FINAL REPORT
September 1999
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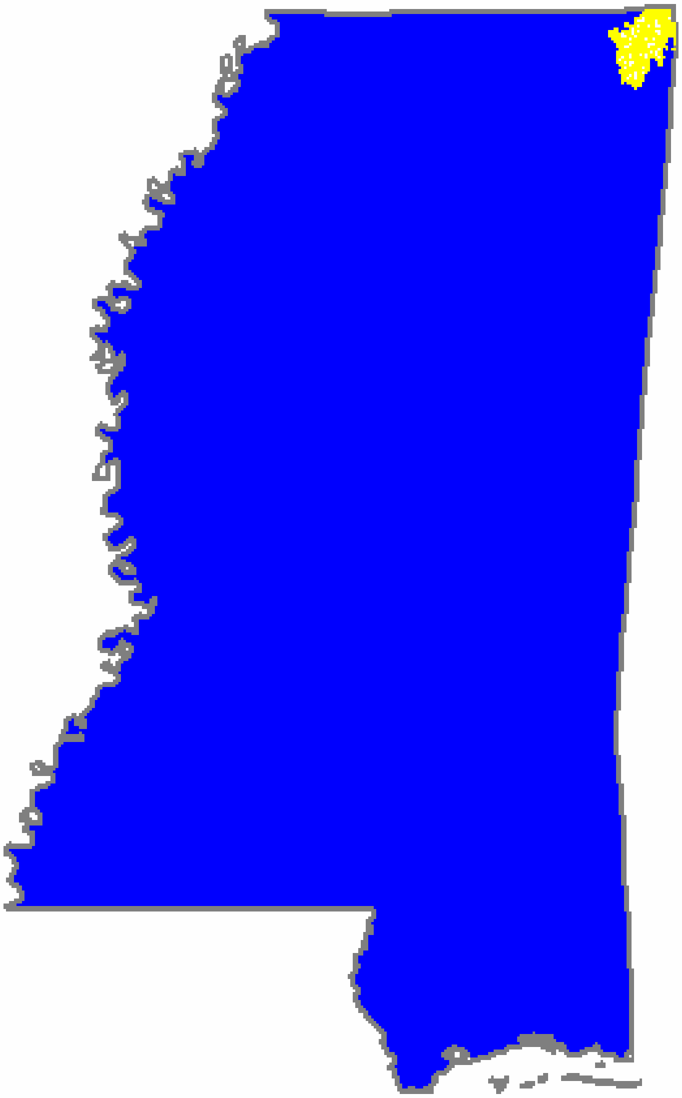
Total Maximum Daily Load
For Organic Enrichment/Low DO

Indian Creek

Tennessee Basin
Tishomingo County, Mississippi



Prepared By

**Mississippi Department of
Environmental Quality**

**Office of Pollution Control
TMDL/WLA Section
Water Quality Assessment
Branch**

**MDEQ
PO Box 10385
Jackson, MS 39289-0385
(601) 961-5171
www.deq.state.ms.us**

FOREWORD

This report has been prepared in accordance with the schedule contained within the federal consent decree dated December 22, 1998. (*Sierra Club v. Hankinson, No. 97-CV-3683* (*N.D. Ga.*)) The report contains one or more Total Maximum Daily Loads (TMDLs) for waterbody segments found on Mississippi's 1996 Section 303(d) List of Impaired Waterbodies. Because of the accelerated schedule required by the consent decree, many of these TMDLs have been prepared out of sequence with the State's rotating basin approach. The segments addressed are comprised of monitored segments that have data indicating impairment. The implementation of the TMDLs contained herein will be prioritized within Mississippi's rotating basin approach.

Although this report is based on reliable scientific data, if additional information becomes available, the TMDLs may be updated. Such information may include additional water quality and quantity data, changes in pollutant loadings, or changes in landuse within the watershed.

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MONITORED SEGMENT IDENTIFICATION

Name:	Indian Creek seg 2
Waterbody ID:	MS192IM2
Location:	At Iuka: From Iuka POTW outfall to confluence with Pickens Creek.
County:	Tishomingo County, Mississippi
USGS HUC Code:	06030005
NRCS Watershed:	192
Length:	3 miles
Use Impairment:	Fish and Wildlife
Cause Noted:	Organic Enrichment/Low DO Indicated by Biological Sampling
Priority Rank:	147
NPDES Permits:	Iuka POTW, NPDES Permit Number MS0025062
Pollutant Standard:	Dissolved oxygen concentrations shall be maintained at a daily average of not less than 5.0 mg/L with an instantaneous minimum of not less than 4.0 mg/L in streams.
Waste Load Allocation:	162.9 lbs/day of TBODu in the summer (May – October) 238.0 lbs/day of TBODu in the winter (November – April)
Load Allocation:	33.2 lbs/day of TBODu in the summer (May – October) 33.2 lbs/day of TBODu in the winter (November – April)
Margin of Safety:	Implicit modeling assumptions - The model was run for critical, low-flow, high-temperature conditions and checked for seasonality.
Total Maximum Daily Load (TMDL):	196.1 lbs/day of TBODu in the summer (May – October) 271.2 lbs/day of TBODu in the winter (November – April)

EXECUTIVE SUMMARY

A segment of Indian Creek has been placed on the Mississippi 1998 Section 303(d) List of Waterbodies as an impaired waterbody segment. The impairment was detected based on biological monitoring. Biological impairment indicates impairment for waterbodies in which at least one biological assemblage (fish, macroinvertabrates, or algae) indicates less than full support with moderate modification of the biological community noted. Based on an evaluation of available data, it was determined that organic enrichment which causes low instream dissolved oxygen (DO) levels is the specific pollutant responsible for the biological impairment in Indian Creek. Thus, this TMDL has been developed for total ultimate biochemical oxygen demand (TBODu), based on the applicable state standard for DO. For the waterbody segment, the applicable state standard specifies that the DO concentrations shall be maintained at a daily average of not less than 5.0 mg/L with an instantaneous minimum of not less than 4.0 mg/L.

Photo 1. Indian Creek North of Iuka, MS

Indian Creek is a waterbody in the Tennessee River Basin. The headwaters of Indian Creek begin in Tishomingo County at Iuka, MS. It flows in a northeastern direction to its confluence with Pickwick Lake, which is an impoundment of the Tennessee River. The entire length of Indian Creek, from headwaters to confluence with Pickwick Lake is approximately 13 miles. This TMDL, however, has been developed for the segment of Indian Creek found on the 1998 303(d) list. Segment MS192IM2 begins at the Iuka POTW and continues downstream for 3 miles, ending at the confluence of Pickens Branch. The location of the segment is shown in Figure 1.

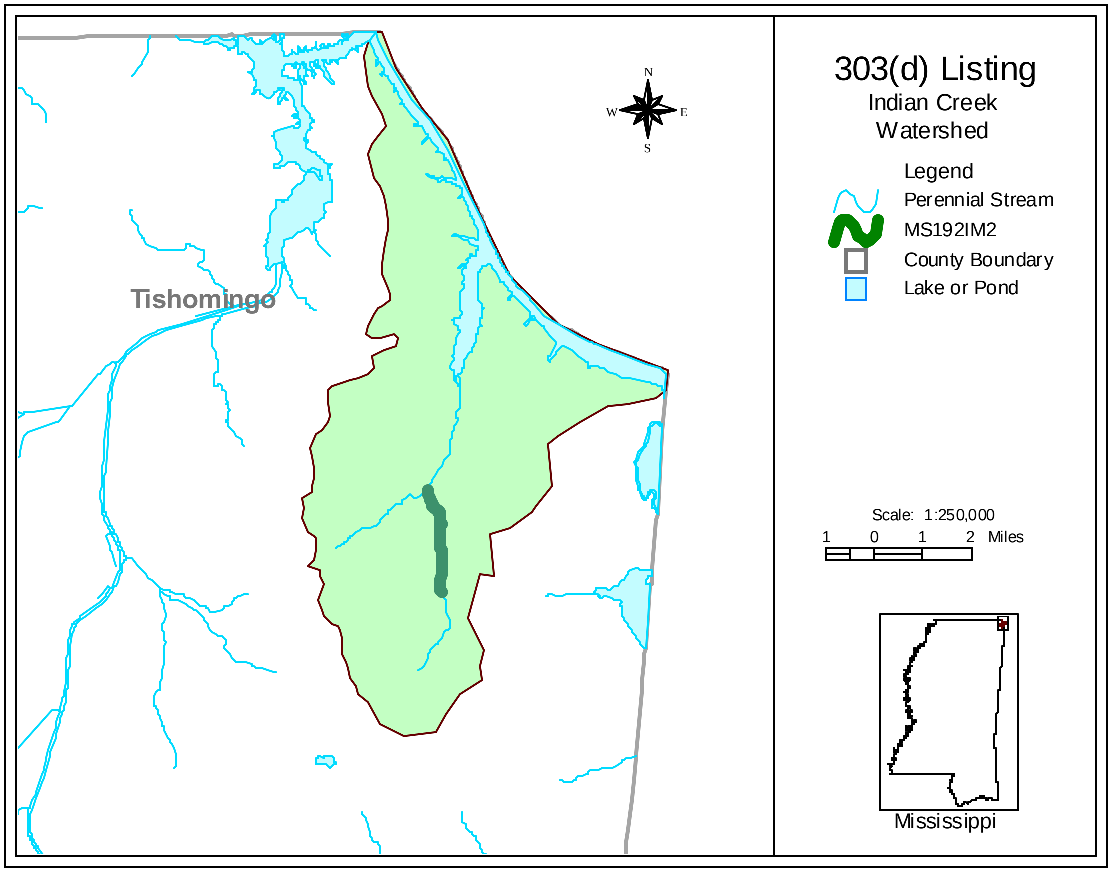


Figure 1. Location of the Impaired Segment of Indian Creek

A mathematical model for DO distribution in streams, QUAL2E, was selected as the model for performing the TMDL allocations for this study. The model was calibrated using data that were collected during an intensive study of Indian Creek conducted by MDEQ in August - September 1998. The TMDL was developed using critical instream conditions at the 7Q10 flow. Load allocations and waste load allocations were developed to account for seasonal variations in stream temperature, DO saturation, and ultimate carbonaceous biochemical oxygen demand (CBODu) decay rate.

The model used in developing this TMDL included both nonpoint and point sources of TBODu. TBODu loading from nonpoint sources in the watershed was accounted for by measuring the background loads of TBODu in the headwaters of Indian Creek. The Iuka POTW facility is the primary point source of TBODu in the watershed. The assimilative capacity of Indian Creek is less than the existing NPDES permitted load from the Iuka POTW facility. Thus, a commensurate reduction in the facility's permit limit is recommended by this TMDL.

1.0 INTRODUCTION

1.1 Background

The identification of waterbodies not meeting their designated use and the development of total maximum daily loads (TMDLs) for those waterbodies are required by Section 303(d) of the Clean Water Act and the Environmental Protection Agency's (EPA) Water Quality Planning and Management Regulations (40 CFR part 130). The Mississippi Department of Environmental Quality (MDEQ) has identified a segment of Indian Creek as being impaired for a total length of 3 miles as reported in the Mississippi 1998 Section 303(d) List of Waterbodies. The TMDL process is designed to restore and maintain the quality of those impaired waterbodies through the establishment of pollutant specific allowable loads. The TMDL process can be used to establish water quality based controls to reduce pollution from both point and nonpoint sources, and restore and maintain the quality of water resources.

The pollutant of concern for this TMDL is organic enrichment/low DO. Organic enrichment is measured in terms of total ultimate biochemical oxygen demand (TBODu). TBODu is the oxygen consumed by microorganisms while stabilizing or degrading carbonaceous and nitrogenous compounds under aerobic conditions over an extended time period. The carbonaceous compounds are referred to as CBODu, and the nitrogenous compounds are referred to as NBODu. TBODu is equal to the sum of NBODu and CBODu, Equation 1.

$$\boxed{\mathbf{TBODu = CBODu + NBODu}} \qquad \text{(Equation 1)}$$

Indian Creek is in the Tennessee River Basin Hydrologic Unit Code (HUC) 06030005 in northeastern Mississippi. The drainage area of Indian Creek, from the headwaters to the end of the segment MS192IM2, is approximately 6,116 acres and lies entirely within Tishomingo County. Figure 2 shows the landuse distribution within the watershed. The 6,116-acre drainage area of Indian Creek contains many different landuse types, including urban areas, forests, cropland, pasture, barren, and wetlands. The landuse information is based on data collected by the State of Mississippi's Automated Resource Information System (MARIS). This data set is based on Landsat Thematic Mapper digital images taken between 1992 and 1993.

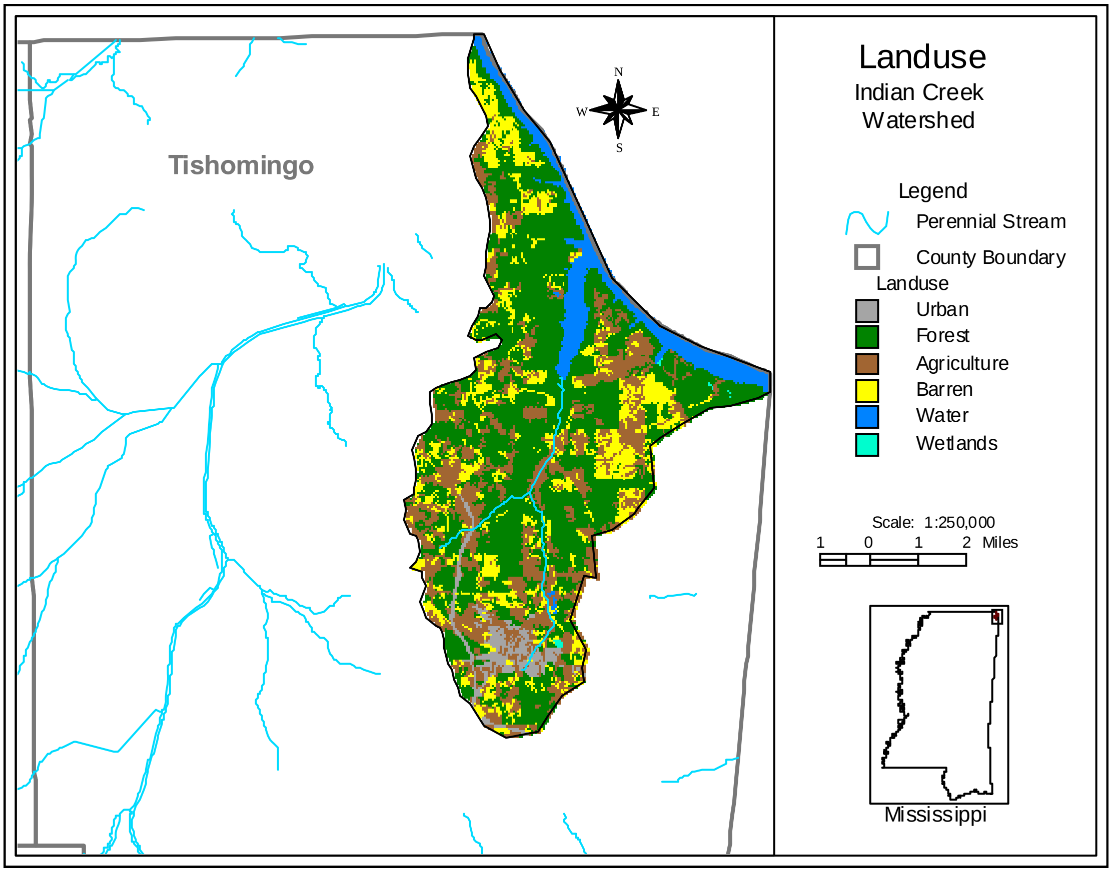


Figure 2. Landuse Map

1.2 Applicable Waterbody Segment Use

Designated beneficial uses and water quality standards are established by the *State of Mississippi Water Quality Criteria for Intrastate, Interstate, and Coastal Waters* regulations. The designated use for Indian Creek as defined by the regulations is Fish and Wildlife Support. Waters with this classification are intended for fishing and propagation of fish, aquatic life, and wildlife. Waters that meet the Fish and Wildlife Support criteria shall also be suitable for secondary contact recreation, which is defined as incidental contact with water, including wading and occasional swimming.

1.3 Applicable Waterbody Segment Standard

The water quality standard applicable to the use of the waterbody and the pollutant of concern is defined in the *State of Mississippi Water Quality Criteria for Intrastate, Interstate, and Coastal Waters*. The applicable standard specifies that the DO concentrations shall be maintained at a daily average of not less than 5.0 mg/L with an instantaneous minimum of not less than 4.0 mg/L. This water quality standard will be used as a targeted endpoint to evaluate impairment and establish this TMDL.

2.0 TMDL ENDPOINT AND WATER QUALITY ASSESSMENT

2.1 Selection of a TMDL Endpoint and Critical Condition

One of the major components of a TMDL is the establishment of instream numeric endpoints, which are used to evaluate the attainment of acceptable water quality. Instream numeric endpoints, therefore, represent the water quality goals that are to be achieved by meeting the load and waste load allocations specified in the TMDL. The endpoints allow for a comparison between observed instream conditions and conditions that are expected to restore designated uses. The instream DO target for this TMDL is a daily average of not less than 5.0 mg/L.

Low DO typically occurs during seasonal low-flow periods of late summer and early fall. Elevated oxygen demand is of primary concern during dry periods because the effects of low-flow, minimum dilution, and high temperatures combine to produce the worst case potential effect on water quality (USEPA 1997). The low-flow, high-temperature period is referred to as the critical condition. The maximum impact of a TBODu load is generally not at the location of the discharge, but at some distance downstream. The point of maximum impact is the point at which the maximum DO deficit occurs. The DO deficit is defined as the difference between the DO concentration at 100 % saturation and the actual DO. This TMDL will require that the TMDL endpoint, a daily DO average of not less than 5.0 mg/L, will be maintained at the point of maximum DO deficit during critical conditions.

2.2 Discussion of Instream Water Quality

Mississippi’s 1998 Section 305(b) Water Quality Assessment Report was reviewed to assess water quality conditions and data available for the watershed. According to the report, Indian Creek segment MS192IM2 is threatened for aquatic life support.

The segment of Indian Creek was placed on the 1996 303(d) list based on water quality data that were collected in 1993. This data consisted of analysis of the benthic macroinvertebrate community, habitat evaluations, and limited physical/chemical monitoring for conventional pollutants. Data in 1993 were collected at sites upstream and downstream of the Iuka POTW, as part of a waste load allocation investigation to provide information to support the National Pollutant Discharge Elimination System (NPDES). The data indicated that slight/moderate impairment of the benthic macroinvertebrate community existed in Indian Creek downstream of the Iuka POTW discharge. An additional assessment of the benthic macroinvertebrate community was performed in Indian Creek in 1997. This study, which was conducted as part of a basin-wide water quality bioassessment survey, showed that there was impairment of the macroinvertebrate community downstream of the Iuka POTW. This study is described in *Indian Creek TMDL Development: Macroinvertebrate Bioassessment* (MDEQ 1998)

Biological impairment is not a pollutant, but it is an indicator of impairment due to a particular pollutant or pollution. The disruptions of the benthic macroinvertebrate community found in Indian Creek downstream of the Iuka POTW were localized in the area downstream of the discharge. Impairment of the biological community in Indian Creek was not found upstream of the POTW discharge or downstream, at the confluence of Pickens Branch. Because the effluent from the Iuka POTW accounts for greater than one-third of the total flow in segment MS192IM2 of Indian Creek during low-flow conditions, it is the professional judgment of MDEQ that the Iuka POTW effluent is the pollutant source causing impairment. Oxygen demanding substances in the facility's effluent are the cause of the noted biological impairment. Subsequently, MDEQ prepared this TMDL based on organic enrichment/low DO.

