Patton Creek TMDL Report Summary

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Patton Creek is a Cahaba River tributary, located in Jefferson County, in Hoover and Vestavia Hills. The Patton Creek watershed comprises of 17 square miles of drainage area and has a Fish and Wildlife (F&W) use classification. The land use/cover characteristics of the watershed are primarily forested and residential. Patton Creek has been on Alabama's §303(d) list since 1996 for organic enrichment/dissolved oxygen (OE/DO). A data analysis and field assessment identified low DO levels in the Patton Creek watershed associated with low flows and high levels of sediment oxygen demand (SOD) in the impoundment area at the downstream end of the creek before the confluence at the Cahaba River, and high nutrient loads from leaking septic tanks and urban runoff. In accordance with the water quality criteria for the State of Alabama, OE/DO numeric targets are 5.0 mg/L concentrations that are found by taking water samples at the stream's mid-depth level if the depth is less than 10 feet, or at the 5-foot level if the depth is greater than 10 feet.

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 in-stream water quality conditions so that 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. The pollutants shown in the TMDL table for the listed segment includes ultimate carbonaceous biochemical oxygen demand (CBOD) and nitrogenous biochemical oxygen demand (NBOD). The CBOD and NBOD measures the oxygen required for the total degradation of organic material (ultimate carbonaceous demand) and/or the oxygen to oxidize reduced nitrogen compounds (ultimate nitrogenous demand).[2] The TMDL for Patton Creek includes reductions necessary to reduce long-term sediment oxygen demand (SOD) within the system to meet water quality standards for DO. For the critical flow simulation, the TMDL used data from the summer month of August because it is typically the month with the lowest rainfall amount for the region. Compliance under critical summer conditions assures that standards are met throughout the year.

The ADEM Spreadsheet Water Quality Model (SWQM) was used to simulate the DO scenarios for the critical conditions of Patton Creek, in order to determine the TMDL concentrations. The TMDL is presented in Table 1.

Table 1 Maximum Allowable NBOD and CBOD Loads for Patton Creek

Constituent	Existing Load (lb/day)	TMDL (lb/day)	Load Reduction	
	WLA_{MS4} + LA	WLA_{MS4} + LA	WLA_{MS4}	LA
$NBOD_U$	76.8	26.4	66%	66%
$CBOD_U$	25.5	19.5	24%	24%

NOTE: The load reductions are expressed as both WLA_{MS4} and LA percent reductions because the entire Patton Creek watershed is contained within the boundaries of the Jefferson County MS4 Phase I Permit (ALS000001).

The wasteload allocation (WLA) of the TMDL represents the contributions from point source discharges, including the storm water sewer system. The Patton Creek watershed lies within a Phase I Municipal Separate Storm Sewer System (MS4). Since no facilities are currently permitted to discharge oxygen-consuming wastes directly to Patton Creek, the only National Pollutant Discharge Elimination System (NPDES) permit in the watershed is the MS4 Phase I permit. Therefore, the WLA represents loads from land use activities in the watershed that are regulated under the MS4 Phase I Permit. The entire watershed is within a MS4 area. Therefore, all sources of urban runoff will be considered as stormwater wasteloads. The load reduction required for NBOD in Patton Creek is 76.8 to 26.4 pounds per day, which is a reduction of 50.4 pounds per day or a 66% reduction. The load reduction required for CBOD in Patton Creek is 25.5 to 19.5 pounds per day, which is a reduction of 6 pounds per day or a 24% reduction. The TMDL developed for the Patton Creek watershed is consistent with a phased-approach where estimates are made of needed pollutant reductions, load reduction controls are them implemented, and water quality is then monitored for plan effectiveness.

DO concentrations less than 5.0 mg/L are caused by historic and anthropogenic loads of oxygen consuming waste to the creek. Also, DO is low due to high SOD concentrations occurring naturally at the impoundment at the downstream end of the creek. Historically, a wastewater treatment facility discharged to the system but ceased operation in 1996. Current anthropogenic sources of oxygen consuming waste are attributed to urban runoff and leaking septic systems in the watershed. The TMDL specifies NBOD and CBOD reductions to reduce the oxygen demanding sources in the stream and also to reduce the SOD in the impoundment area to ensure DO concentrations of at least 5.0 mg/L at all times.

