets, so the critical period was chosen based on the period with the most data available. Examples of this approach include:

- **Total Maximum Daily Loads of Nitrogen and Phosphorus for the Upper and Middle Chester River, Kent and Queen Anne's Counties, Maryland (MDE 2006).** The models were calibrated to the period of 1997-1999, which was the most recent period for which all of the needed data were available and consistent with the Chesapeake Bay Program modeling efforts of the Tributary Strategies. Only the output from 1997 was used to investigate different nutrient loading scenarios and calculate the annual average and growing season TMDLs for the Upper and Middle Chester Rivers because in 1999, the region experienced extreme weather conditions (prolonged drought followed by Hurricane Floyd) resulting in atypically high flows and loads. Based on the flow gauge, it was determined that the flow in 1997 was representative of the average annual flow and loads. The timeframe selected includes representative wet and dry periods, accounting for seasonality and critical conditions.

- **Total Maximum Daily Load for Dissolved Oxygen in Mill Creek, Northampton County, Virginia (VADEQ 2009).** The observations show that the instantaneous DO levels fell below the water quality criterion of 4 mg/L minimum repeatedly throughout the period of 1997-2003. Because the nutrients data in the watershed were not available, an interactive approach of calibration of watershed and in-stream water quality model was conducted using all available in-stream monitoring data. The water quality model was calibrated in Mill Creek using the observation data. A six-year model simulation (1998-2003) was conducted. Seasonal variations involved changes in surface runoff, stream flow, and water quality condition as a result of hydrologic and climatologic patterns. These were accounted for by the use of this long-term simulation to estimate the current load and reduction targets.

Overall, the approaches to determine the critical period involved attempts to incorporate low flow conditions. Some TMDLs specifically incorporated 7Q10 flows. Others, often due to lack of reliable data, chose general low flow years and did not specify whether they were 7Q10 flows.

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