The impact of nutrients, a cause given on the 1996 303(d) list, was considered in this TMDL. Nutrients are not considered as a separate pollutant. Rather, nutrients are considered within the TBODu allocations. The process of nitrification (conversion of ammonia-N to nitrate-N) is included in the TMDL modeling and subsequent determination of the seasonal load and waste load allocations. The impact of nitrogen and phosphorous species on algal growth and respiration is also included in the TMDL model. A TMDL is not needed for the other causes listed in 1996; pesticides, siltation, and other habitat modifications. During an intensive study performed in 1998, it was determined that these causes are not impairing the designated use of Indian Creek.

2.2.1 Inventory and Analysis of Available Water Quality Monitoring Data

The TMDL and water quality modeling are based on data collected during an intensive study of Indian Creek performed by the Water Quality Assessment Branch of MDEQ. In order to accurately investigate the worst-case impact of point source pollution, the water quality study was conducted during critical conditions of low-flow and high-temperature in late August and early September of 1998. Data collected during this study consisted of analysis of the benthic macroinvertebrate community, habitat evaluations, water chemistry sampling, and continuous in-situ monitoring of water quality parameters. In addition, flow, water velocity, and stream slope were measured during the study period. All data collected during the study and a detailed analysis of the data are given in Appendix A. The data collected during the critical condition study confirmed that the biological impairment of Indian Creek is caused by low levels of instream DO due to organic enrichment.

2.2.2 Stream Channel Modifications

Following the intensive study of August - September 1998, the City of Iuka began work on modifications to the stream channel of Indian Creek for the purpose of flood control in urban areas of the city. The work included removing trees and other vegetation from the riparian zone of the creek, straightening and dredging the channel, and placing rip-rap along the sides and bottom of the channel. The channel modifications involved only the headwaters of Indian Creek, within the City of Iuka.

Although the modifications involved only the headwater reaches of the creek and the location of the upstream monitoring station used in the 1998 study, it is recognized that the changes could potentially affect the hydrology, water chemistry, and biological communities observed in the downstream monitoring stations. Potential hydrological changes include increased peak flow and water velocity, particularly during periods of runoff following rain events. However, since the TMDL was developed for low-flow conditions, the impact of hydrological modifications would be minimal. Removal of the canopy cover in the channelized areas has the potential to affect the water chemistry and macroinvertebrate community of the creek. A reduced canopy will allow more direct sunlight to reach the creek. Direct sunlight increases algae photosynthesis in the photic zone, shifting the photosynthesis/respiration ratio. Allocthonous material previously provided by leaves and woody matter falling from trees in the riparian zone will likely be replaced by autochthonous material provided by increased primary production. Additional direct sunlight may also decrease the thermal stability of the creek, resulting in greater diurnal shifts of temperature. The changes caused by removal of the canopy cover, however, will likely be localized in the area of channel modifications. Since the DO sag and recovery zones are located several miles downstream of the modification, the modifications are unlikely to have a significant impact of the assimilative capacity of the creek in these locations.

The changes resulting from the channel modifications are shown in Photo 2 and Photo 3. The photos of Indian Creek were taken before and after the channel modifications at monitoring station IC-1. Photo 2 shows the headwater station as it appeared in 1998, during the intensive study prior to modification of the channel. Photo 3 shows the same location after the modifications. Even though the photos show that there were major modifications to the stream channel in the headwaters of Indian Creek, the data collected during the intensive study were considered to be valid for model calibration and subsequent calculation of the TMDL.

Photo 2. IC-1, Looking Downstream from Eastport Road, September 1998

Photo 3. IC-1, Looking Downstream from Eastport Road, March 2000.

3.0 SOURCE ASSESSMENT

The TMDL evaluation summarized in this report examined all known potential sources of TBODu in segment MS192IM2 of Indian Creek. The source assessment was used as the basis of development for the model and ultimate analysis of the TMDL allocation options. Sources were characterized with the best available information, monitoring data, literature values, and local management activities. This section documents the available information.

3.1 Assessment of Point Sources

One point source of TBODu is located in the watershed of Indian Creek, the Iuka POTW facility. This wastewater treatment plant serves a variety of activities in the City of Iuka including residential subdivisions and other businesses. The effluent from this discharger was characterized based on all available data including information on the facility's wastewater treatment system, permit limits, and discharge monitoring reports. The Iuka POTW facility consists of a conventional lagoon with two cells in series, Photo 4. Prior to release, the effluent flows through a chlorine contact chamber.

Photo 4. Iuka POTW Facility, Second Cell

Discharge monitoring reports (DMRs) are the best data source for characterizing effluent because they report measurements of flow and BOD_5 present in effluent samples. The National Pollutant Discharge Elimination System (NPDES) permit for the Iuka POTW Facility requires the submission of DMR reports on a quarterly basis. The reports submitted since April 1998 indicated only one reported violation in the permit limit for BOD_5 (36 mg/L in August 1998). Based on quarterly DMRs, the effluent produced by the Iuka POTW in April 1998 through June 2000 had an average flow of 0.27 MGD (0.418 cfs), an average BOD_5 concentration of 13.8 mg/L, an average DO concentration of 7.56 mg/L, and an average TSS concentration of 23.0 mg/L, Table 1. Thus, based on the DMR reports for the period of 04/01/98 through 06/30/00, the average BOD_5 load from the Iuka POTW was 31.07 lbs/day. The NPDES permit limits for the Iuka POTW facility include a flow of 0.36 MGD (0.557 cfs) and effluent concentrations of 30 mg/L BOD_5, 6 mg/L DO, and 90 mg/L TSS. Thus, the maximum permitted BOD_5 load from the Iuka POTW Facility is 90.07 lbs/day. Comparing the actual BOD_5 load (31.07 lbs/day) to the maximum permitted BOD_5 load (90.07 lbs/day), it can be seen that the facility was discharging approximately 34% of its total permitted load (lbs/day) of BOD_5 during the period of 04/01/98 through 06/30/00.

Table 1. Inventory of DMR Data

Monitoring Period	Effluent Flow (MGD)	Influent BOD_5 (mg/L)	Effluent BOD_5 (mg/L)	BOD_5 percent removal	Effluent DO (mg/L)	Effluent TSS (mg/L)
04/01/98 – 06/30/98	0.24	40	17	57.5	7.0	34
07/01/98 – 09/30/98	0.23	104	36	65.3	7.3	43
10/01/98 – 12/31/98	0.28	143	16	88.8	6.8	20
01/01/99 – 03/31/99	0.26	132	13	90.2	9.2	20
04/01/99 – 06/30/99	0.31	37	8	78.4	7.1	15
07/01/99 – 09/30/99	0.27	44	2	95.5	6.8	17
10/01/99 – 12/31/99	0.29	82	18	78.0	7.8	25
01/01/00 – 03/31/00	0.31	118	13	89.0	7.8	20
04/01/00 – 06/30/00	0.27	100	1	99.0	8.2	14
Average	**0.27**	**88.9**	**13.8**	**82.4**	**7.6**	**23**

3.2 Assessment of Nonpoint Sources

Nonpoint loading of organic material in a waterbody results from the transport of the material into receiving waters by overland surface runoff and groundwater infiltration. Landuse activities within the drainage basin, such as agriculture, silvaculture, and urbanization contribute to nonpoint source loading. Other nonpoint pollution sources include atmospheric deposition and natural weathering of rocks and soil.

Measurements of the background levels of DO, CBODu, and nutrients were collected during the field study in 1998. Background measurements were taken at two monitoring stations that were upstream of the POTW discharge. The measured background flows and concentrations were used to set the headwater conditions of the model. Since there are no point sources in the upper reaches of the creek, the headwater load of TBODu was assumed to be completely due to nonpoint source contributions. Incremental inflow in the reaches downstream of the POTW discharge accounts for the nonpoint source contributions in the lower reaches of Indian Creek.

Incremental inflow is the increase in the flow measured between monitoring stations that is due to groundwater infiltration and the confluence of minor tributaries with Indian Creek. Background values of 3.50 mg/L of CBODu, 6.65 mg/L of DO, and a temperature of 22ºC (71.6°F) were assumed for the incremental inflow, based on the water quality conditions observed in the upper reaches of Indian Creek. Estimated values of nutrient parameters are given in Table 2. The values of these parameters are based on water quality conditions measured in the upper reaches of Indian Creek.

Table 2. Estimated Non-Point Source Nutrient Concentrations

Organic-N (mg/L)	Ammonia-N (mg/L)	Nitrite-N (mg/L)	Nitrate-N (mg/L)	Organic-P (mg/L)	Dissolved-P (mg/L)	Chlorophyll-*a* (μg/L)
0.01	0.18	0.01	0.19	0.09	0.01	5.00

4.0 MODELING PROCEDURE: LINKING THE SOURCES TO THE ENDPOINT

Establishing the relationship between the instream water quality target and the source loading is a critical component of TMDL development. It allows for the evaluation of management options that will achieve the desired source load reductions. The link can be established through a range of techniques, from qualitative assumptions based on sound scientific principles to sophisticated modeling techniques. Ideally, the linkage will be supported by monitoring data that allow the TMDL developer to associate certain waterbody responses to flow and loading conditions. In this section, the selection of the modeling tools, setup, and model application are discussed.

4.1 Modeling Framework Selection

A mathematical model for DO distribution in freshwater streams, QUAL2E, was used for developing the TMDL. QUAL2E is the Enhanced Stream Water Quality Model, and is the latest in a series of water-quality management models initially developed by the Texas Water Development Board in the 1960s. QUAL2E has been widely used after extensive review and testing and is presently supported by EPA.

QUAL2E simulates several water-quality constituents in branching stream systems. The model uses a finite-difference solution of the advective-dispersive mass transport and reaction equation. A stream reach is divided into a number of subreaches, and for each subreach a hydrologic balance in terms of discharge and a materials balance in terms of concentration are calculated. Both advective and dispersive transport processes are considered in the materials balance. Mass is gained or lost from the subreaches by transport processes or internal processes such as benthic sources or biological transformations. The program simulates changes in conditions in time by computing the conditions in a series of reaches, with water passing from one reach to the next (Maidment 1992).

The model includes the major interactions of the nutrient cycles, algal production, benthic and carbonaceous oxygen demand, atmospheric reaeration, and their effect on the DO balance. The nitrogen cycle is divided into four components: organic-N, ammonia-N, nitrite-N, and nitrate-N. In a similar manner, the phosphorous cycle is divided into two components: organic-P and dissolved-P. The algae cycle is simulated by using an assumed algae concentration derived from user-input chlorophyll-*a* concentrations. The model uses chlorophyll-*a* as in indicator of planktonic algae biomass. The amount of oxygen produced during photosynthesis coupled with an algae growth rate are used to simulate photosynthesis. The amount of oxygen uptake during growth coupled with an algae respiration rate simulate respiration. Equation 2, from the *QUAL2E User Manual*, gives the general equation used to calculate the DO concentration rate of change in each computational element (USEPA 1987).

$$\delta O/\delta t = \underbrace{k_2(O^*-O)}_{\text{Reaeration}} - \underbrace{k_1 L}_{\substack{\text{CBODu}\\ \text{Decay}}} - \underbrace{k_4/d}_{\text{SOD}} - \underbrace{\alpha_5\beta_1 N_1}_{\substack{\text{Ammonia-N}\\ \text{Oxidation}}} - \underbrace{\alpha_6\beta_2 N_2}_{\substack{\text{Nitrite-N}\\ \text{Oxidation}}} + \underbrace{(\alpha_3\mu - \alpha_4\rho)A}_{\substack{\text{Algal Photosynthesis}\\ \text{and Respiration}}} \qquad \text{(Equation 2)}$$

Where
$\delta O/\delta t$ = dissolved oxygen rate of change
k_2 = reaeration coefficient, day^{-1}
O = dissolved oxygen concentration , mg/L
O* = saturation concentration of dissolved oxygen at local temperature and pressure, mg/L
k_1 = CBODu first-order decay rate, day^{-1}
L = CBODu concentration, mg/L
k_4 = SOD rate, mg of oxyen/$\text{ft}^2\text{day}^{-1}$
d = mean stream depth, ft
α_5 = oxygen consumed by oxidation of Ammonia-N to Nitrite-N, mg-oxygen/mg-nitrogen
β_1 = ammonia-N oxidation rate coefficient, day^{-1}
N_1 = ammonia-N concentration, mg/L
α_6 = oxygen consumed by oxidation of nitrite-N to nitrate-N, mg-oxygen/mg-nitrogen
β_2 = nitrite-N oxidation rate coefficient, day^{-1}
N_2 = nitrite-N concentration, mg/L
α_3 = oxygen production during photosynthesis per unit of algal biomass, mg-oxygen/mg-algae
μ = algal growth rate, day^{-1}
α_4 = oxygen uptake during respiration per unit of algal biomass, mg-oxygen/mg-algae
ρ = algal respiration rate, day^{-1}
A = algal biomass concentration, mg-algae/L

4.2 Model Setup

Five reaches of Indian Creek were included in the QUAL2E model, according to the setup shown in Figure 3. The headwaters of the creek, above monitoring station IC-3, were not modeled directly. Instead, the flow and water quality conditions measured at IC-3 were set as the background conditions for the model. Since station IC-3 is approximately 0.1 mile downstream of the Iuka POTW outfall, the flow and water quality conditions measured at IC-3 include the effects of the Iuka POTW effluent. In setting the water quality conditions measured at IC-3 as the background conditions for the model, it was assumed that the river water and POTW effluent were uniformly mixed at this point. Within each modeled reach, the segments were divided into uniform computational elements of 0.1 mile.

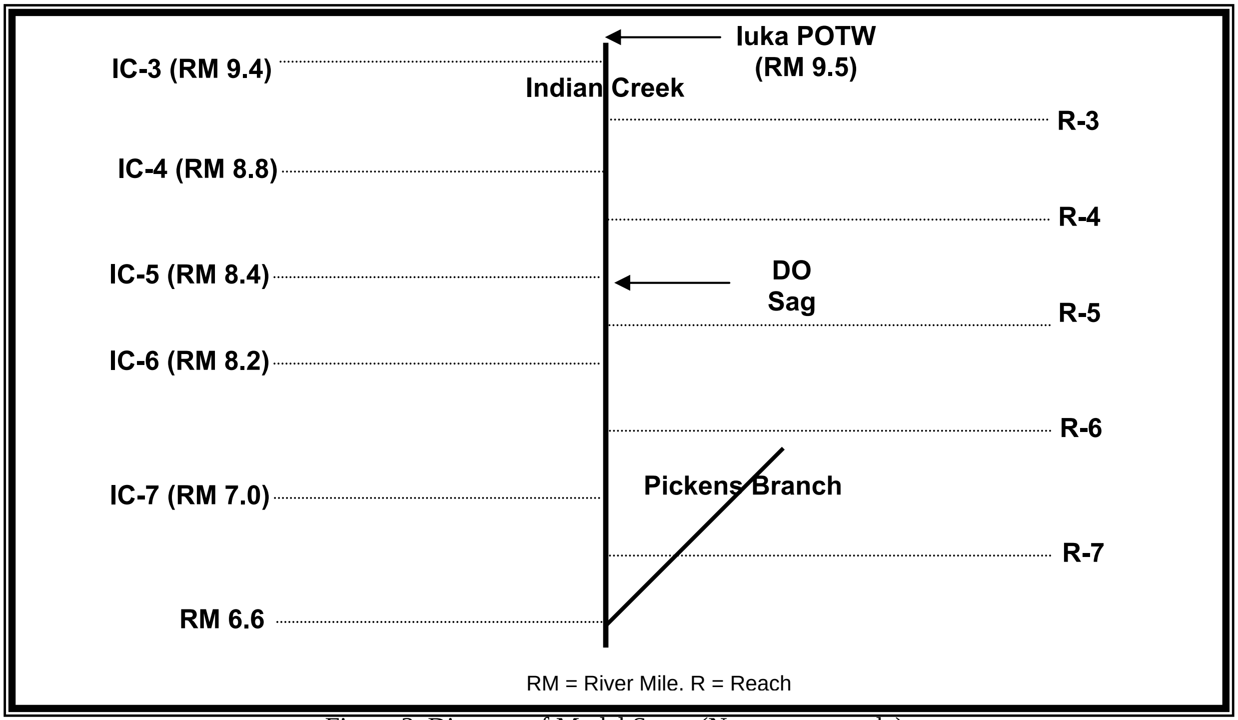


Figure 3. Diagram of Model Setup (Note: not to scale)

The Indian Creek model was set up as a steady-state QUAL2E simulation. In a steady-state simulation, climatological characteristics are held constant throughout the model simulation period. The model subroutines for simulating CBODu decay, the algae cycle, the phosphorous cycle, the nitrogen cycle, and the DO balance were activated. Temperature was not simulated in the model due to the tendency of QUAL2E to overestimate instream temperatures. Instead, global temperatures were input into the model, based on the in-situ data that were collected during the intensive study. Default temperature correction factors were used for adjusting the temperature-dependent reaction rates.

The model requires the input of initial conditions for water quality parameters in the headwaters and in each modeled reach. Initial conditions include the temperature, DO, flow, and instream concentrations of CBODu, chlorophyll-*a*, organic-N, ammonia-N, nitrite-N, nitrate-N, organic-P, and dissolved-P. All of these consistuents were measured during the intensive study as described in Appendix A. The initial conditions are used by the model as starting points for simulating CBODu decay, the nitrogen and phosphorous cycles, and respiration and photosynthesis of algae.

4.2.1 Hydrology

QUAL2E contains subroutines that simulate steady-state hydrology using two different methods; discharge coefficients and trapezoidal channels. The method of discharge coefficients was selected for the Indian Creek model. Discharge coefficients for each reach were calculated using data collected during the intensive study. Based on the discharge coefficients, the model calculates channel width, depth, and cross-sectional area for each computational element. In order to ensure an accurate hydrological model, the simulated travel times through each reach were compared to the travel times measured during the dye study. For all reaches, the exponents were adjusted slightly until the simulated travel times matched the measured travel times with less than a 5% error.