Jefferson County, the City of Birmingham, and 22 other municipalities are included in one MS4 permit regulated by the NPDES program (ALS000001). During rain events sediment and other compounds, including oxygen-consuming waste, from urban areas are transported to the stream by road drainage systems and storm drain outlets. The potential sources of loading are therefore numerous and have been identified based on an evaluation of available landuse/cover (e.g., urban high density or forested land). A source assessment was used as the basis of development of the SWQM model and the ultimate analysis of the TMDL allocations.

A landuse map of the Patton Creek watershed was used to identify the landuse percentages listed in Table 2. The predominant land use practices within the watershed is forest and residential with 55.3 percent and 32 percent, respectively. Each landuse type has the potential to contribute to the organic loading in the watershed due to organic material on the land surface that potentially can be washed off into the receiving waters.

Table 2 Percent Landuse for the Patton Creek Watershed:

Cataloging Unit	Forest	Residential	Urban	Open Water	Other
Patton Creek (AL/03150202-030_03)	55.3%	32%	3.4%	0.5%	8.8%

The dissolved oxygen deficit in Patton Creek can be attributed to oxygen consuming loads that are delivered to the creek measured by BOD (5-day) and ammonia (NH3) concentrations, and the deposition of organic matter in the impoundment that exerts an oxygen demand as the matter decays over time called sediment oxygen demand (SOD).

An evaluation of the density of septic systems was conducted to consider the possibility of oxygen consuming wastes from leaking septic systems in the watershed. Areas in the north and western portions of the watershed were found to have a high distribution of septic systems. The high distribution was considered in the ammonia calibration of the SWQM used in the TMDL development.

ADEM has collected chemical and in situ data at various locations on Patton Creek since 1995. The most intensive of these studies were conducted during 2002 and 2003. This data is necessary to characterize loading inputs in the watershed. Physiographic data used to determine the TMDL include watershed topography and landuse activities. This data was used to simulate flows and water quality in Patton Creek. Digital elevation maps (DEMs) in conjunction with the national hydrography database reach network (NHD) was used to establish watershed boundaries and flow paths. Finally, multi-resolution land coverage (MRLC) provided the landuse practices and distributions. The MRLC maps are made using remote sensing software with algorithms on aerial photography. The algorithm used is a Normalized Difference Vegetation Index (NDVI), which is a graphical indicator that identifies and quantifies whether a target area being observed contains live green vegetation or not.[3]

In 1995, ADEM began monitoring Patton Creek just upstream of its confluence with the Cahaba River and downstream of the small impoundment at PA1A. In addition to PA1A, ADEM has collected water quality data at five other locations, shown in Figure 1. The stations were monitored as part of the §303(d) rotating basin program in 2002 then again in 2003. This data was collected over several months in both years and even in the summer months so that the water quality could be represented during dry and wet seasons. This data was the focus of the source assessment, model inputs, and calibration. The data in 2003 was collected under higher flow conditions due to more precipitation during these months. Figure 2 is evident of the higher flow conditions in 2003 versus 2002 and the increase in DO violations during a dry time period in 2002.

Figure 1 ADEM Monitoring Stations on Patton Creek

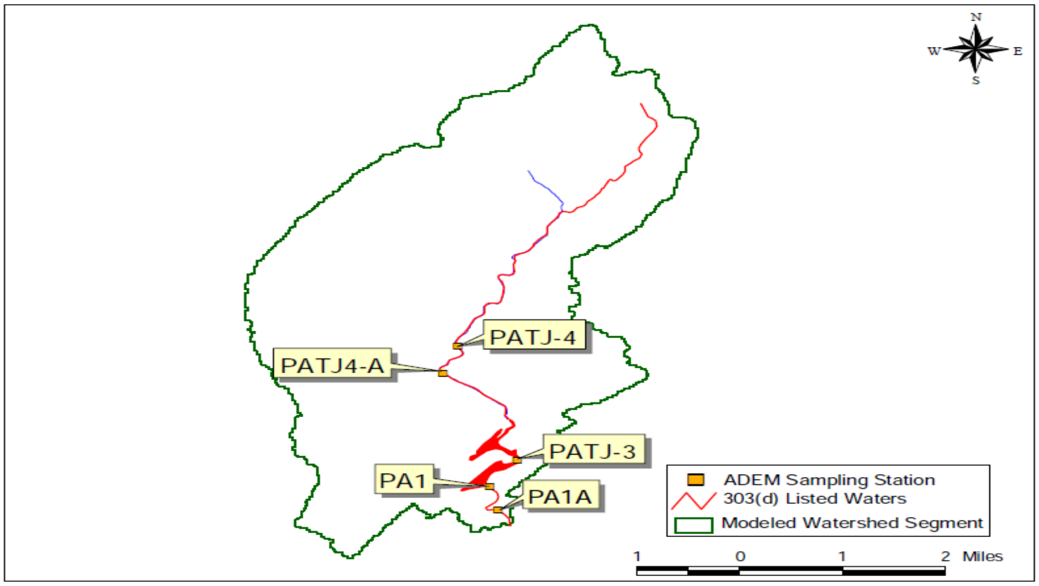
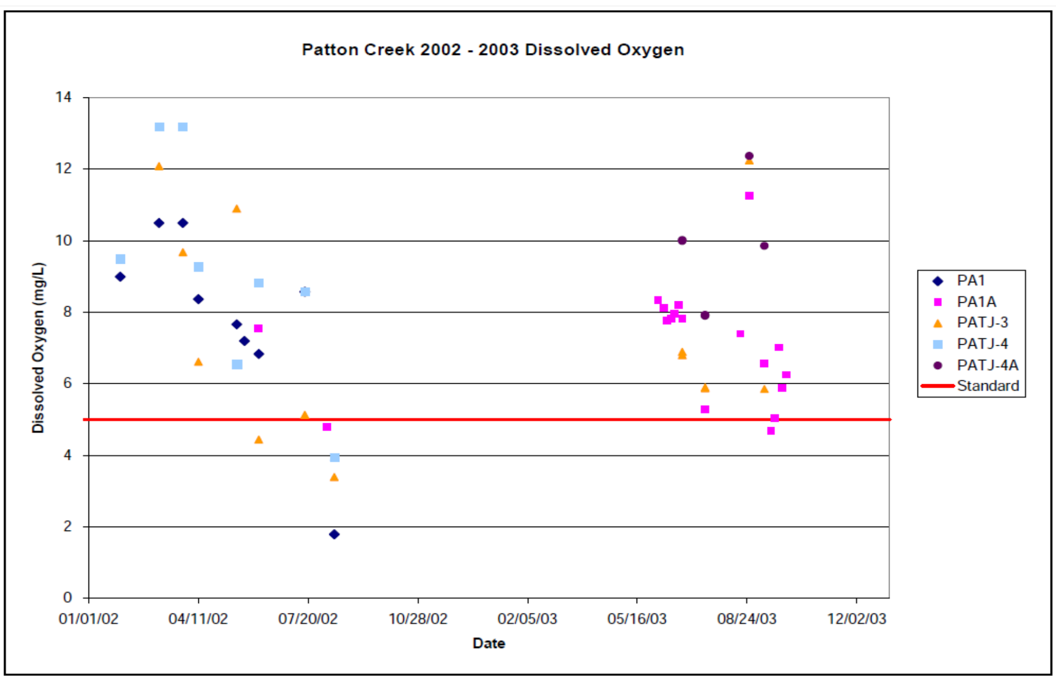
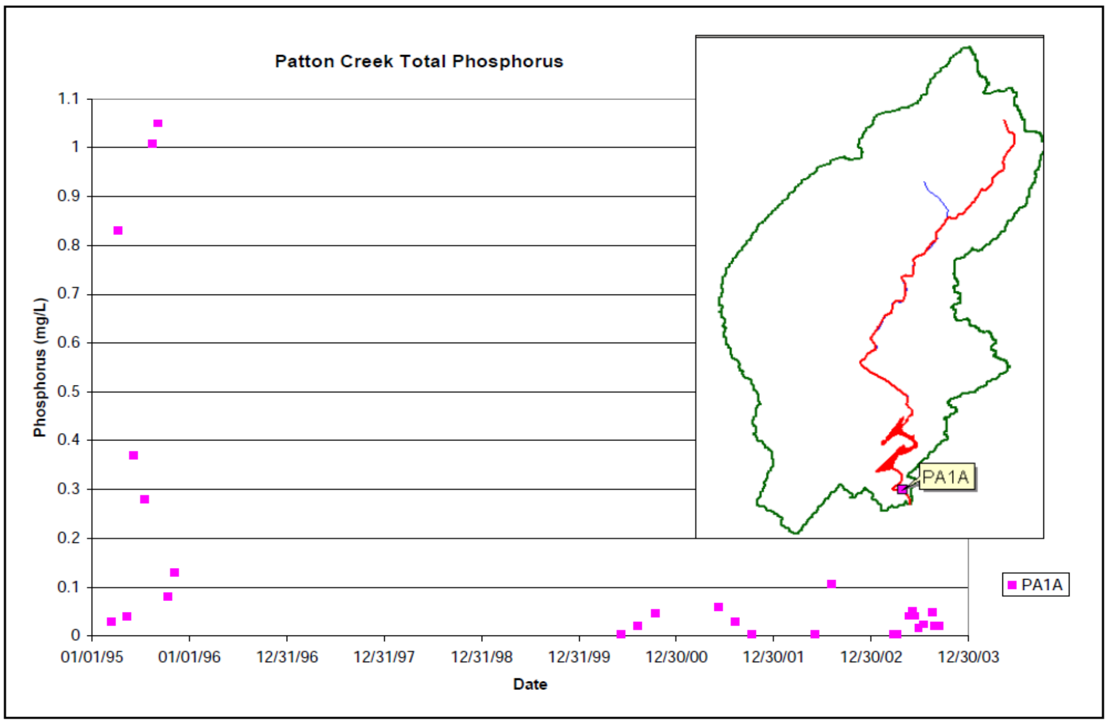