4.2.2 CBODu Simulation

In the QUAL2E model, there are two important processes that effect the concentration of CBODu in the water column. Those processes are oxidation and settling of CBODu. The QUAL2E model uses a first-order reaction to describe the oxygen demand exerted by oxidation of CBODu in the stream. However, the CBODu removed from the water column by settling does not exert an oxygen demand in the QUAL2E model according to the *QUAL2E User Manual* (USEPA 1987). The oxidation rate of CBODu was calculated from data collected during the intensive study, and is derived in Appendix A. The settling rate of CBODu was estimated by using the model default values. The differential equation governing the concentration of CBODu is given as Equation 3.

$$\delta L/\delta t = -k_1 L - k_3 L \qquad \text{(Equation 3)}$$

Where
k_1 = CBODu first-order decay rate, day^{-1}
L = CBODu concentration, mg/L
k_3 = rate of CBODu loss due to settling, day^{-1}

4.2.3 Reaeration

In the QUAL2E model, there are eight options for calculating or specifying the reaeration coefficient. The accuracy and applicability of these options have been the subject of a great deal of study and comparison, resulting in recommendations for conditions under which each of the options should be used. For example, the method developed by Tsivoglou and Wallace, is recommended for use in small streams in Mississippi with flows less than 10 cfs in *Empirical Stream Model Assumptions for Conventional Pollutants and Conventional Water Quality Models* (MDEQ 1995). The Tsivoglou and Wallace method, which was used in the Indian Creek model, calculates the reaeration coefficient according to Equation 4. The stream slopes were calculated with precise measurements of the water surface elevation at several sites on Indian Creek. These data are shown in Appendix A.

$$\mathbf{k_2 = CSu} \qquad \text{(Equation 4)}$$

Were
k_2 = reaeration coefficient, day^{-1}
C = 0.11 for streams with flow less than 10 cfs
S = stream slope, ft/mile
u = reach velocity, mile/day

4.2.4. Sediment Oxygen Demand (SOD)

The QUAL2E model represents SOD as an oxygen demand with the units of gm-oxygen/ft^2/day. One limitation to the QUAL2E simulation of SOD is that it is not linked to other components of the water quality simulation such as CBODu settling and the algae and nutrient cycles. Thus, SOD must be assessed individually and input into the model as independent variable in each reach. The values of SOD were calculated using data collected during the intensive study. Calculation of SOD rates is described in Appendix A.

4.2.5 Nitrogen Simulation

The four-component nitrogen cycle simulates the instream concentrations of organic-N, ammonia-N, nitrite-N, and nitrate-N. The instream concentration of organic-N depends on the nitrogen fraction of the algal biomass and the algal respiration rate. Organic-N is removed through settling and hydrolysis. Sources of ammonia-N include release from sediments and formation from hydrolysis of organic-N. Removal of ammonia-N is simulated through nitrification and uptake by algae during growth. A preference factor for ammonia-N and nitrate-N is used to simulate uptake of these species of ammonia during algae growth. Nitrate-N is produced through nitrification of ammonia-N. Removal of nitrate-N is due to algal uptake during growth. Nitrification, an oxygen demanding process, is inhibited when the instream concentration of DO is low. Differential equations governing the transformations of nitrogen species are given below as Equation 5 through Equation 8.

$$\delta N_4/\delta t = \alpha_1 \rho A - \beta_3 N_4 - \sigma_4 N_4 \qquad \text{(Equation 5)}$$

Where
N_4 = organic-N concentration mg-N/L
α_1 = nitrogen fraction of algal biomass, mg-N/mg-algae
ρ = algal respiration rate, day^{-1}
A = algal biomass concentration, mg-algae/L
β_3 = organic-N hydrolysis rate coefficient, day^{-1}
σ_4 = organic-N settling rate, day^{-1}

$$\delta N_1/\delta t = \beta_3 N_4 - \beta_1 N_1 + \sigma_3/d - f_1\alpha_1\mu A$$ (Equation 6)

Where

N_1 = ammonia-N concentration, mg/L

β_3 = organic-N hydrolysis rate coefficient, day^{-1}

N_4 = organic-N concentration mg-N/L

β_1 = ammonia-N oxidation rate coefficient, day^{-1}

σ_3 = ammonia-N source rate from sediment, mg-N/L

d = mean stream depth, ft

f_1 = fraction of nitrogen uptake by algae from the available ammonia-N

α_1 = nitrogen fraction of algal biomass, mg-N/mg-algae

μ = algal growth rate, day^{-1}

A = algal biomass concentration, mg-algae/L

$$\delta N_2/\delta t = \beta_1 N_1 - \beta_2 N_2$$ (Equation 7)

Where

N_2 = nitrite-N concentration, mg/L

β_1 = ammonia-N oxidation rate coefficient, day^{-1}

N_1 = ammonia-N concentration, mg/L

β_2 = nitrite-N oxidation rate coefficient, day^{-1}

$$\delta N_3/\delta t = \beta_2 N_2 - \alpha_1\mu(1-f_1)A$$ (Equation 8)

Where

N_3 = nitrate-N concentration, mg/L

β_2 = nitrite-N oxidation rate coefficient, day^{-1}

N_2 = nitrite-N concentration, mg/L

α_1 = nitrogen fraction of algal biomass, mg-N/mg-algae

μ = algal growth rate, day^{-1}

A = algal biomass concentration, mg-algae/L

f_1 = fraction of nitrogen uptake by algae from the available ammonia-N

4.2.6 Phosphorous Simulation

The two-component phosphorous cycle simulates instream concentrations of dissolved-P and organic-P. Inorganic, dissolved-P is used primarily by algae during growth. Organic-P is produced through the respiration of algae. Removal of organic-P occurs through hydrolysis and settling. Input mechanisms of dissolved-P include hydrolysis of organic-N and input from sediments. Removal of dissolved-P is dependent on the algae growth rate and the algal biomass concentration. Differential equations which govern the transformations of the two phosphorous forms are given as Equation 9 and Equation 10.

$$\delta P_1/\delta t = \alpha_2 \rho A - \beta_4 P_1 - \sigma_5 P_1 \quad \text{(Equation 9)}$$

Where

P_1 = organic-P concentration mg/L

α_2 = phosphorous fraction of the algal biomass, mg-P/mg-algae

ρ = algal respiration rate, day^{-1}

A = algal biomass concentration, mg-algae/L

β_4 = organic-P hydrolysis rate coefficient, day^{-1}

σ_5 = organic-P setting rate, day^{-1}

$$\delta P_2/\delta t = \beta_4 P_1 - \alpha_2 \mu A + \sigma_2/d \quad \text{(Equation 10)}$$

Where

P_2 = dissolved-P concentration, mg/L

α_2 = phosphorous fraction of the algal biomass, mg-P/mg-algae

μ = algal growth rate, day^{-1}

A = algal biomass concentration, mg-algae/L

σ_2 = dissolved-P source rate from sediment, mg-P/day/ft^2

d = mean stream depth, ft

In general, default values were used for many of the rate coefficients that govern the processes of the nitrogen and phosphorous cycles, Equation 5 through Equation 10. Default factors, which are based on literature values, are recommended for use in the QUAL2E model when reliable site-specific field data are not available. Measuring many of these factors is difficult and expensive, and the literature values are well-accepted by the scientific community.

4.2.7 Algae Simulation

QUAL2E simulates the respiration rate of algae with a single, user input, respiration rate parameter. The respiration rate is used to approximate the endogenous respiration of algae, the conversion of algal phosphorous to organic phosphorous, and the conversion of algal nitrogen to organic nitrogen. The algal respiration rate was measured at each monitoring station during the field study using light and dark bottle tests, described in Appendix A. Because the QUAL2E model requires a constant respiration rate throughout all the modeled reaches, an average respiration rate was calculated from the measured rates at stations IC-3 through IC-7. An average algal respiration rate of 1.60 mg-oxygen/mg-algae was used. This rate is within the recommended range of respiration values included in the *QUAL2E User Manual* (USEPA 1987).

The model has several options for simulating the growth rate of algae and the effect of light and nutrient concentrations on the growth rate. As described in the *QUAL2E User Manual*, the local specific growth rate of algae is known to be coupled to the availability of light and required nutrients (nitrogen and phosphorous). There are a variety of mathematical expressions for describing these interactions. QUAL2E has the capability to model the interaction among these limiting factors in three different ways; multiplicative, limiting nutrient, and harmonic mean. For the Indian Creek model, the limiting nutrient option was used. This option represents the local algal growth rate as limited by light and either nitrogen or phosphorous, but not both. Thus, the algal growth is controlled by the nutrient with the smaller growth limitation factor, Equation 11. The growth attenuation factors for nitrogen and phosphorous, FN and FP, are calculated by the model using the instream concentration of nutrients (USEPA 1987).

$$\mu = \mu_{MAX}\ (FL)\ \mathrm{Min}\ (FN, FP) \qquad \text{(Equation 11)}$$

Where
μ = average algal growth rate, day^{-1}
μ_{MAX} = maximum algal growth rate, day^{-1}
FL = algal growth light attenuation factor for light at intensity I_z
FN = growth attenuation factor for nitrogen
FP = growth attenuation factor for phosphorous

QUAL2E has three options available for calculating FL, the light function; half saturation, Smith's function, and Steel's equation. Although the three options differ in mathematical form, the relationships exhibit similar characteristics, showing an increasing rate of photosynthesis with increasing light intensity up to a maximum value. At high light intensities, some of the expressions exhibit photoinhibition, while others show photosynthetic activity remaining at the maximum rate. For the Indian Creek model the first option, half saturation, was used. This option requires the input of a light intensity and a half saturation coefficient in BTU/ft^2/hour. The default values given in the *QUAL2E User Manual* for the half saturation coefficient, 0.11 BTU/ft^2/min, and light intensity, 1,300 BTU/ft^2/day, were used as estimates. FL was calculated according to Equation 12 (USEPA 1987).

$$FL = (I_z)/(K_L + I_z) \qquad \text{(Equation 12)}$$

Where
FL = algal growth light attenuation factor for light at intensity I_z
I_z = light intensity at a given depth (z), BTU/ft^2/hour
K_L = half-saturation coefficient for light, BTU/ft^2/hour
z = depth variable, ft

4.3 Source Representation

Point and nonpoint sources of nutrients were represented in the model in terms of concentrations of organic-N, ammonia-N, nitrite-N, nitrate-N, organic-P, and dissolved-P. The use of ultimate carbonaceous oxygen demand versus 5-day carbonaceous demand allows a higher level of accuracy for modeling CBODu decay, according to the *QUAL2E User Manual* (USEPA 1987). Thus, for use in the Indian Creek QUAL2E model, carbonaceous oxygen demand in terms of CBODu was used. Discharge from the NPDES permitted source was included in the model as a direct input into the appropriate reach of the waterbody. Spatially distributed inputs, which represent nonpoint surface water runoff and groundwater infiltration, were modeled as an evenly distributed flow in each reach.

4.4 Model Calibration Process

Calibration of the water quality model used to calculate the TMDL is a critical part of TMDL development. Multiple versions of the QUAL2E model were developed for calculating the TMDL; a calibrated, existing condition model and a critical condition model. The calibrated, existing condition model was developed to simulate the conditions measured during the intensive study. The flows, concentrations of nutrients and organic substances, and rate coefficients measured during the study were used to set the initial conditions for the model. In order to calibrate the existing condition model, adjustments of parameters affecting the hydrology and instream water quality were made. The default values were used as starting points for many of the rate coefficients used in the model. Selected default rate coefficients were adjusted so that the measured flow and water quality conditions matched the modeled flow and water quality conditions as closely as possible. These rate coefficients were only adjusted within the recommended range of the default values given in the *QUAL2E User Manual* (USEPA 1987).

Through the use of a first-order sensitivity analysis, it was determined that the model output was highly dependent upon the value of certain parameters. Because small adjustments of the sensitive parameters have a large effect on the model output, reliable field-measured values were used to determine these parameters. The sensitive parameters include initial temperature, flow, and CBODu concentration and decay rate. All of these parameters were measured with a high level of accuracy during the field study.

The modeled DO is also highly dependent upon sediment oxygen demand (SOD). The value of SOD was calculated for each reach using data collected during the field study. However, SOD is extremely difficult to characterize using field measurements due to the spatial variability in the sediment material along stream reaches. Variations in the size of sediment material (course gravel vs. fine sands), the depth and velocity of water flowing over the sediments, and temperature impact the measured SOD values. In addition, spatial changes in the microbial community along stream reaches can impact the SOD (USEPA 1986). For this reason, the field-measured values of SOD were used as estimates of the value of SOD in each reach. These values were used a starting points for model setup. SOD was then adjusted until the modeled instream DO matched the conditions measured during the intensive study. Comparisons of measured instream conditions and output from the calibrated model are shown in graphical format in Appendix B.

4.5 Critical Condition Model Development

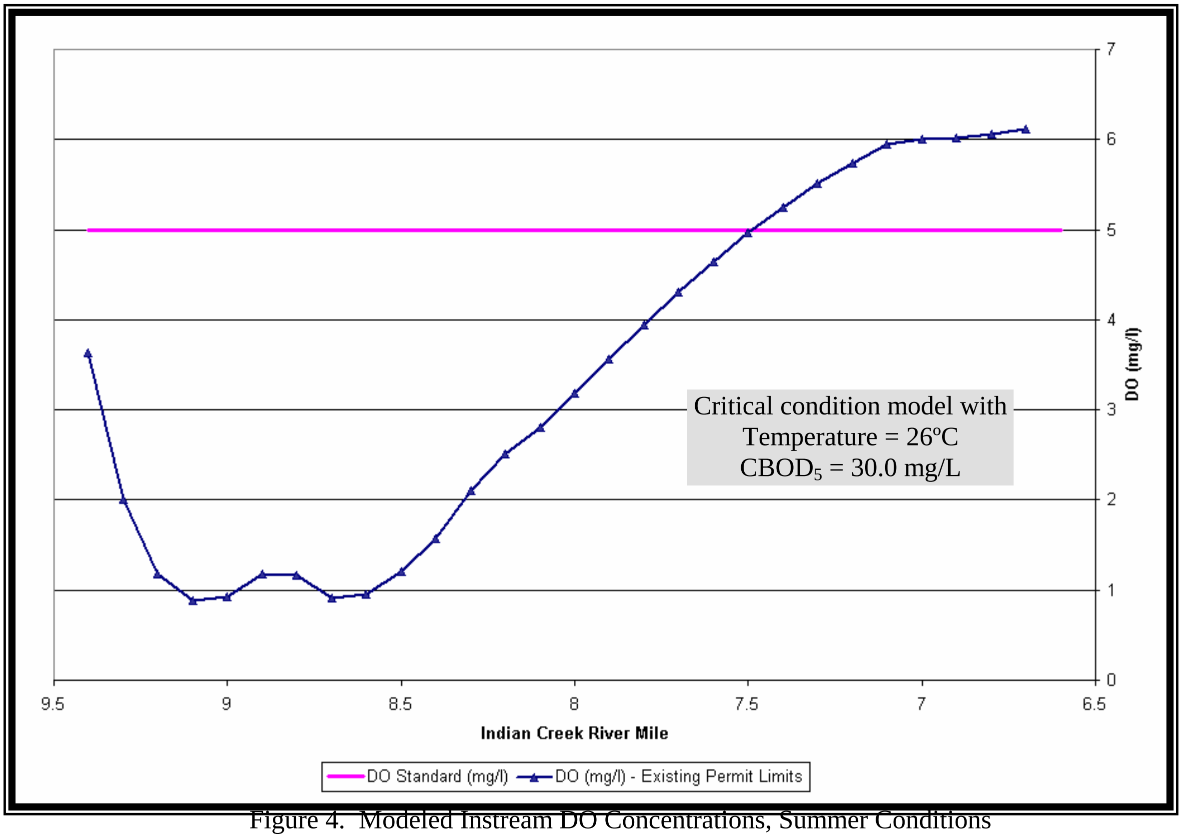
Once the existing condition model was developed and calibrated to simulate the water quality characteristics observed during the study, models representing the critical condition period were developed. The critical condition models included the effluent from the Iuka POTW at the facility's maximum permitted flow and $TBOD_5$ concentration. The minimum permitted DO concentration and the nutrient concentrations measured in the effluent during the intensive study were used to further characterize the effluent, Table 3. The value of CBODu in the effluent was calculated using the $CBOD_5$ to CBODu ratio, 5.54 mg/L of CBODu per mg/l of $CBOD_5$. Development of this ratio is described in Appendix A.

Table 3. Iuka POTW Effluent Characteristics

Flow (cfs)	0.557
Temp (ºC)	26.0
DO (mg/L)	6.0
$CBOD_5$ (mg/L)	30.0
CBODu (mg/L)	166.2
Chlorophyll-*a* (µg/L)	300.0
Organic-N (mg/L)	8.35
Ammonia-N (mg/L)	2.00
Nitrite-N (mg/L)	0.01
Nitrate-N (mg/L)	0.03
Organic-P (mg/L)	0.90
Dissolved-P (mg/L)	0.10

In order to account for seasonal variations in the stream temperature and their effect on DO saturation and rate coefficients such as CBODu decay, the model was run under both summer and winter temperature conditions. The temperatures used in the model are 26°C in the summer (May through October) and 20°C in the winter (November through April). These temperatures are specified in *Empirical Stream Model Assumptions for Conventional Pollutants and Conventional Water Quality Models* (MDEQ 1995).

The 7Q10 flow for Indian Creek was used to establish the flow for the critical condition model. 7Q10 is the minimum flow expected for seven consecutive days during a time period of ten years. The use of the 7Q10 flow for calculating wasteload allocations is required in *Empirical Stream Model Assumptions for Conventional Pollutants and Conventional Water Quality Models* (MDEQ 1995). The 7Q10 flow was calculated according to a method provided by the USGS in *Techniques for Estimating 7-Day, 10-Year Low Flow Characteristics on Ungaged Sites on Streams in MS*. According to this method, the 7Q10 flow for unguaged streams is calculated using a 7Q10 flow coefficient. The USGS used all available flow monitoring data in the watershed, and assumed that hydrological characteristics between adjacent watersheds were similar to calculate this coefficient. The 7Q10 flow coefficient (in units of cfs/mi^2 of drainage area) was used to determine the 7Q10 flow in the modeled reaches (1992). For the Indian Creek Watershed, the 7Q10 flow coefficient is 0.01 cfs/mi^2. The drainage area of Indian Creek, from the headwaters to the point directly upstream of the Iuka POTW discharge is 7.0 mi^2. Thus, the 7Q10 flow for Indian Creek at this point is equal to 0.7 cfs. Output from the critical condition model, run with the 7Q10 flow condition during summer temperature conditions, are shown in Figure 4.



Critical condition model with
Temperature = 26ºC
$CBOD_5$ = 30.0 mg/L

Figure 4. Modeled Instream DO Concentrations, Summer Conditions

4.6 Ammonia-N Toxicity

Ammonia-N must not only be considered due to its effect on DO in the receiving water, but also its toxicity potential. According to *Empirical Stream Model Assumptions for Conventional Pollutants and Conventional Water Quality Models* (MDEQ 1994), allowable effluent ammonia-N concentrations should meet the water quality criteria given in *Quality Criteria for Water, 1986* (EPA 440/5-86-001) for a pH of 7.0 and a temperature of 25°C. The maximum allowable instream ammonia-N concentration under these conditions is 1.20 mg/L. Based on this instream limit, a mass balance calculation was used to determine the maximum allowable ammonia-N concentration in the Iuka POTW effluent, Figure 5.

$$C_E = \frac{(C_T * Q_T) - (C_H * Q_H)}{Q_E}$$

$$C_E = \frac{(1.20 * 1.257) - (0.18 * 0.70)}{0.557}$$

C_E = 2.48 mg/L ammonia-N

Where: C_E = allowable effluent ammonia –N concentration, mg/L
C_T = ammonia-N criteria, 1.20 mg/L
Q_T = stream flow after mixing, 1.257 cfs
C_H = background ammonia-N concentration, 0.18 mg/L
Q_H = background 7Q10 flow, 0.70 cfs
Q_E = effluent flow, 0.557 cfs

Figure 5. Mass-Balance Calculation for Ammonia-N

4.7 Model Results

The critical condition model for each season was run, using a trial-and-error process, to determine the maximum daily load of TBODu that would not cause a violation of the water quality standard for DO in Indian Creek. The daily load of TBODu was adjusted by changing the concentration of $CBOD_5$ in the Iuka POTW effluent until the model showed no violation of the daily average DO concentration of 5.0 mg/L. Ammonia-N concentrations were kept lower than the allowable toxicity limit. Table 4 shows the characteristics of the Iuka POTW effluent for each season after the $CBOD_5$ was adjusted.