Figure 2 Patton Creek Dissolved Oxygen in 2002 and 2003



Data collected by ADEM includes flow measurements, DO, and nutrient sampling. This data was plotted to establish trends in water quality. The presence of the wastewater discharge can be seen in the total phosphorus samples collected by ADEM at PA1A in 1995 and 2002-2003, as shown in Figure 3. Changes in creek nutrient quality based on phosphorous concentrations can be seen before and after the closing of the waste water treatment plant in 1996.

Figure 3 Patton Creek Total Phosphorous



For the TMDL, the ADEM Spreadsheet Water Quality Model (SWQM) was used to relate DO concentrations in the stream to Carbonaceous Biochemical Demand (CBOD), Nitrogenous Biochemical Oxygen Demand (NBOD), Sediment Oxygen Demand (SOD) and reaeration. A steady state model, SWQM, was used to represent the source-response linkage in the watershed. The model was selected for OE/DO TMDL development based on the availability of data, seasonal variations in DO concentrations, and low flow conditions in Patton Creek. SWQM is based on the Streeter-Phelps DO deficit equation with modifications to account for oxygen demand resulting from nitrification of ammonia (nitrogenous biochemical oxygen demand) and organic demand fund in the water body sediment. The Streeter-Phelps relationship with additional components to account for nitrification and SOD is show below as Equation (1).

$$(1)\ D = \frac{K_1 L_0}{K_2 - K_1}\left(e^{-K_1 t} - e^{-K_2 t}\right) + \frac{K_3 N_0}{K_2 - K_3}\left(e^{-K_3 t} - e^{-K_2 t}\right) + \frac{SOD}{K_2 H}(1 - e^{-K_2 t}) + D_0 e^{-K_2 t}$$

where: D = DO deficit at time t, mg/l
L_0 = initial CBOD, mg/l
N_0 = initial NBOD, mg/l (NBOD = NH_3-N x 4.57)
D_0 = initial DO deficit, mg/l
K_1 = CBOD decay rate, 1/day
K_2 = reaeration rate, 1/day
K_3 = nitrification rate, 1/day
SOD=sediment oxygen demand, g O_2/ft^2/day
H=average stream depth, ft
t = time, days

The CBOD concentration, expressed as L_0 in the above equation, is the ultimate carbonaceous biochemical oxygen demand (CBOD), which can be determined by Equation (2), as shown below.

$$(2)\ L = L_u e^{-K_1 t}$$

where: L = CBOD remaining at any time, t, mg/l
L_u = $CBOD_U$, mg/l = Lo
(Eqn 1)
K_1 = CBOD decay rate, 1/day
t = time, days

In the presence of nitrifying bacteria, ammonia is oxidized first to nitrite, then to nitrate. The oxidation reaction is assumed to be first order and would have the form shown in the Equation (3):

$$(3)\quad N = N_0 e^{-K_3 t}$$

where: N = NBOD remaining at any time, t, mg/l
N_0 = initial NBOD, mg/l
K_3 = nitrification rate, 1/day
t = time, days

The conversion of organic nitrogen to ammonia is assumed to follow first-order kinetics and is represented by Equation (4):

$$(4)\quad NH_3 - N = ORG\left(1 - e^{-K_4 t}\right)$$

where: NH_3-N = ammonia nitrogen produced by hydrolysis of organic nitrogen, mg/l
ORG = initial organic nitrogen concentration, mg/l
K_4 = organic nitrogen hydrolysis rate, 1/day
t = time, days

The process by which oxygen enters a stream is known as reaeration. Equation (1) shows the net effect on DO concentration of the simultaneous processes of deoxygenation through the decay of carbonaceous organic matter, nitrification of ammonia, SOD, and reaeration. Numerous equations for estimating a stream's reaeration rate have been developed and many are presented in Rates, Constants, and Kinetic Formulations in Surface Water Quality Modeling, 2nd edition, USEPA. Reaeration rates in the SWQM can be either entered directly or computed using the formula developed by E.C. Tsivoglou and shown in Equation (5).

$$(5)\ K_2 = C(Slope)(Velocity)$$

where: K_2 = reaeration rate at 20°C, 1/day
C = Tsivoglou Coefficient
C = 1.8 when stream flow < 10 cfs
C = 1.3 when stream flow > 10 cfs and < 25 cfs
C = 0.88 when stream flow > 25 cfs
Slope = water surface slope, feet/mile
Velocity = water velocity, feet/second

Another commonly used method for estimating a stream's reaeration rate is the O'Conner-Dobbins formulation shown in Equation (6). This formulation generally works best for streams with a depth of greater than 5 feet and a slope of less than 2 feet/mile.

$$(6)\ K_2 = \frac{12.9U^{0.5}}{H^{1.5}}$$

where: K_2 = reaeration rate at 20°C, 1/day
U = stream velocity, feet/second
H = stream depth, feet

Temperature affects the rate at which reactions proceed. Reaction rates are generally expressed with units of per day at 20°C. If the reactions are occurring at a temperature other than 20°C, then the reaction rates must be corrected for the new temperature. The most commonly used expression to adjust reaction rates for temperature is the modified Arrhenius relationship shown in Equation (7):

$$(7)\ K_{T_2} = (K_{20^\circ C})\Theta^{(T_2 - 20)}$$

where: K_{T2} = reaction rate at the new temperature, 1/day
$K_{20^\circ C}$ = reaction rate at 20°C, 1/day

The model was calibrated to critical low flow conditions using data collected during low flow conditions in August 2002. Rates for CBOD decay, nitrification, and total organic nitrogen (TON) hydrolysis were consistent in each of the modeled segments. Reaeration rates were calculated in most of the segments but input in segments to represent conditions in the impoundment and just upstream of the impoundment, which is located at segments 5, 6, and 7. Table 3 shows the adjusted rate constants used Equation (1) for the SWQM.

Table 3 SWQM Parameters Used in Model Calibration and TMDL Allocation Scenarios

Parameter in SWQM	Definition	Value Used in Model Calibration and TMDL	Units
K_d	CBOD Decay Rate	0.1	1/day
K_{NH3}	Nitrification rate	0.1	1/day
K_{TON}	TON Hydrolosis Rate	0.05	1/day
K_a	Reaeration Rate	0.6 to 2.06	1/day