Concentrations of ammonia-N were converted into an oxygen demand, NBODu, in Table 4. A conversion factor of 4.57 pounds of oxygen per pound of ammonia-N oxidized to nitrate-N was used for this calculation. The use of this factor is a conservative modeling assumption because it assumes that all of the ammonia-N in the Iuka POTW effluent is converted to nitrate-N through nitrification after reaching the receiving stream.

Table 4. Modeled Iuka POTW Effluent Characteristics, Critical Condition Model

	Summer Condition	**Winter Condition**
Flow (cfs)	0.557	0.557
Temp (°C)	26	20
DO (mg/L)	6.0	6.0
CBODu (mg/L)	45.0	70.0
$CBOD_5$ (mg/L)	**8.12**	**12.64**
Chlorophyll-*a* (µg/L)	300	300
Organic-N (mg/L)	8.35	8.35
Ammonia-N (mg/L)	2.00	2.00
NBODu (mg/L)	9.14	9.14
Nitrite-N (mg/L)	0.01	0.01
Nitrate-N (mg/L)	0.03	0.03
Organic-P (mg/L)	0.90	0.90
Dissolved-P (mg/L)	0.10	0.10

Figure 6 and Figure 7 show the output from the adjusted critical condition models. The figures show the modeled DO in Indian Creek for summer and winter temperature conditions, beginning directly below the Iuka POTW outfall, river mile 9.4, and ending with river mile 6.6. The DO sag, or maximum DO deficit, occurs near river mile 8.4. The dashed line on both graphs represents the DO standard of 5.0 mg/L.

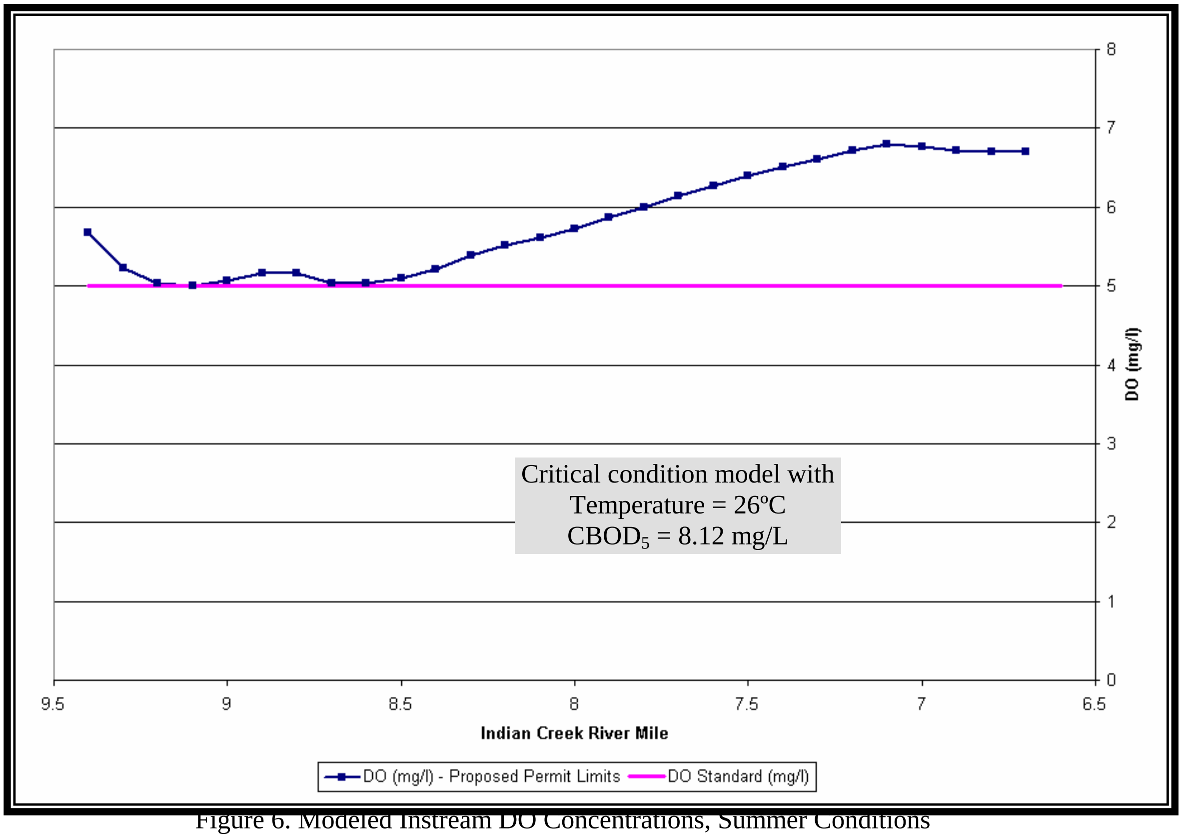
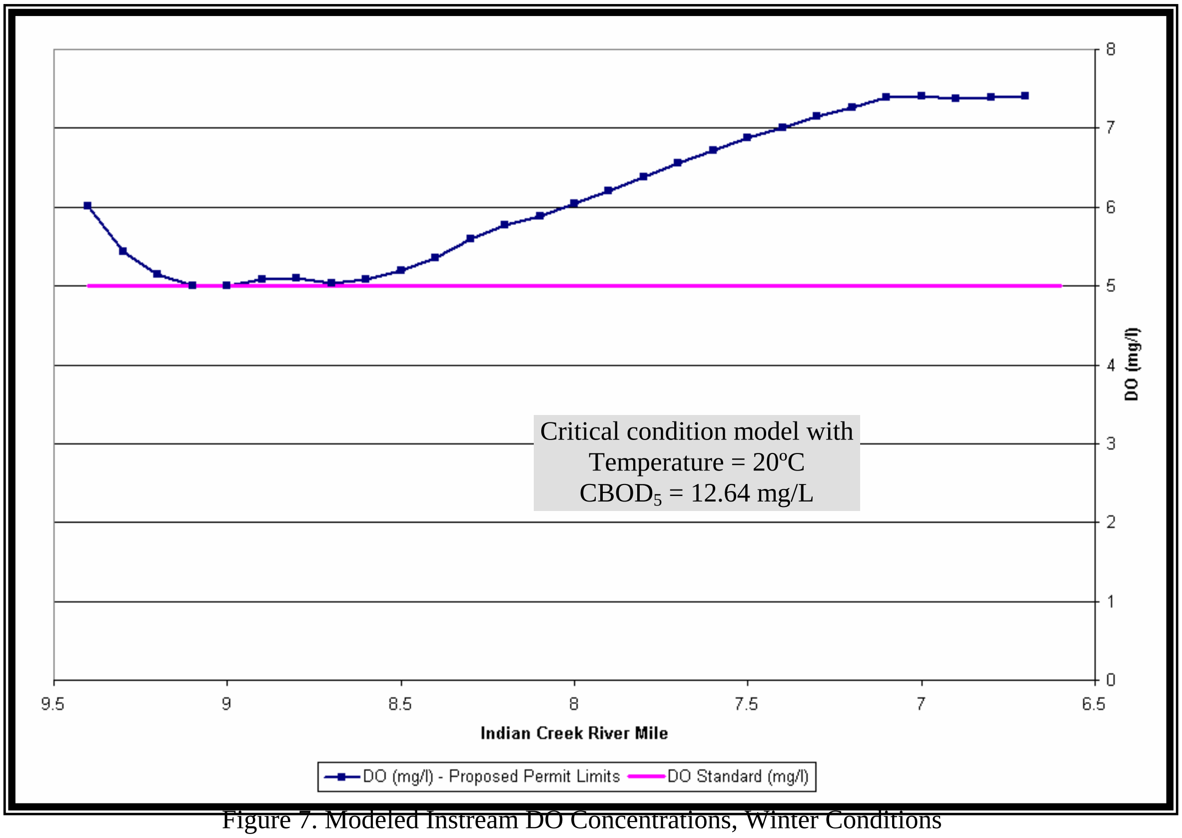


Figure 6. Modeled Instream DO Concentrations, Summer Conditions



Critical condition model with
Temperature = 20ºC
$CBOD_5$ = 12.64 mg/L

Figure 7. Modeled Instream DO Concentrations, Winter Conditions

5.0 ALLOCATION

The allocation for this TMDL involves a wasteload allocation for point sources and a load allocation for nonpoint sources necessary for attainment of water quality standards in segment MS192IM2. The maximum loads that allow attainment of water quality standards were calculated with the use of calibrated, predictive models. The load allocation and wasteload allocation for Indian Creek were developed as seasonal loads, based on the critical condition model results for summer and winter conditions.

5.1 Wasteload Allocation

The Iuka POTW Facility is the only NPDES permitted discharger of TBODu in segment MS192IM2. Thus, it is the only contributor to the wasteload allocation in this segment of Indian Creek. The wasteload allocation includes a seasonal load of TBODu divided into carbonaceous and nitrogenous components, Table 5. The sum of CBODu and NBODu is equal to the wasteload allocation for TBODu. The concentrations of CBODu and NBODu in given in Table 5 were calculated using the critical condition model described in Section 4.7.

Table 5. Wasteload Allocation for Indian Creek Segment MS192IM2 (Note: cfs x mg/L x 5.4 = lbs/day)

Season	Flow (cfs)	CBODu (mg/L)	CBODu (lbs/day)	NBODu (mg/L)	NBODu (lbs/day)	TBODu (lbs/day)
Summer (May –October)	0.557	45.0	135.4	9.14	27.5	**162.9**
Winter (November– April)	0.557	70.0	210.5	9.14	27.5	**238.0**

Sections 301(b)(1)(c) and 402(a)(1) of the Clean Water Act specify that NPDES permits must contain effluent limitations more stringent than required by applicable technology-based standards where such limits are necessary to achieve compliance with applicable water quality standards. Regulations at 40 CFR §122.44(d)(1)(vii)(A) require that for all NPDES permitted dischargers "the level of water quality to be achieved by limits on point sources … is derived from and complies with all applicable water quality standards". The effluent limitations necessary to achieve applicable water quality standards are called Water Quality Based Effluent Limitations (WQBELs). Modification of current the NPDES permit for the Iuka POTW facility is recommended to meet the WQBELs developed in this TMDL.

WQBELs for the Iuka POTW facility are based on the seasonal wasteload allocation given in Table 5. Effluent limits for oxygen-demanding, organic material in NPDES permits are generally expressed in terms of a $TBOD_5$ concentration in mg/L, which is a measure of the oxidation of carbonaceous ($CBOD_5$) and nitrogenous ($NBOD_5$) material over a 5-day incubation period. $TBOD_5$ is equal to the sum of $CBOD_5$ and $NBOD_5$, Equation 13.

$$\boxed{\mathbf{TBOD_5 = CBOD_5 + NBOD_5}} \qquad \text{(Equation 13)}$$

Oxidation of nitrogenous material, called nitrification, usually does not take place within the first five days of TBODu exertion because *Nitrosomonas* and *Nitrobacter*, the two types of bacteria that are responsible for nitrification, are normally not present in large numbers in effluent from conventional lagoons. A measurable oxygen demand is often not exerted for six to ten days because the reproductive rates of these bacteria are extremely slow (Metcalf and Eddy 1991). Effluent samples from the Iuka POTW collected during the intensive study in 1998 showed that oxidation of nitrogenous material did not occur within the first five days of TBODu testing. Thus, $NBOD_5$ is equal to zero and Equation 13 simplifies to Equation 14.

$$\boxed{\mathbf{TBOD_5 = CBOD_5}} \qquad \text{(Equation 14)}$$

In order to calculate the appropriate permit limit in terms of $TBOD_5$, the CBODu concentrations given in Table 7 were converted to $CBOD_5$ concentrations using the CBODu to $CBOD_5$ ratio. This ratio, which was developed based on the results of TBODu testing of samples of the Iuka POTW effluent, is equal to 5.54 mg/L of CBODu per mg/L of $CBOD_5$. Calculation of this ratio is shown in Table 6. Recommended WQBELs, which are based on the CBODu to $CBOD_5$ ratio, are given in Table 7.

Table 6. Calculation of the CBODu to $CBOD_5$ Ratio

Station	CBODu (mg/L)	$CBOD_5$ (mg/L)	CBODu to $CBOD_5$ Ratio
Iuka POTW	78.96	15.20	5.19
Iuka POTW	84.88	14.40	5.89
Average			**5.54**

Table 7. Recommended WQBELs for the Iuka POTW

Season	Flow (MGD)	DO (mg/L)	CBODu (mg/L)	$TBOD_5$ = CBODu/5.54 (mg/L)	$TBOD_5$ (lbs/day)	Ammonia-N (mg/L)	Ammonia-N (lbs/day)
Summer (May–October)	0.36	6.0	45.0	**8.1**	24.4	**2.0**	6.0
Winter (November–April)	0.36	6.0	70.0	**12.6**	38.0	**2.0**	6.0

5.2 Load Allocations

The load allocation is the portion of the TMDL allocated to nonpoint sources that do not require an NPDES permit such as atmospheric deposition, groundwater infiltration, and background sources of pollutants. The load allocation of TBODu for segment MS192IM2 of Indian Creek consists of the spatially distributed loads. Data collected during the field study were used to calculate the load allocation for the spatially distributed loads each reach, Table 8. Because the load allocation does not vary by season, it is given on an annual basis. No reduction of the load allocation for segment MS192IM2 is required by this TMDL.

Table 8. Load Allocation for Indian Creek Segment MS192IM2

Reach	Flow (cfs)	CBODu (lbs/day)	NBODu (lbs/day)	TBODu (lbs/day)
R-3	0.42	7.94	1.87	9.80
R-4	0.28	5.29	1.24	6.54
R-5	0.08	1.51	0.36	1.87
R-6	0.48	9.07	2.13	11.20
R-7	0.16	3.02	0.71	3.73
Total		**26.84**	**6.31**	**33.15**

5.3 Incorporation of a Margin of Safety (MOS)

The two types of MOS development are to implicitly incorporate the MOS using conservative model assumptions or to explicitly specify a portion of the total TMDL as the MOS. The MOS selected for this model is implicit. Conservative assumptions which place a higher demand of DO on the waterbody than may actually be present are considered part of the MOS. The assumption that all of the ammonia-N present in the waterbody is oxidized to nitrate-N, for example, is a conservative assumption. Setting up the critical condition model with the 7Q10 low-flow is another MOS.

5.4 Calculation of the TMDL

The TMDL was calculated based on Equation 15.

$$\mathbf{TMDL = WLA + LA + MOS} \qquad \text{(Equation 15)}$$

Where
WLA = waste load allocation, lbs-TBODu /day
LA = load allocation, lbs-TBODu /day
MOS = margin of safety

The TMDL for TBODu was calculated on a seasonal basis, based on the maximum allowable loading of the pollutant for Indian Creek according to the model. The TMDL calculations are shown in Table 9. The wasteload allocations incorporate the TBODu contributions from the NPDES permitted facility. The load allocations include the headwater and spatially distributed TBODu contributions from surface runoff and groundwater infiltration.

Table 9. TMDLs for TBODu, for Indian Creek Segment MS192IM2

Season	WLA (lbs/day)	LA (lbs/day)	MOS	TMDL (lbs/day)
Summer (May-October)	162.90	33.15	Implicit	**196.05**
Winter (November – April)	238.00	33.15	Implicit	**271.15**

All of the segment's assimilative capacity for TBODu has been assigned to existing point and nonpoint sources. The WQBELs recommended for the Iuka POTW will result in a reduction from the current NPDES permit limits in both the summer and winter seasons for this facility. Tables 10 and 11 show seasonal comparisons of the current NPDES permit limits, the actual discharge, and the recommended WQBELs. The actual discharge was characterized by averaging the flow and $TBOD_5$

concentrations reported in DMRs submitted to MDEQ from April 1, 1998 to July 31, 2000.

Table 10. Comparison of $TBOD_5$ Permit Limits, Actual Discharge, and WQBELs, Summer (May – October)

	Current NPDES Permit Limits	Actual Discharge	WQBELs
Flow, MGD	0.36	0.27	0.36
$TBOD_5$, mg/L	30.00	13.78	8.12
$TBOD_5$, lbs/day	90.07	31.03	24.38
Difference Between Current Permit Limits and WQBELs	90.07 lbs/day – 24.38 lbs/day = 65.69 lbs/day Equal to a 73% reduction from current permit limits.		
Difference Between Actual Discharge and WQBELs	31.03 lbs/day – 24.38 lbs/day = 6.65 lbs/day Equal to a 22% reduction from actual discharge.		

Table 11. Comparison of $TBOD_5$ Permit Limits, Actual Discharge, and WQBELs, Winter (November – April)

	Current NPDES Permit Limits	Actual Discharge	WQBELs
Flow, MGD	0.36	0.27	0.36
$TBOD_5$, mg/L	30.00	13.78	12.64
$TBOD_5$, lbs/day	90.07	31.03	37.95
Difference Between Current Permit Limits and WQBELs	90.07 lbs/day – 37.95 lbs/day = 52.12 lbs/day Equal to a 58% reduction from current permit limits.		
Difference Between Actual Discharge and WQBELs	31.03 lbs/day – 37.95 lbs/day = -6.92 lbs/day No reduction from actual discharge is required.		

6.0 CONCLUSION

6.1 Future Monitoring

MDEQ has adopted the Basin Approach to Water Quality Management, a plan that divides Mississippi's major drainage basins into five groups. During each one-year cycle, MDEQ resources for water quality monitoring will be focused on one of the basin groups. During the next monitoring phase in the Tennessee Basin, Indian Creek may receive additional monitoring to identify any change in water quality. Future NPDES Permits for discharge of $TBOD_5$ and ammonia-N in segment MS192IM2 of Indian Creek will not be issued unless they are accompanied by a commensurate reduction of the WQBELs established for the Iuka POTW. MDEQ produced guidance for future Section 319 project funding will encourage NPS restoration projects that attempt to address TMDL related issues within Section 303(d)/TMDL watersheds in Mississippi.

6.2 Public Participation

This TMDL will be published for a 30-day public notice. During this time, the public will be notified by publication in the statewide newspaper and a newspaper in Tishomingo County. The public will be given an opportunity to review the TMDL and submit comments. At the end of the 30-day period, MDEQ will determine the level of interest in the TMDL and make a decision on the necessity of holding a public hearing.

If a public hearing is deemed appropriate, the public will be given a 30-day notice of the hearing to be held at a location near the watershed. That public hearing would be an official hearing of the Mississippi Commission on Environmental Quality, and would be transcribed.

All comments received during the public notice period and at any public hearings become a part of the record of this TMDL. All comments will be considered in the ultimate approval of this TMDL by the Commission on Environmental Quality and for submission of this TMDL to EPA Region IV for final approval.

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DEFINITIONS

5-Day Biochemical Oxygen Demand: Also called BOD_5, the amount of oxygen consumed by microorganisms while stabilizing or degrading carbonaceous or nitrogenous compounds under aerobic conditions over a period of 5 days.

Allochtonous: Refers to organic carbon that is produced outside the waterbody.

Ammonia: Inorganic form of nitrogen (NH_3); product of hydrolysis of organic nitrogen and denitrification. Ammonia is preferentially used by phytoplankton over nitrate for uptake of inorganic nitrogen.

Ammonia-N: The measured ammonia concentration reported in terms of equivalent ammonia concentration; also called total ammonia as nitrogen (NH_3-N)

Assimilative Capacity: The capacity of a body of water or soil-plant system to receive wastewater effluents or sludge without violating the provisions of the State of Mississippi Water Quality Criteria for Intrastate, Interstate, and Coastal Waters and Water Quality regulations.

Autochtonous: Refers to organic carbon that is produced within the waterbody

Background: The condition of waters in the absence of man-induced alterations based on the best scientific information available to MDEQ. The establishment of natural background for an altered waterbody may be based upon a similar, unaltered or least impaired, waterbody or on historical pre-alteration data.

Biological Impairment: Condition in which at least one biological assemblages (e.g. , fish, macroinvertabrates, or algae) indicates less than full support with moderate to severe modification of biological community noted.

Carbonaceous Biochemical Oxygen Demand: Also called CBODu, the amount of oxygen consumed by microorganisms while stabilizing or degrading carbonaceous compounds under aerobic conditions over an extended time period.

Calibrated Model: A model in which reaction rates and inputs are significantly based on actual measurements using data from surveys on the receiving waterbody.

Conventional Lagoon: An un-aerated, relatively shallow body of water contained in an earthen basin of controlled shape and designed for the purpose of treating water.

Critical Condition: Hydrologic and atmospheric conditions in which the pollutants causing impairment of a waterbody have their greatest potential for adverse effects.

Daily Discharge: The "discharge of a pollutant" measured during a calendar day or any 24-hour period that reasonably represents the calendar day for purposes of sampling. For pollutants with limitations expressed in units of mass, the "daily discharge" is calculated as the total mass of the pollutant discharged over the day. For pollutants with limitations expressed in other units of measurement, the "daily average" is calculated as the average.

Designated Use: Use specified in water quality standards for each waterbody or segment regardless of actual attainment.

Discharge Monitoring Report: Report of effluent characteristics submitted by a NPDES Permitted facility.

Dissolved Oxygen: The amount of oxygen dissolved in water. It also refers to a measure of the amount of oxygen that is available for biochemical activity in a water body. The maximum concentration of dissolved oxygen in a waterbody depends on temperature, atmospheric pressure, and dissolved solids concentration.

Dissolved Oxygen Deficit: The saturation dissolved oxygen concentration minus the actual dissolved oxygen concentration.

Dissolved Oxygen Sag: Longitudinal variation of dissolved oxygen representing the oxygen depletion and recovery following a waste load discharge into a receiving water.

Dissolved-P: Forms of phosphorous which are present in a filtered water sample, including orthophosphorous, polyphosphates, and organic colloids. The most significant form of dissolved phosphorous is orthophosphate, an inorganic form of phosphorous which is the only directly utilizable form of dissolved phosphorous.

Effluent Standards and Limitations: All State or Federal effluent standards and limitations on quantities, rates, and concentrations of chemical, physical, biological, and other constituents to which a waste or wastewater discharge may be subject under the Federal Act or the State law. This includes, but is not limited to, effluent limitations, standards of performance, toxic effluent standards and prohibitions, pretreatment standards, and schedules of compliance.

Effluent: Treated wastewater flowing out of the treatment facilities.

First Order Kinetics: Describes a reaction in which the rate of transformation of a pollutant is proportional to the amount of that pollutant in the environmental system.

Groundwater: Subsurface water in the zone of saturation. Groundwater infiltration describes the rate and amount of movement of water from a saturated formation.

Hydrolysis: A chemical reaction in which the bond of a molecule is cleaved and a new bond is formed with the hydrogen and hydroxyl components of water

Impaired Waterbody: Any waterbody that does not attain water quality standards due to an individual pollutant, multiple pollutants, pollution, or an unknown cause of impairment.

Land Surface Runoff: Water that flows into the receiving stream after application by rainfall or irrigation. It is a transport method for nonpoint source pollution from the land surface to the receiving stream.

Load Allocation (LA): The portion of a receiving water's loading capacity attributed to or assigned to nonpoint sources (NPS) or background sources of a pollutant

Loading: The total amount of pollutants entering a stream from one or multiple sources.

Mass Balance: An equation that accounts for the flux of mass going into a defined area and the flux of mass leaving a defined area, the flux in must equal the flux out.

Nonpoint Source: Pollution that is in runoff from the land. Rainfall, snowmelt, and other water that does not evaporate become surface runoff and either drains into surface waters or soaks into the soil and finds its way into groundwater. This surface water may contain pollutants that come from land use activities such as agriculture; construction; silvaculture; surface mining; disposal of wastewater; hydrologic modifications; and urban development.

Nitrification: The oxidation of ammonium salts to nitrites via *Nitrosomonas* bacteria and the further oxidation of nitrite to nitrate via *Nitrobacter* bacteria.

Nitrogenous Biochemical Oxygen Demand: Also called NBODu, the amount of oxygen consumed by microorganisms while stabilizing or degrading nitrogenous compounds under aerobic conditions over an extended time period.

NPDES Permit: An individual or general permit issued by the Mississippi Environmental Quality Permit Board pursuant to regulations adopted by the Mississippi Commission on Environmental Quality under Mississippi Code Annotated (as amended) §§ 49-17-17 and 49-17-29 for discharges into State waters.

Organic-P: More than 90 % of the phosphorous in freshwater occurs in this form, which includes

Oxiation: The chemical union of oxygen with metals or organic compounds accompanied by a removal of hydrogen or another atom.

Photosynthesis: The biochemical synthesis of carbohydrate based organic compounds from water and carbon dioxide using light energy in the presence of chlorophyll.

Point Source: Pollution loads discharged at a specific location from pipes, outfalls, and conveyance channels from either wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving stream.

Pollution: Contamination, or other alteration of the physical, chemical, or biological properties, of any waters of the State, including change in temperature, taste, color, turbidity, or odor of the waters, or such discharge of any liquid, gaseous, solid, radioactive, or other substance, or leak into any waters of the State, unless in compliance with a valid permit issued by the Permit Board.

Publicly Owned Treatment Works: A waste treatment facility owned and/or operated by a public body or a privately owned treatment works which accepts discharges which would otherwise be subject to Federal Pretreatment Requirements.

Reaeration: The net flux of oxygen occurring from the atmosphere to a body of water across the water surface.

Regression Coefficient: An expression of the functional relationship between two correlated variables that is often empirically determined from data, and is used to predict values of one variable when given values of the other variable.

Respiration: The biochemical process by means of which cellular fuels are oxidized with the aid of oxygen to permit the release of energy required to sustain life. During respiration, oxygen is consumed and carbon dioxide is released.

Sediment Oxygen Demand: The solids discharged to a receiving water are partly organics, which upon settling to the bottom decompose aerobically, removing oxygen from the surrounding water column.

Total Ultimate Biochemical Oxygen Demand: Also called TBODu, the amount of oxygen consumed by microorganisms while stabilizing or degrading carbonaceous or nitrogenous compounds under aerobic conditions over an extended time period.

Total Kjeldahl Nitrogen: Also called TKN, organic nitrogen plus ammonia nitrogen.

Total Maximum Daily Load or TMDL: The calculated maximum permissible pollutant loading to a waterbody at which water quality standards can be maintained.

Waste: Sewage, industrial wastes, oil field wastes, and all other liquid, gaseous, solid, radioactive, or other substances which may pollute or tend to pollute any waters of the State.

Wasteload Allocation (WLA): The portion of a receiving water's loading capacity attributed to or assigned to point sources of a pollutant.

Water Quality Standards: The criteria and requirements set forth in *State of Mississippi Water Quality Criteria for Intrastate, Interstate, and Coastal Waters*. Water quality standards are standards composed of designated present and future most beneficial uses (classification of waters), the numerical and narrative criteria applied to the specific water uses or classification, and the Mississippi antidegradation policy.

Water Quality Criteria: Elements of State water quality standards, expressed as constituent concentrations, levels, or narrative statements, representing a quality of water that supports the present and future most beneficial uses.

Waters of the State: All waters within the jurisdiction of this State, including all streams, lakes, ponds, wetlands, impounding reservoirs, marshes, watercourses, waterways, wells, springs, irrigation systems, drainage systems, and all other bodies or accumulations of water, surface and underground, natural or artificial, situated wholly or partly within or bordering upon the State, and such coastal waters as are within the jurisdiction of the State, except lakes, ponds, or other surface waters which are wholly landlocked and privately owned, and which are not regulated under the Federal Clean Water Act (33 U.S.C.1251 et seq.).

Watershed: The area of land draining into a stream at a given location.

ABBREVIATIONS

7Q10	Seven-Day Average Low Stream Flow in a Ten-Year Occurrence Period
Ammonia-N	Ammonia as Nitrogen
BMP	Best Management Practice
CBOD$_5$	5-Day Carbonaceous Biochemical Oxygen Demand
CBODu	Ultimate Carbonaceous Biochemical Oxygen Demand
CWA	Clean Water Act
Dissolved-P	Dissolved Phosphorous
DMR	Discharge Monitoring Report
GPS	Global Positioning System
HUC	Hydrologic Unit Code
LA	Load Allocation
MARIS	Mississippi Automated Resource Information System
MDEQ	Mississippi Department of Environmental Quality
MGD	Million Gallons per Day
MOS	Margin of Safety
NBOD$_5$	5-Day Nitrogenous Biochemical Oxygen Demand
NBODu	Ultimate Nitrogenous Biochemical Oxygen Demand
Nitrate-N	Nitrate Nitrogen
Nitrite-N	Nitrite Nitrogen
NPDES	National Pollution Discharge Elimination System
NPSM	Nonpoint Source Model
Organic-N	Organic Nitrogen
POTW	Publicly Owned Treatment Works

RBA	Rapid Biological Assessment
$TBOD_5$	5-Day Total Biochemical Oxygen Demand
TBODu	Total Ultimate Biochemical Oxygen Demand
TKN	Total Kjeldahl Nitrogen
TOC	Total Organic Carbon
Total-P	Total Phosphorous
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WLA	Waste Load Allocation
WQBELs	Water Quality Based Effluent Limitations

Appendix A: Water Quality Study

A.1 Introduction

The Mississippi Department of Environmental Quality conducted a study of Indian Creek near Iuka, MS in late August and early September of 1998. The purpose of this study was to assess the water quality in the creek through field study and to provide data to calibrate a QUAL2E model of Indian Creek. The model, which is representative of the cause and effect relationships between pollutant loads and the resulting water quality, allowed for predictive modeling and the development of a TMDL for segment MS192IM2 of Indian Creek.

Indian Creek is a meandering creek, with many deep pools along with shallow fast-flowing runs. The upper reaches of Indian Creek are located on Coastal Plain Sediments, while the lower reaches are located on Fort Payne Chert (Merrill, et al. 1988). The stream channel is composed of gravel, with some deposits of sand and silt in the pool areas. Much of the stream is surrounded by a dense canopy, resulting in decreased direct sunlight and a substantial amount of allochotonous material in the stream channel. The entire length of Indian Creek, from headwaters to confluence with the Pickwick Lake, an impoundment of the Tennessee River, is approximately 13 miles. The segment found on Mississippi’s 1998 303(d) List, however, occupies only 3 miles, less than one fourth of this length. Slopes, ranging from 8 to 20 feet per mile are present in the sections. The headwaters of Indian Creek flow mainly from runoff from urban areas of Iuka, rural surrounding areas, and groundwater infiltration. Throughout its 13 miles, the creek is fed by groundwater infiltration and many small tributaries (Merrill, et al. 1988).

The data collection plan for this study was developed to allow a full characterization of the dissolved oxygen profile and all oxygen sources and sinks in Indian Creek. The main sources of oxygen are atmospheric reaeration and algal photosynthesis. The main sinks of oxygen are CBODu decay, nitrification, sediment oxygen demand, and algal respiration. These processes are represented graphically in Figure A-1.

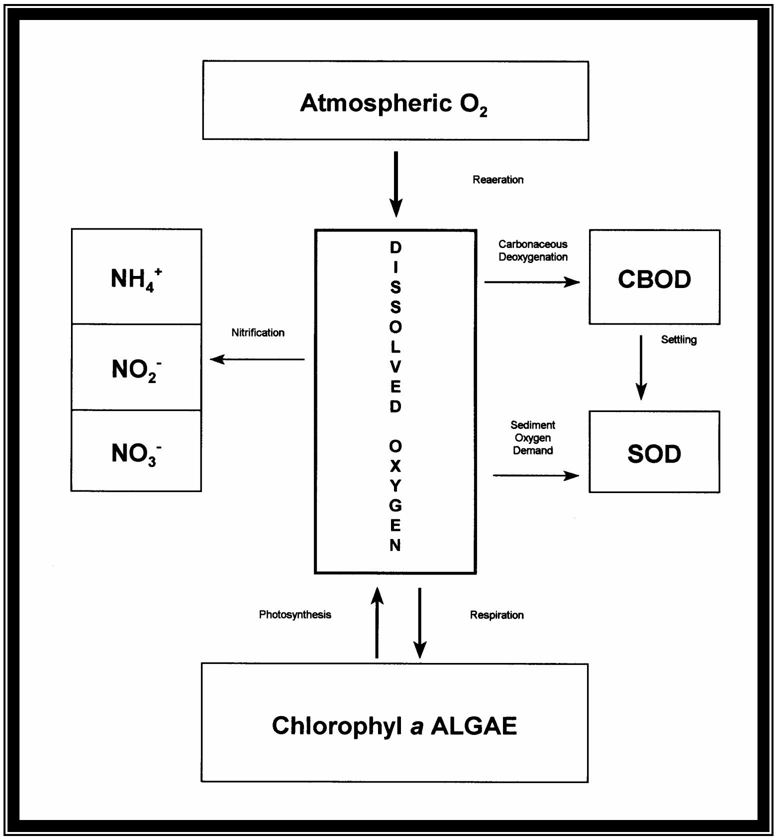

Figure A-1. Instream Processes Effecting the Dissolved Oxygen

Hydrological data such as stream geometry and flow are critical to modeling the transport of pollutants and the reaeration process within a stream. The hydrological data collected in the study consisted of measurements of flow, cross sectional area, channel width and depth, and stage readings. Streambed and water surface elevations for several sampling stations were measured with GPS equipment. Also, a dye study was conducted to determine the travel time between the reaches and the velocity of the stream flow. Instantaneous flows were measured at the beginning of each modeled stream reach. The rate of effluent discharge from Iuka POTW was monitored continuously during the study.

Water chemistry data were collected to allow an accurate characterization of chemical processes occurring in the stream such as the stabilization of CBODu after its release from the POTW, the nitrogen cycle, the phosphorous cycle, and the photosynthesis and respiration of algae. Multiple measurements of TOC, total phosphorous, TKN, ammonia-N, nitrite-N, nitrate-N, TSS, and chlorophyll-*a* were collected at each monitoring station. In-situ measurements of DO, temperature, pH, and conductivity were collected in 30-minute intervals for at least a 24-hour period at each station. The daily amount of sunlight and the diurnal temperature changes were measured throughout the study. Light and dark bottles were used to study the respiration and photosynthesis of algae in the water column.

Analysis of the instream biology and habitat was performed at four of the monitoring stations on Indian Creek and at Pickens Branch, a tributary of Indian Creek. Biological data collected at Pickens Branch, were used to establish reference conditions for a non-impaired stream for comparison purposes. The biological evaluations consisted of a habitat assessment and an analysis of the benthic macroinvertabrates found in the stream. The use of benthic macroinvertabrates in bioassessments provides an indication of the long-term water quality of a stream. Most benthic macroinvertabrates remain in the same area for most of their life. In addition, certain types of these organisms are extremely sensitive to various types of pollution, thus the presence or absence of sensitive organisms in an area provides a long-term indication of the quality of the water to which they have been exposed.

Benthic macroinvertabrates were collected according to a specific protocol called a rapid biological analysis or RBA. The RBAs were performed at stations IC-2, IC-3, IC-5, and IC-7. The RBAs performed at the station above the Iuka POTW discharge, IC-2, and furthest downstream from the POTW discharge, IC-7, showed the best water quality conditions compared to the reference site. However, notable differences from the reference site, indicating poorer water quality, were found at stations IC-3 and IC-5. Habitat assessments were performed at all of the monitoring sites, which indicated that all stations had relatively good habitat. The results of the RBAs and habitat evaluations are described in further detail in *Indian Creek TMDL Development: Macroinvertabrate Assessment* (MDEQ 1998).

A.2 Station Locations

Based on the instream DO concentrations, a stream impaired by a point source of organic material from a wastewater treatment plant can be divided into three zones; the background zone, the sag zone, and the recovery zone. The background zone is upstream of the point source, and has DO concentrations at or near saturation and low levels of organic material. The sag zone begins downstream of the point source where decay of organic material occurs at a rapid rate, causing a DO deficit. As the instream DO decreases, atmospheric reaeration provides DO to compensate for the DO deficit. At the critical point, the DO depletion and reaeration balance and the lowest DO concentration occurs. Downstream of the critical point, reaeration increases the DO. In the recovery zone, DO levels return to background conditions and the water becomes clearer (Chapara 1997). The locations of these zones in Indian Creek are shown in Figure A-2, along with the average instream DO concentrations measured during the study.