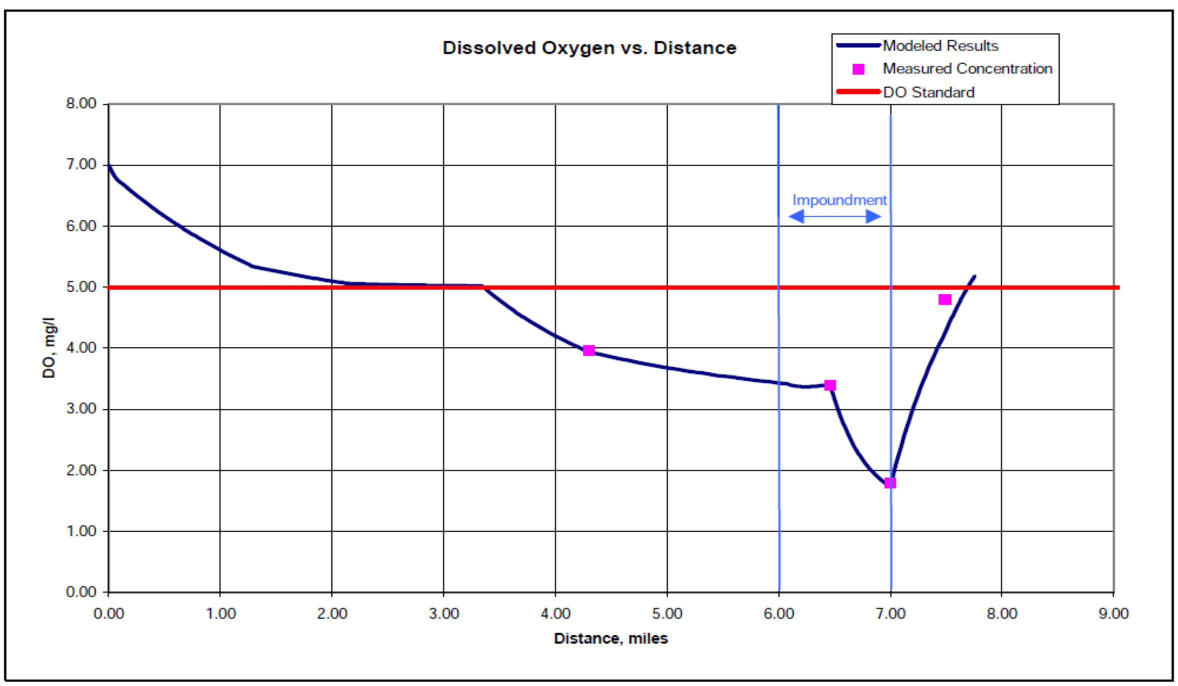
SOD rates were also input into the model and varied by segment. Table 4-2 represents the SOD rates used to calibrate the Patton Creek SWQM. The rates in the impoundment, at segments 5, 6, and 7, of Patton Creek are believed to be much higher than in the upper segment as sediment settles out of the water column.

Table 4 Sediment Oxygen Demand Calibrated on Patton Creek

Segment #	SOD, gm-O_2/ft^2/day	SOD, gm-O_2/m^2/day
1	0.010	0.11
2	0.010	0.11
3	0.010	0.11
4	0.050	0.54
5	0.100	1.08
6	0.250	2.69
7	0.250	2.69
8	0.010	0.11
9	0.010	0.11

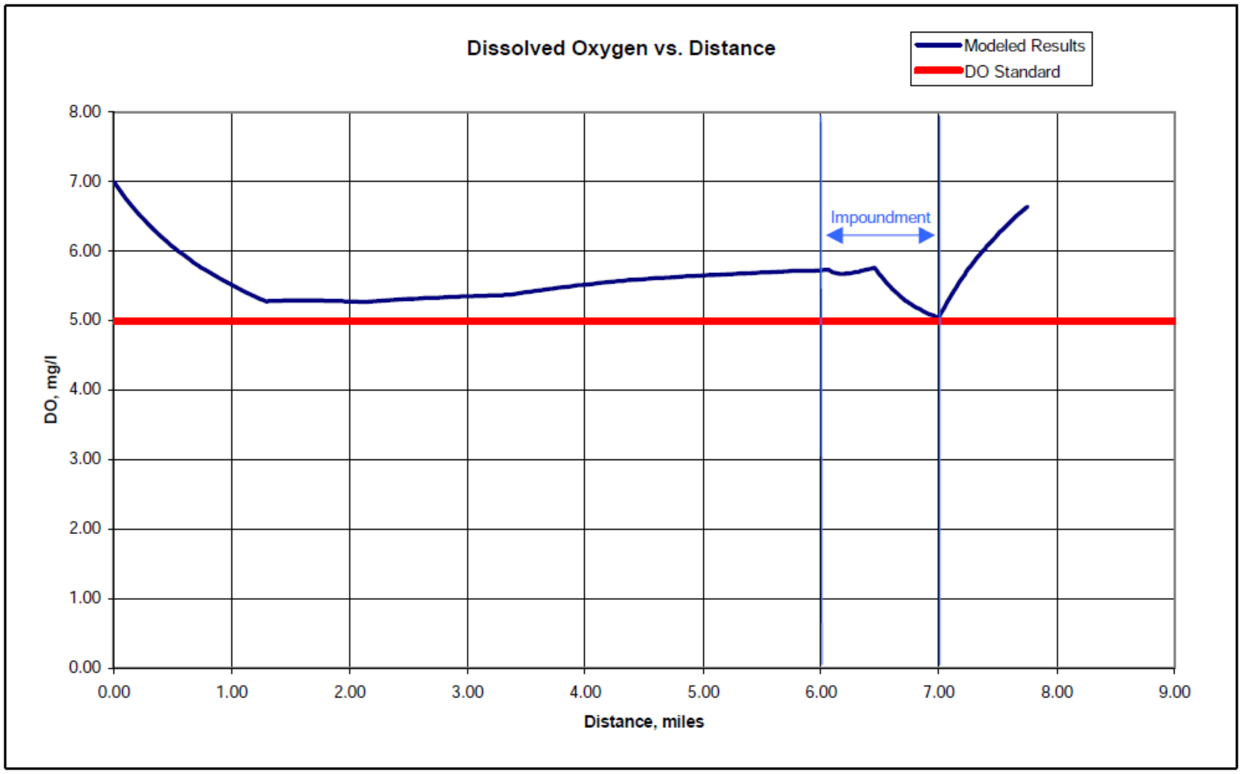
The modeled DO calibration and TMDL scenario are illustrated in Figures 4. Dramatic changes in longitudinal water quality concentrations can be seen at the small impoundment where it holds water between mile 6.0 and 7.0.