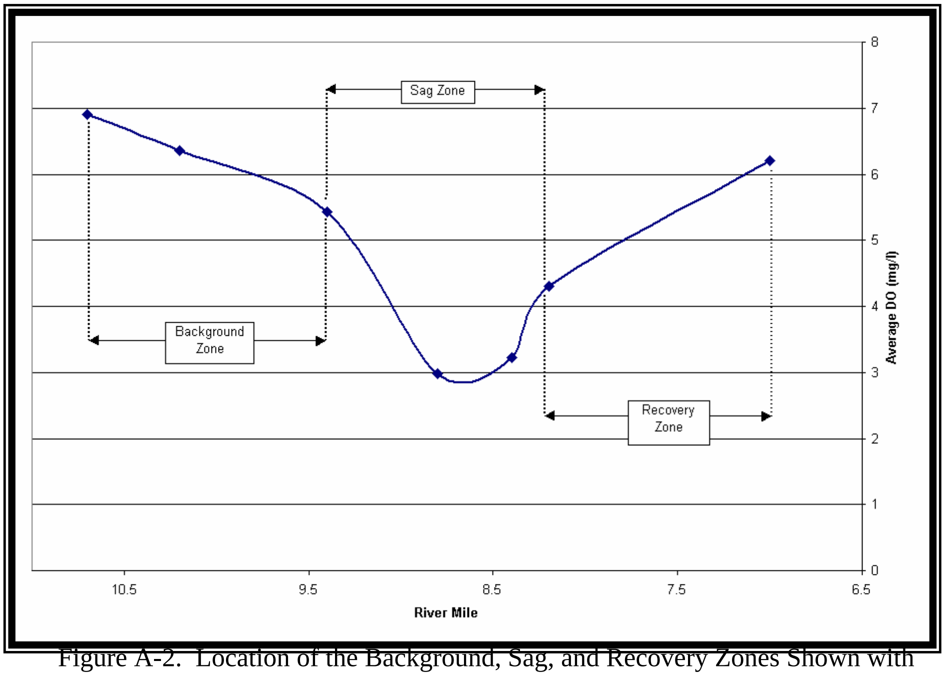

Figure A-2. Location of the Background, Sag, and Recovery Zones Shown with Daily Average DO Measured in Indian Creek

The reach divisions and sampling station locations for the study were chosen after carefully considering several factors such as the location of the DO zones, point source discharge locations, and accessibility of the creek. After initial reconnaissance trips to the creek, it was decided that 6 monitoring stations in Indian Creek and one monitoring station at the POTW discharge point would be sufficient to account for these factors. EPA suggests that the minimal instream sampling effort should include the headwater of each stream reach being modeled, effluent samples of all point sources before they enter the stream, and the downstream end of the study area (USEPA 1986). The sampling station locations provided a basis for dividing the creek into reaches. Each sampling station was used as the most upstream point in each of the 7 reaches included in the study. Figure A-3 shows the approximate locations of the sampling stations.

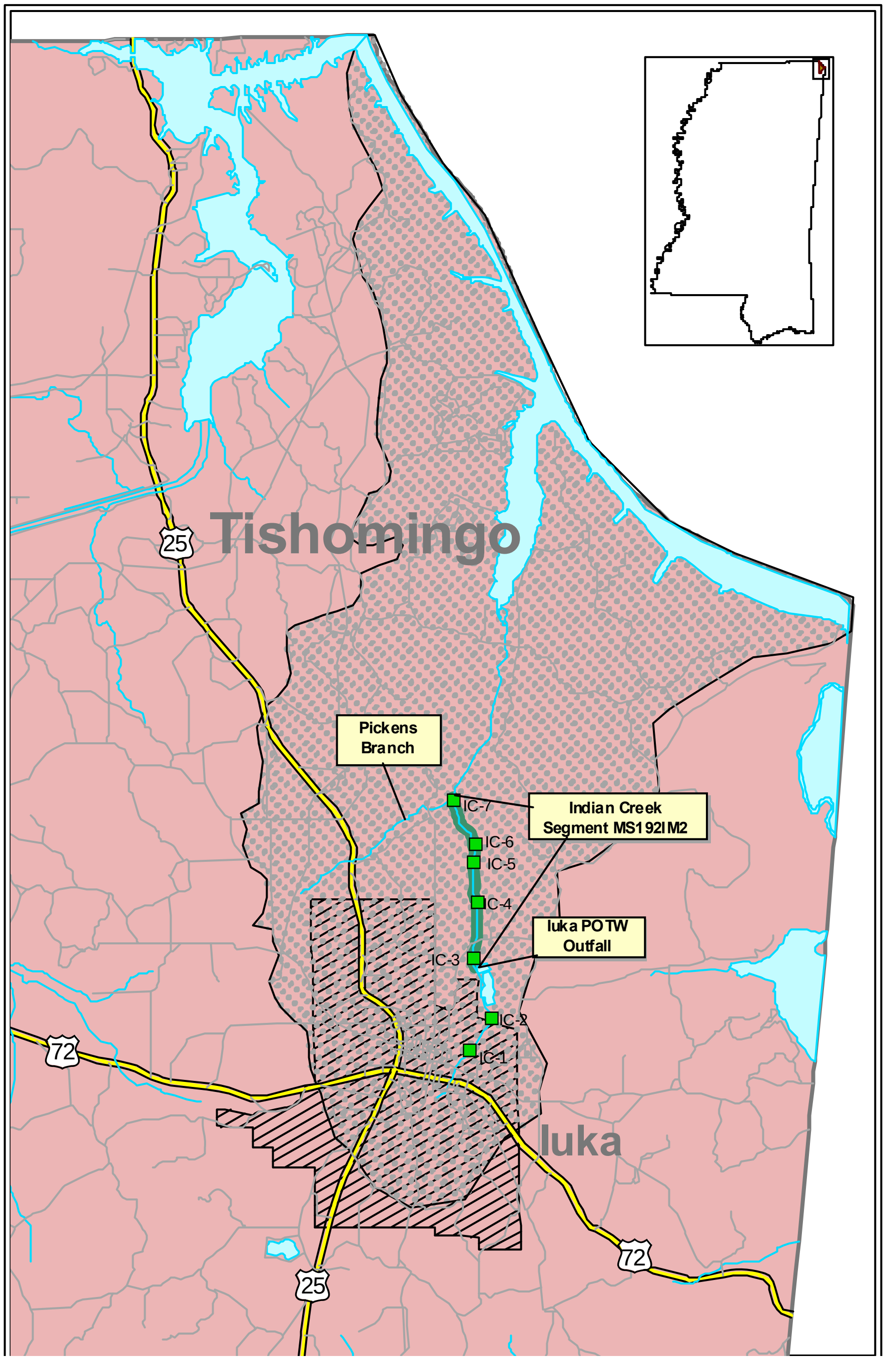

Figure A-3. Indian Creek Sampling Station Locations

Two stations were chosen upstream of the Iuka POTW in order to fully characterize the headwater and background conditions. These stations were also chosen to evaluate the impact of urban areas on water quality conditions because the headwaters of Indian Creek flow through the City of Iuka. These stations, labeled IC-1 and IC-2, are located at river miles 10.7 and 10.2 respectively. Sampling sites were also set up at the effluent discharge and approximately 200 yards downstream of the discharge pipe, river mile 9.4. The station at river mile 9.4 was designated IC-3, Photo A-1.

Photo A-1. Station IC-3, Looking Downstream

Stations IC-4 and IC-5 were established to characterize the water quality conditions in the DO sag zone. The minimum DO concentration was observed at station IC-4, which was located at river mile 8.8. The daily average DO concentration measured at this station was 2.98 mg/L. This concentration is well below the daily average standard of 5.0 mg/L. The daily average DO concentration increased slightly to 3.23 mg/L at station IC-5, which was located at river mile 8.4. Two stations were also set up in the DO recovery zone, IC-6 and IC-7. IC-6 was located at river mile 8.2. At this station, the daily average DO levels were 4.31 mg/L. The furthest downstream station, IC-7, was located at river mile 7.0. The dissolved oxygen in the Indian Creek recovered to a concentration of 6.21 mg/L, a level above the water quality standard, at station IC-7. The confluence of Pickens Branch with Indian Creek occurs at river mile 6.6. The location of some of the stations was measured with a Trimble 4800 GPS System, Table A-1.

Table A-1. Indian Creek Monitoring Station Locations

Station	Position
IC-3	N 34º 49’ 47.1” W 88º 10’ 51.4”
IC-4	N 34º 50’ 0.3” W 88º 10’ 50.9”
IC-5	N 34º 50’ 16.5” W 88º 10’ 49.3’
IC-6	N 34º 50’ 30.7” W 88º 10’ 52.8”

A.3 Hydrological Data

The first step in calibrating a water quality model is establishing the hydrological characteristics of a system. The hydrology of a waterbody determines the rate and magnitude of many physical and chemical processes occurring in a system. These processes include settling and resuspension of particulate organic matter and algae, decay of CBODu, and atmospheric reaeration. Hydrology also has a major impact on the life cycle of benthic macroinvertabrates living in a waterbody and the types and density of aquatic and terrestrial plant life that can grow in and near a waterbody. The hydrological data collection plan was established in order to characterize these processes. The data collection plan consisted of stream flow measurements, surveys of channel geometry and water level elevations, and a dye study.

Instantaneous stream flow measurements were collected at the monitoring stations on Indian Creek during the study period. Additional flow measurements were collected in September 2000. Flow measurements were conducted at each site by stretching a marked line across each cross section to be measured. The marked line was used to divide the cross section into subsections that were approximately one-third foot in width. The velocity at 60% depth was measured in each subsection. A wadding rod, digimeter, and Price (AA) or mini current meter were used to conduct the velocity measurements. Flow was calculated for each subsection by multiplying the velocity measured at 60% depth by the cross-sectional area of each subsection, according to the continuity equation, Equation A-1. The flows for each subsection were summed to obtain the total flow of each cross section.

$$\mathbf{Q = V*A} \qquad \text{(Equation A-1)}$$

Where
Q = flow, cfs
V = velocity, fps
A = area, ft^2

The flow measurements taken on Indian Creek, along with the stream cross sectional area, are presented in Table A-2. Because the QUAL2E model was calibrated using chemical data collected during the intensive study period of September 14-18, 1998, only the flow data collected during this week was used for hydrological calibration. The flow measurements that were used for the hydrological calibration of the model are shown in bold in the table.

Table A-2. Instantaneous Stream Flow Measurements

Station Name	Measurement Date	Measurement Time	Width of Cross Section (ft)	Area of Cross Section (ft^2)	Flow (cfs)
IC-1	**9/14/1998**	**07:45**	**8.10**	**3.28**	**1.03**
IC-1	9/01/1998	16:20	10.90	3.47	1.27
IC-2	9/14/1998	15:14	9.20	6.13	1.55
IC-2	9/02/1998	15:03	9.70	6.07	2.05
IC-3	**9/14/1998**	**11:02**	**12.20**	**1.35**	**1.76**
IC-3	8/20/1998	16:10	8.80	6.83	2.94
IC-3	9/01/1998	15:00	12.20	2.43	2.30
IC-3	9/26/2000	17:00	12.00	3.25	2.56
IC-4	9/26/2000	17:45	5.50	2.27	2.47
IC-5	**9/15/1998**	**10:30**	**10.00**	**5.69**	**2.46**
IC-5	9/02/1998	13:40	12.40	6.60	2.38
IC-5	9/27/2000	08:45	17.00	4.44	2.35
IC-6	9/17/1998	07:15	12.00	6.76	2.17
IC-6	9/27/2000	08:15	14.00	3.61	2.32
IC-7	**9/15/1998**	**12:20**	**17.00**	**6.04**	**3.01**
IC-7	9/01/1998	17:19	16.70	8.48	3.19

The data in Table A-1 show that there is generally an increase in channel width and flow as water moves downstream in the system. The increase in flow is due to the infiltration of groundwater and the confluence of small tributaries with Indian Creek. For modeling purposes, however, the flow in these small tributaries was not measured or included in the model. To simplify the hydrological model, it was assumed that the increase in flow between monitoring stations was evenly distributed within each reach. Incremental inflow was included in the model by calculating the differences in flow between each station. The calculated incremental inflows are shown in Table A-2. Because the flow measurement taken at IC-6 shows a decrease in flow, it was assumed to be inaccurate and was not used for model calibration. The flow measurements at IC-5 and IC-7 were used to calibrate the hydrology in reaches R-5, R-6, and R-7. Incremental inflow was assumed to be uniformly distributed in these reaches.

Table A-2. Incremental Inflow Characteristics

Reach	River Mile	Reach Distance (miles)	Incremental Inflow (cfs)	Incremental Inflow (cfs/mile)
R-1	10.7 to 10.2	0.50	0.12	0.23
R-2	10.2 to 9.4	0.80	0.18	0.23
R-3	9.4 to 8.8	0.60	0.42	0.70
R-4	8.8 to 8.4	0.40	0.28	0.70
R-5	8.4 to 8.2	0.20	0.08	0.40
R-6	8.2 to 7.0	1.20	0.48	0.40
R-7	7.0 to 6.6	0.40	0.16	0.40

Slopes of each stream reach, a parameter required for the QUAL2E model, were calculated from measurements collected during the intensive study in September 1998 and during an additional recon study in September 2000. In September 1998, the water surface elevation at each station was measured with survey equipment. In September 2000, the elevation of the water surface at stations IC-3, IC-4, IC-5, and IC-6 was measured using a Trimble 4800 GPS System. Reach distances were determined by measuring the distance along the creek between each monitoring station on a USGS quadrangle map. The slope of R-3 through R-6, in feet per mile, was calculated using these measurements, Table A-3.

Table A-3. Stream Reach Slopes

Reach	Change in Elevation (ft)	Slope (ft/mile)
R-3	5.00	14.54
R-4	4.83	15.29
R-5	4.53	17.89
R-6	23.24	19.37

A dye study was used to measure the water velocity and time of travel in Indian Creek. The EPA *Handbook for Stream Sampling for Waste Load Allocations* suggests using the results of dye studies for adjusting measurements of stream geometry and flow. Stream geometry often varies widely within individual stream reaches because lateral inflows due to the confluence of small tributaries and spatial infiltration are hard to define. These variations are difficult to characterize in detail. Access to streams is often difficult, and limitations of time and budgets often restrict the number of sampling sites (USEPA 1986).

Rhodamine WT dye, a non-toxic biodegradable fluorescent dye, was used in the dye study. The dye study began at 08:07 on September 14, 1998 by releasing 350 mL of the dye into Indian Creek at station IC-1. The movement of the dye was traced using a Model 10 Series Florometer, Turner Instruments Inc. The florometer was calibrated before use at each monitoring station. In order to make the florometer readings as accurate as possible, a power supply of uniform voltage was provided by using a small gas-powered generator.

In order to document the movement of the dye cloud at each monitoring station, water samples were collected at regular intervals of time. The samples were collected with a dye boat or by hand, using a 100 mL cuvette. A dye boat is an automatic sampling device which collects surface water samples at an interval preset by the user with the use of spring-loaded syringes. The samples were analyzed for dye concentration using the flurometer. The water sample at each station that contained the highest concentration of dye was labeled as the dye peak. Figure A-4 shows a graph of the dye concentrations measured at each station. The dye concentration at each dye peak decreased as the dye traveled downstream from its point of release. This is due to dispersive forces, which spread out the dye cloud as it travels. After the dye cloud passed station IC-3 it was no longer visible in the creek. However, it was easily detectable with the use of the florometer at all of the monitoring stations. Though the dispersive effects reduce the concentration of dye present at the dye peak, they do not reduce the overall accuracy of the travel times measured.

The time of travel between each monitoring station was calculated by subtracting the amount of time between subsequent dye peaks. The distance along the stream channel divided by the travel time between monitoring stations is equal to the average velocity in each stream reach. These calculations are shown for each reach in Table A-4. Differences in velocity in each reach are attributed to differences in channel geomorphology, channel slope, and obstructions in the channel such as beaver dams and fallen trees.

Table A-4. Time of Travel Calculations

Reach	Station Name	Date of Dye Peak	Time of Dye Peak	Travel Time (hour)	River Mile of Station	Reach Distance (miles)	Reach Velocity (fps)
R-1	IC-1	9/14/98	08:07	7.88	10.7	0.5	0.093
	IC-2	9/14/98	16:00		10.2		
R-2	IC-2	9/14/98	16:00	21.95	10.2	0.8	0.053
	IC-3	9/15/98	13:57		9.4		
R-3	IC-3	9/15/98	13:57	3.3	9.4	0.6	0.267
	IC-4	9/15/98	17:15		8.8		
R-4	IC-4	9/15/98	17:15	4.25	8.8	0.4	0.138
	IC-5	9/15/98	21:30		8.4		
R-5	IC-5	9/15/98	21:30	2.08	8.4	0.2	0.141
	IC-6	9/15/98	23:35		8.2		
R-6	IC-6	9/15/98	23:35	18.75	8.2	1.2	0.094
	IC-7	9/16/98	17:20		7.0		

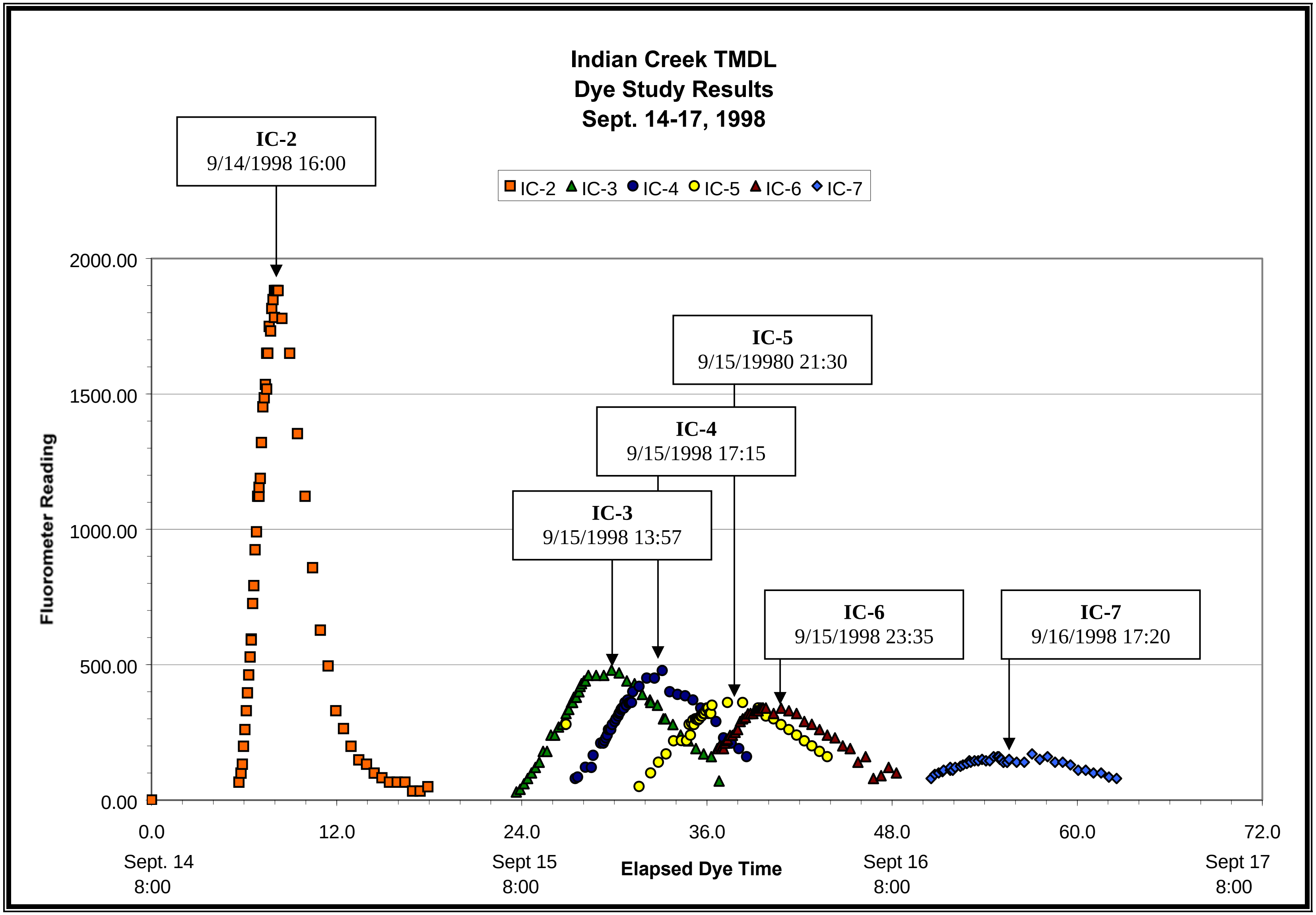

Figure A-3. Dye Peaks

The flow rate of effluent from the Iuka POTW was carefully monitored throughout the study using an ISCO bubble flow meter. The bubble meter measured flow using a submerged pressure transducer that was anchored in the flow stream upstream of the contracted, rectangular weir in the chlorine contact chamber. Bubbles of pressurized air were released from the end of a bubble tube at a constant rate. The pressure required to maintain a uniform rate of bubble release is proportional to a liquid level (Grant and Dawson 1997). The liquid level was used to calculate the head over the weir. Flow was calculated according to the equation for flow over a weir with two end contractions, Equation A-2. The average flow measured during the study was 0.43 cfs, which is less than the permitted flow of 0.36 MGD (0.557 cfs). The flows measured during the study are given in Table A-5.

$$\mathbf{Q = 3.33(L - 0.2*H)*H^{1.5}} \qquad \text{(Equation A-2)}$$

Where

Q = flow, cfs

L = crest length in feet, 1.50 feet

H = head measured at a distance upstream of at least 3 times the measured H, ft

Table A-5. ISCO Bubble Flow Meter Measurements

Interval Start Date	Interval Start Time	Interval End Date	Interval End Time	Interval Volume (ft3)	Average Level (ft)	Average Flow (cfs)
9/13/98	17:53	9/14/98	00:00	13,666	0.2504	0.6284
9/14/98	00:00	9/15/98	00:00	39,184	0.2057	0.4535
9/15/98	00:00	9/16/98	00:00	34,516	0.1887	0.3994
9/16/98	00:00	9/17/98	00:00	37,784	0.2007	0.4372
9/17/98	00:00	9/17/98	08:47	14,149	0.2119	0.4735
Average					**0.2115**	**0.4300**

A.4 Water Chemistry Data

Water chemistry samples were collected in duplicate at each monitoring station on Indian Creek. One sample was also collected at Pickens Branch (station PB-1), near its confluence with Indian Creek. This sample is useful for comparison purposes, as an unimpaired, reference site. The chemical analyses of all samples collected during the study were conducted by the MDEQ laboratory in Pearl, MS. After collection, samples were preserved as appropriate, placed on ice, and transported to the lab within required holding times. Chain-of-custody forms were maintained for all samples.

Timing of the grab sample collection was coordinated with the dye study. At each station, the first water chemistry sample was collected at the time that the dye peak passed the station. Then, the second sample was collected 12 hours after the dye peak. Assuming plug flow conditions in the creek, this strategy allowed sampling of essentially the same volume of water as it traveled downstream. This sampling strategy makes the water chemistry data extremely useful for estimating the rates at which chemical processes are occurring in the system. Instream water chemistry data collected during the study are listed in Table A-6. Water chemistry samples were also collected from the Iuka POTW lagoon, in the second cell near the outfall pipe using an ISCO sampler. The lagoon sample results are given in Table A-7. The sample collection times given in Table A-7 indicate the start of the sample collection since the Iuka POTW samples are composite samples collected over a 24-hour period.

Table A-6. Instream Water Chemistry Data

Station Name	Sample Date	Sample Time	Total Organic Carbon (mg/L)	Total Phosphorous (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Ammonia-N (mg/L)	Nitrite + Nitrate-N (mg/L)	Total Suspended Solids (mg/L)	Chlorophyll-a (μg/L)
IC-1	9/14/98	07:37	3.00	0.11	0.56	0.25	0.22	7.00	1.57
IC-1	9/14/98	20:00	3.00	0.10	0.32	0.11	0.19	4.00	1.30
IC-2	9/14/98	15:58	3.00	1.38	0.31	0.10	0.26	1.00	1.83
IC-2	9/15/98	06:25	3.00	0.09	0.43	0.12	0.23	3.00	2.21
IC-3	9/15/98	12:00	12.00	0.94	4.76	0.19	0.15	33.00	260.67
IC-3	9/15/98	00:16	9.00	0.51	1.89	0.44	0.15	16.00	53.17
IC-4	9/15/98	15:15	11.00	0.34	3.96	0.41	0.14	22.00	143.33
IC-4	9/16/98	07:30	8.00	0.21	1.89	0.44	0.15	3.00	23.05
IC-5	9/15/98	19:20	12.00	0.25	2.94	0.54	0.15	15.00	81.63
IC-5	9/16/98	08:55	8.00	0.19	1.67	0.48	0.15	5.00	20.33
IC-6	9/15/98	23:55	8.00	0.20	2.41	0.55	0.17	9.00	48.27
IC-6	9/16/98	11:05	8.00	0.15	1.54	0.47	0.19	8.00	14.10
IC-7	9/16/98	15:05	5.00	0.08	0.86	0.12	0.36	6.00	7.50
IC-7	9/17/98	06:30	5.00	0.06	0.74	0.12	0.36	16.00	3.09
PB-1	9/14/98	10:46	4.00	0.01	0.12	0.10	0.24	6.00	Not sampled

Table A-7. POTW Water Chemistry Data

Station Name	Sample Date	Sample Time	Total Organic Carbon (mg/L)	Total Phosphorous (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Ammonia-N (mg/L)	Nitrite + Nitrate-N (mg/L)	Total Suspended Solids (mg/L)	Chlorophyll-a (μg/L)
Iuka POTW	9/15/98	07:15	21.00	0.94	7.82	0.16	0.04	54.00	> 300
Iuka POTW	9/16/98	07:00	22.00	0.99	9.17	0.11	0.04	67.00	> 300

The water chemistry samples collected at stations IC-2, IC-3, IC-4, IC-6, and IC-7 were also analyzed for $TBOD_5$ and TBODu. Duplicate analysis of TBODu samples was conducted to ensure accuracy at stations IC-3, IC-4, and IC-6. These stations were most critical for characterizing the DO sag zone and the instream TBODu decay rate. TBODu samples were not collected at all monitoring stations due to limited laboratory space and the additional costs associated with long-term testing.

TBODu testing measures the oxygen demand exerted by the oxidation of both carbonaceous and nitrogenous substances. Oxygen demand must be measured over an extended time period because biochemical oxidation is a slow process and theoretically takes an infinite amount of time to go to completion (Metcalf and Eddy 1991). TBODu testing of samples collected from Indian Creek was conducted by the MDEQ laboratory for a period of 146 days, according to the procedure outlined in *Standard Methods for the Examination of Water and Wastewater, 20th Edition* (1998).

The concentration of TBODu, in the samples was calculated from measurements of dissolved oxygen depletion due to TBODu exertion. Dissolved oxygen depletion was calculated from routine measurements of DO in the BOD bottles. DO measurements were made in the laboratory every two to three days during the first thirty days of the testing. Measurements were made less frequently after this period. Nitrification was measured by routinely analyzing the sample for nitrate-N concentrations. Each mg/L of nitrate-N produced was assumed to use 4.57 mg/L of dissolved oxygen. The DO depletion due to nitrification was calculated using this relationship. Then, the oxygen depletion due to nitrification could be subtracted from the total oxygen depletion, allowing the calculation of CBODu.

The results from the TBODu analysis are shown in graphical format in Figures A-4 through A-11. The graphs show that the oxidation of carbonaceous materials proceeds at the most rapid rate in the first two weeks of the testing. Nitrate concentrations are generally very low for the first two weeks of the testing, indicating that nitrification does not begin to occur at a measurable rate until this time. The graphs show that towards the end of the testing, TBOD decay slows down, and the measured value asymptotically approaches the theoretical value of TBODu. For all of the samples, the measured DO depletion or TBOD exertion at 146 days of testing was assumed to be equal to TBODu.