Figure 4 Patton Creek SWQM Dissolved Oxygen Calibration



The TMDL scenario shown in Figure 5 represents a load reduction to meet the water quality criterion of 5.0 mg/L. The CBOD (BOD), NBOD (NH3), and SOD were reduced until the water column dissolved oxygen in the model met the 5.0 mg/L target. It is well-documented that a reduction in CBOD and NBOD loads will result in an improvement to the SOD exhibited by the sediments. This is especially true for an impoundment, at mile 6 and 7, which tends to capture and concentrate all of the upstream loads from the watershed. For the purposes of this TMDL, the SOD was reduced in the model to a value of 0.12 grams of O_2/ft^2/day (equal to 1.25 grams of O_2/m^2/day) in the impoundment to represent reduced oxygen consumption due to settling and decay of organic matter in the impoundment. After many SOD measurements and DO TMDL developments in the southeast (in particular where SOD measurements and modeling has occurred such as the Flint Creek, Alabama and the southern four basins in Georgia by EPA Region 4), the 1.25 grams of O_2/m^2/day represents an achievable SOD of a mixed land use to meet the water quality standards of DO. Once the model was updated with the reduced SOD, the CBOD and NBOD loads were reduced to meet the 5.0 mg/L target, as shown below in figure 5.

Figure 5 Patton Creek SWQM Dissolved Oxygen TMDL Scenario



A TMDL is expressed as WLA for point source discharges from facilities and activities regulated by the NPDES permit program and Load Allocation (LA) for all nonpoint sources. The TMDL must also incorporate an appropriate margin of safety (MOS), which takes into account any uncertainty concerning the relationship between effluent limitations and water quality. For the purpose of the TMDL, a low flow period month in August 2002 was used to develop the critical conditions.

An implicit margin of safety (MOS) is assumed because of the removal of the wastewater facility. It is expected that there is and will continue to be an improvement of the SOD in the impoundment due to the removal of the plant in 1996. All of the impairments occurred during low flow conditions. Other periods, during higher flows were examined with no DO concentrations below 5.0 mg/L, resulting in a higher assimilative capacity. A higher assimilative capacity refers to an increased ability of a body of water to cleanse itself, and an increase in its capacity to receive waste waters or toxic materials without detrimental effects and without damage to aquatic life or humans who consume the water.[4] There are no facilities permitted under the NPDES program permitted to discharge directly to Patton Creek. The TMDL concentration will ensure the necessary watershed wasteloads meet water quality standards for DO.

An effective water quality monitoring program is a key component of a TMDL process that incorporates adaptive management; it provides vital information concerning the effectiveness of control measures being implemented as well as provides the necessary data to address known data gaps and uncertainties. ADEM has adopted a basin approach to water quality management; an approach that divides Alabama's fourteen major river basins into five groups. Each year, the ADEM water quality resources are concentrated in one of the basin groups. One goal is to continue to monitor §303(d) listed waters. By implementing and enforcing TMDL standards, ADEM's management of the basins water quality is upgraded from simply monitoring to actually improving the water quality of the watershed, which should be the goal of any storm water management program.

Works Cited

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