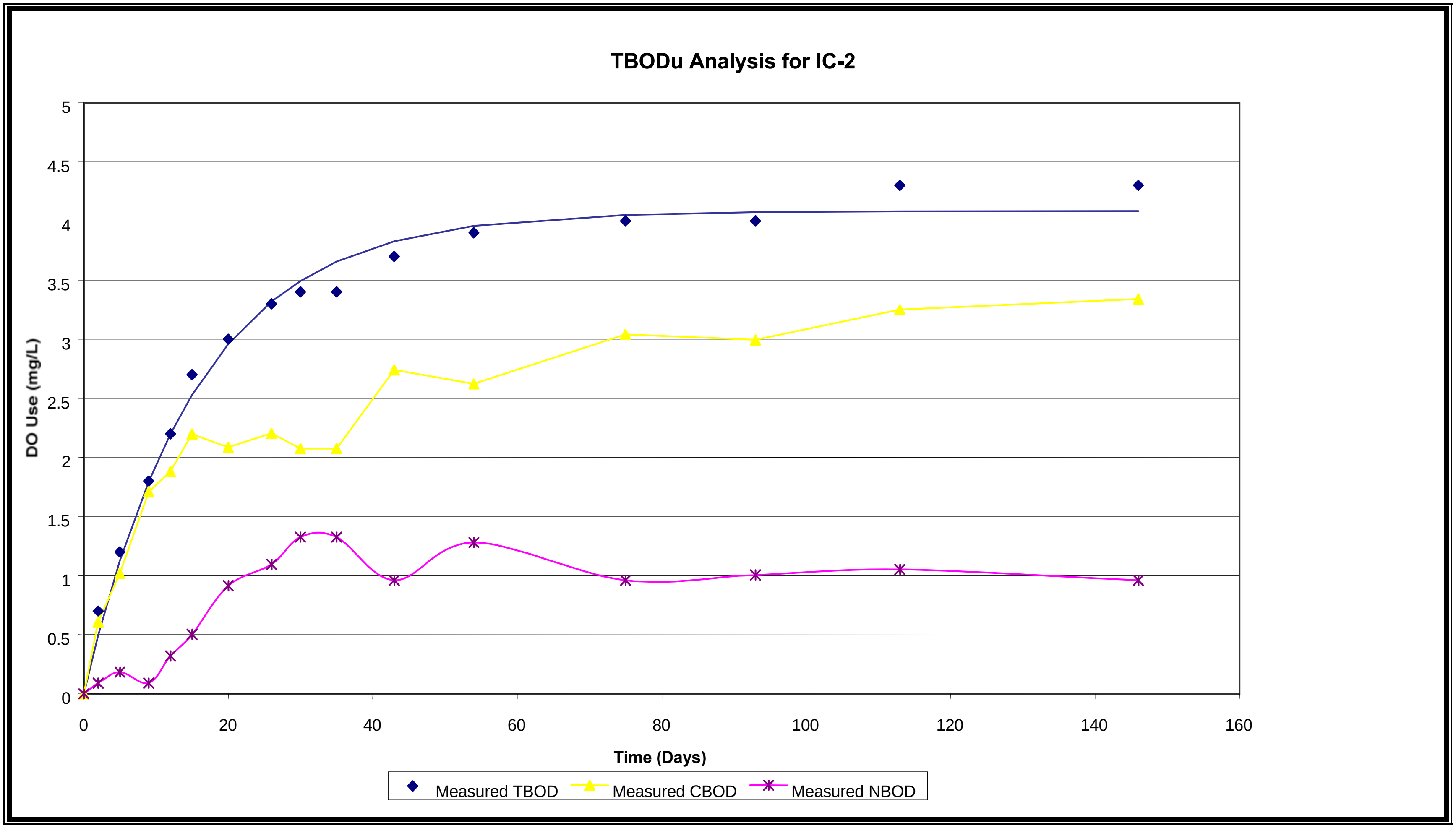

Figure A-4. TBODu Analysis of Sample from Station IC-2

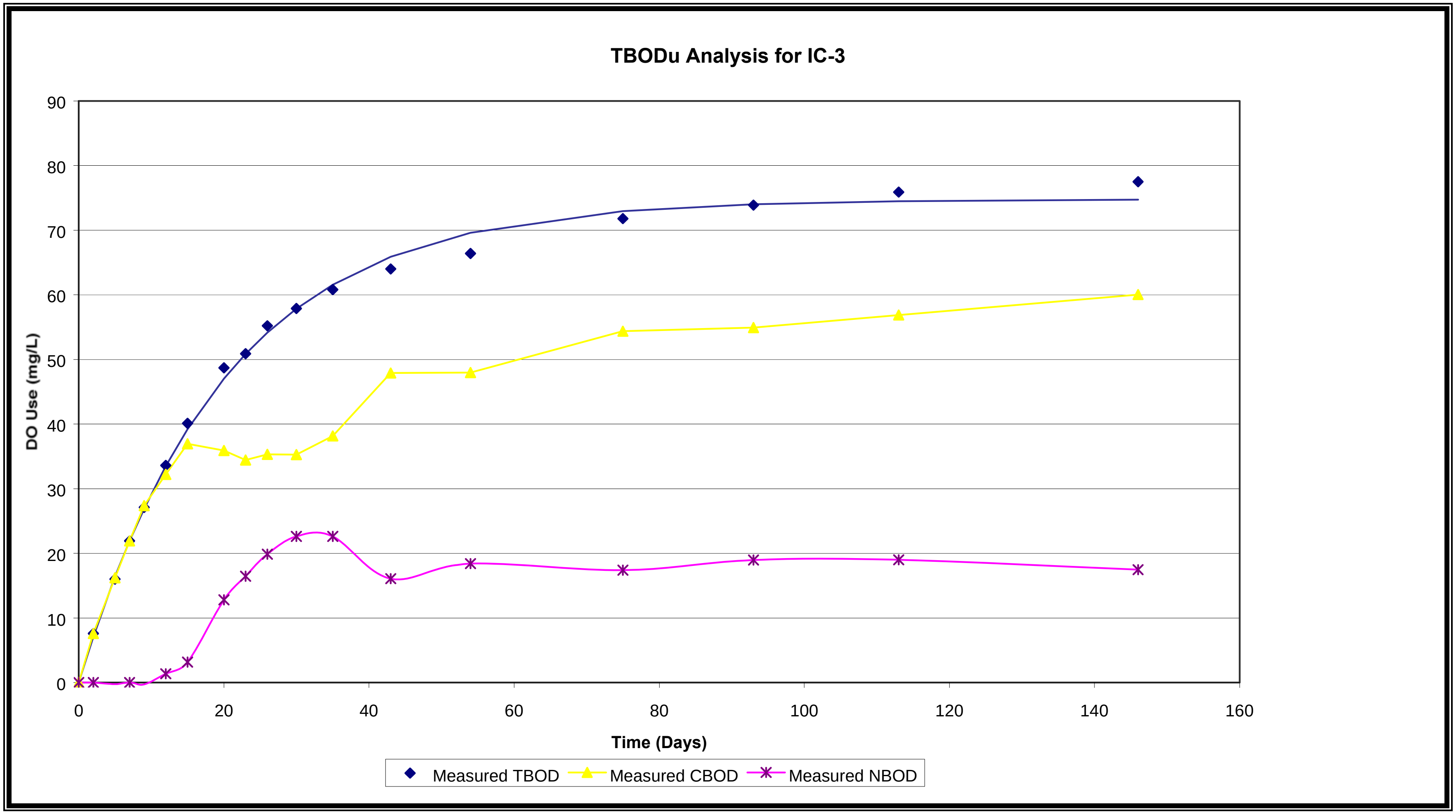

Figure A-5. TBODu Analysis of Sample from Station IC-3

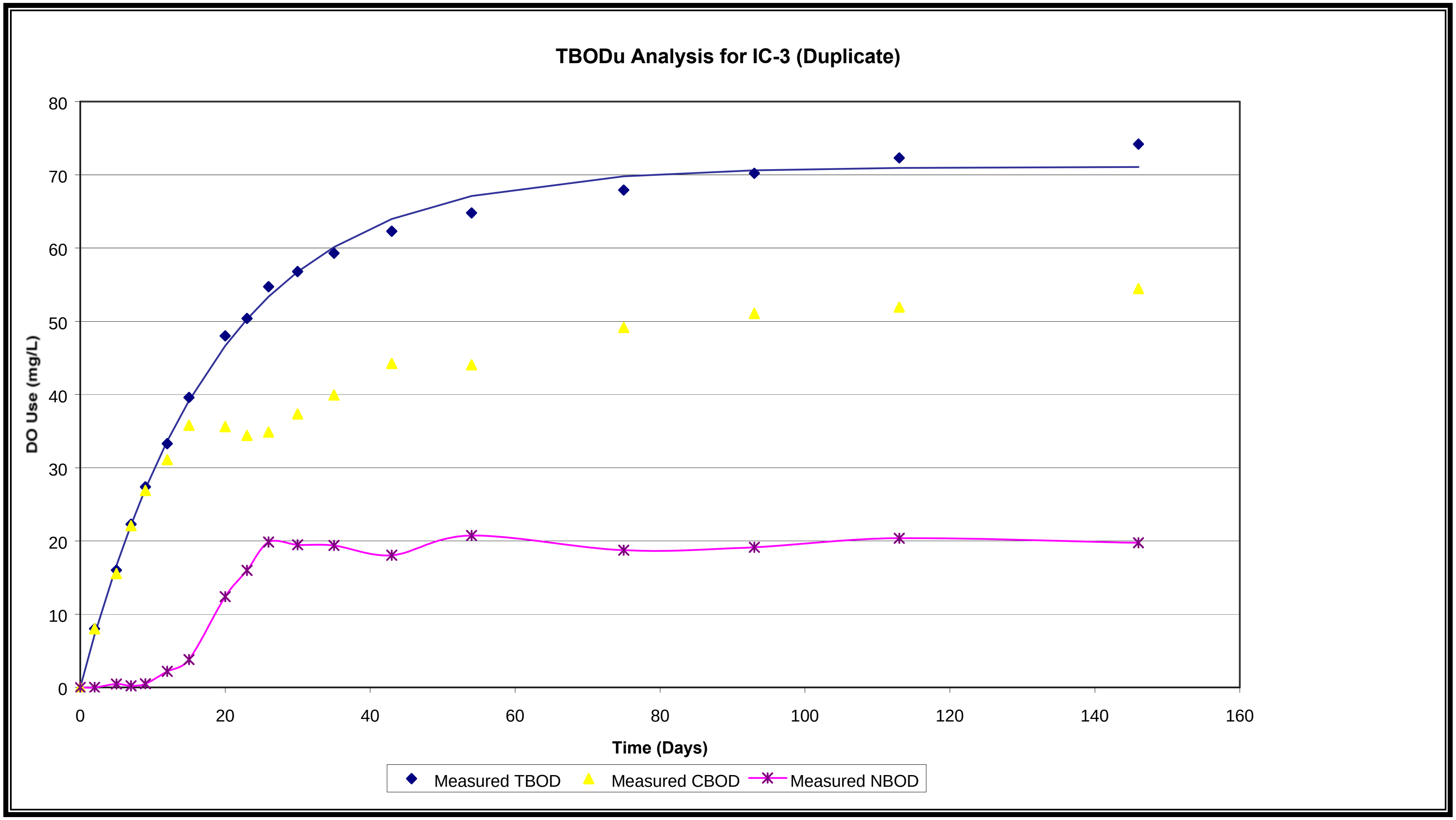

Figure A-6. TBODu Analysis of Duplicate Sample from Station IC-3

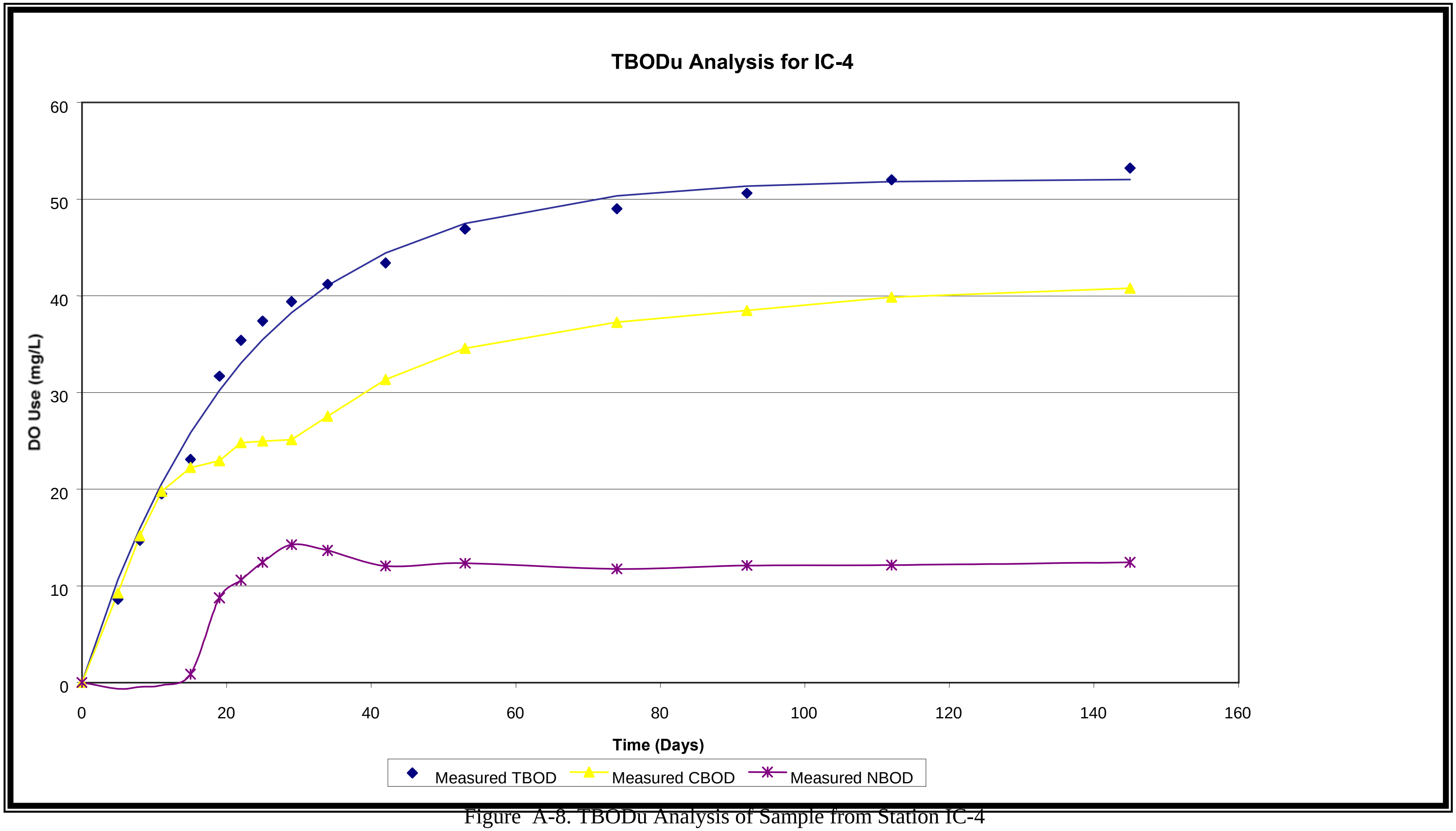

Figure A-8. TBODu Analysis of Sample from Station IC-4

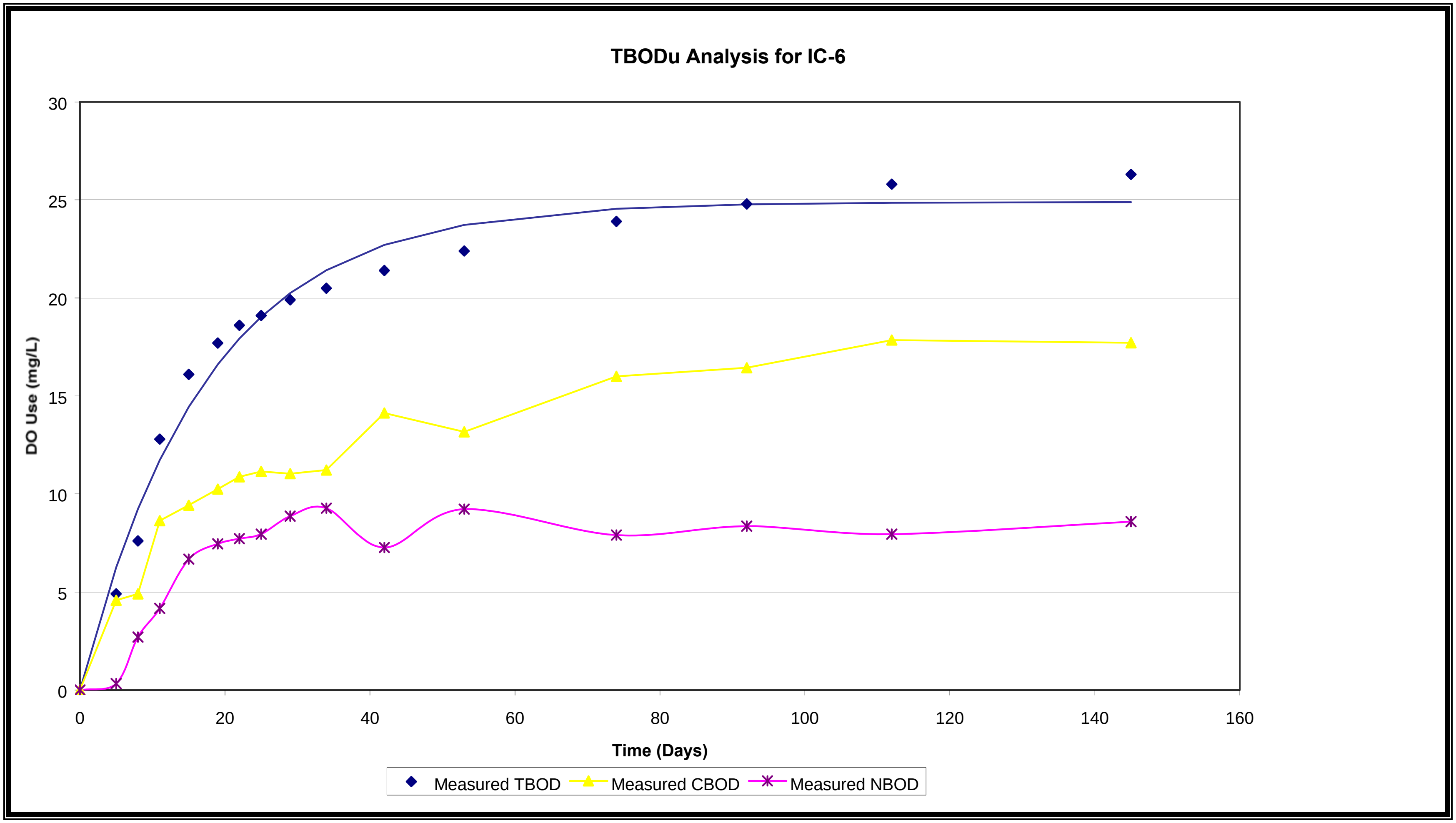

Figure A-9. TBODu Analysis of Sample from Station IC-6

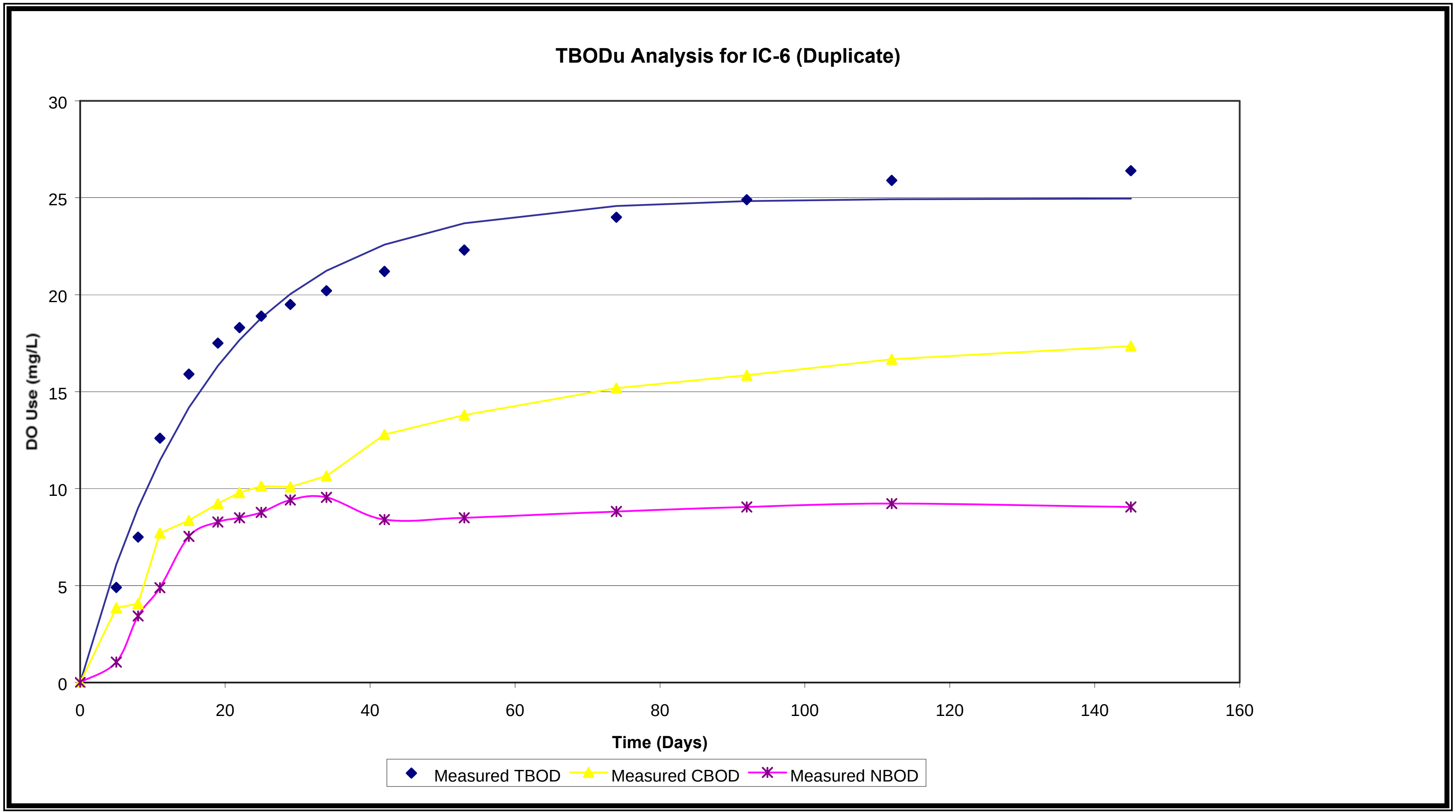

Figure A-10. TBODu Analysis of Duplicate Sample from Station IC-6

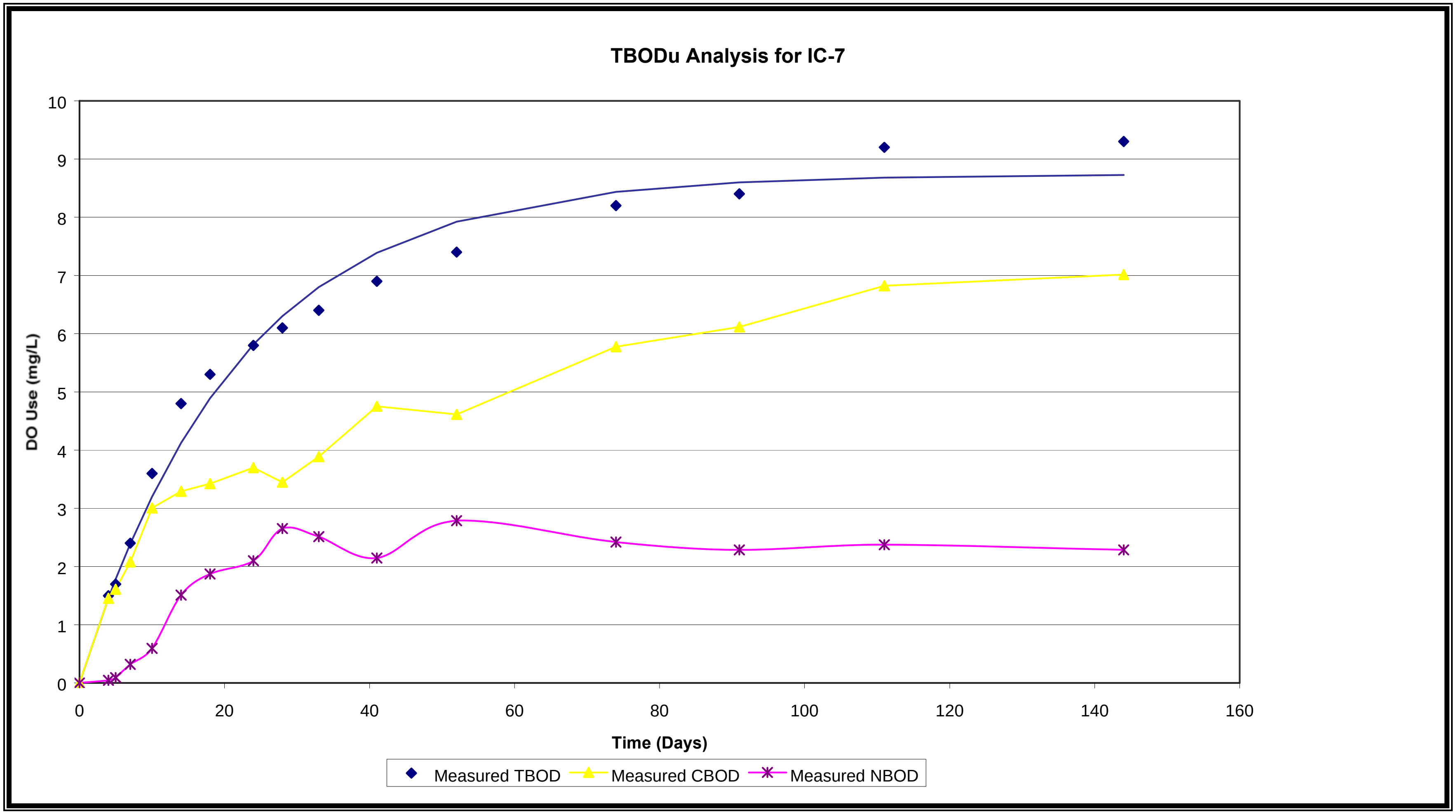

Figure A-11. TBODu Analysis of Sample from Station IC-7

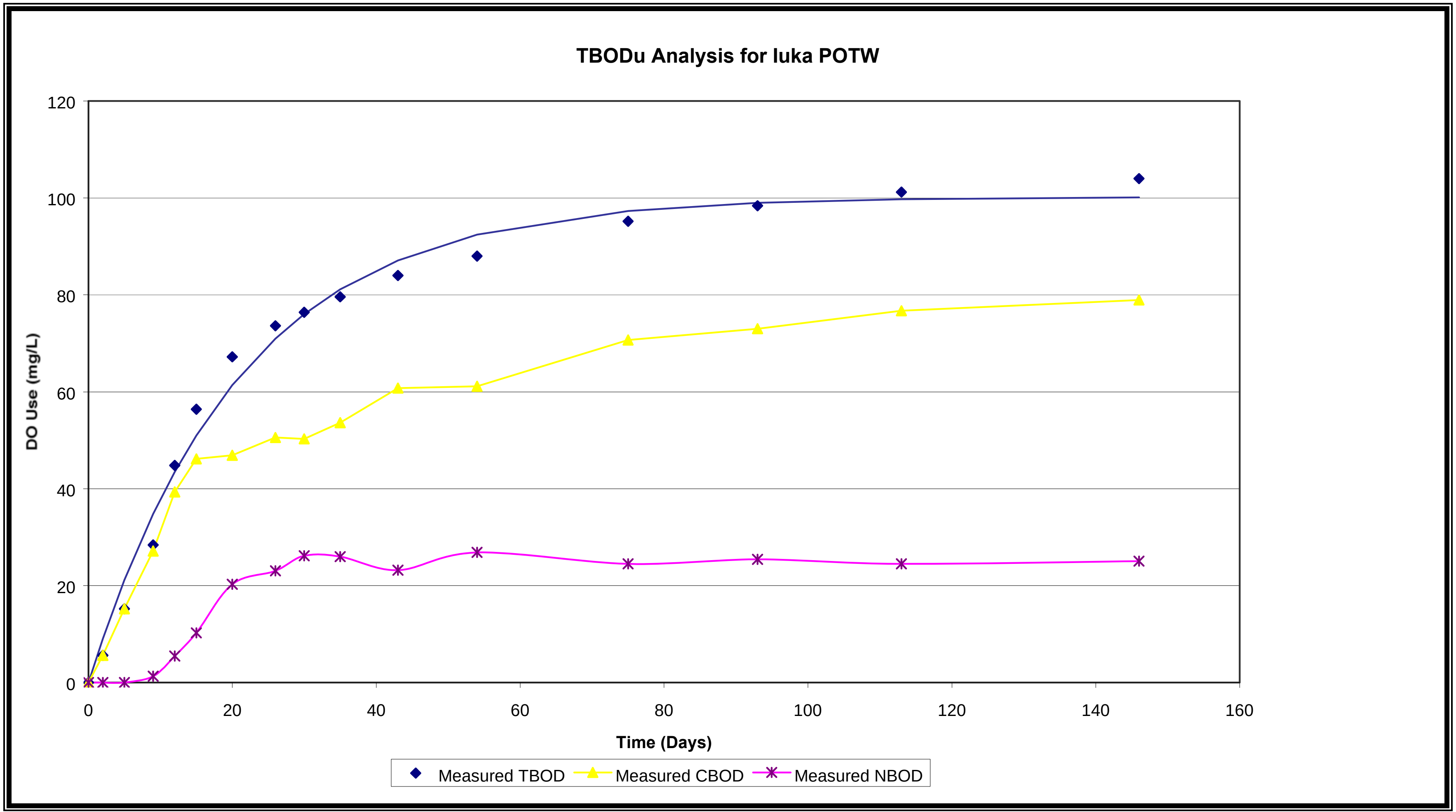

Figure A-12. TBODu Analysis of Sample from Iuka POTW

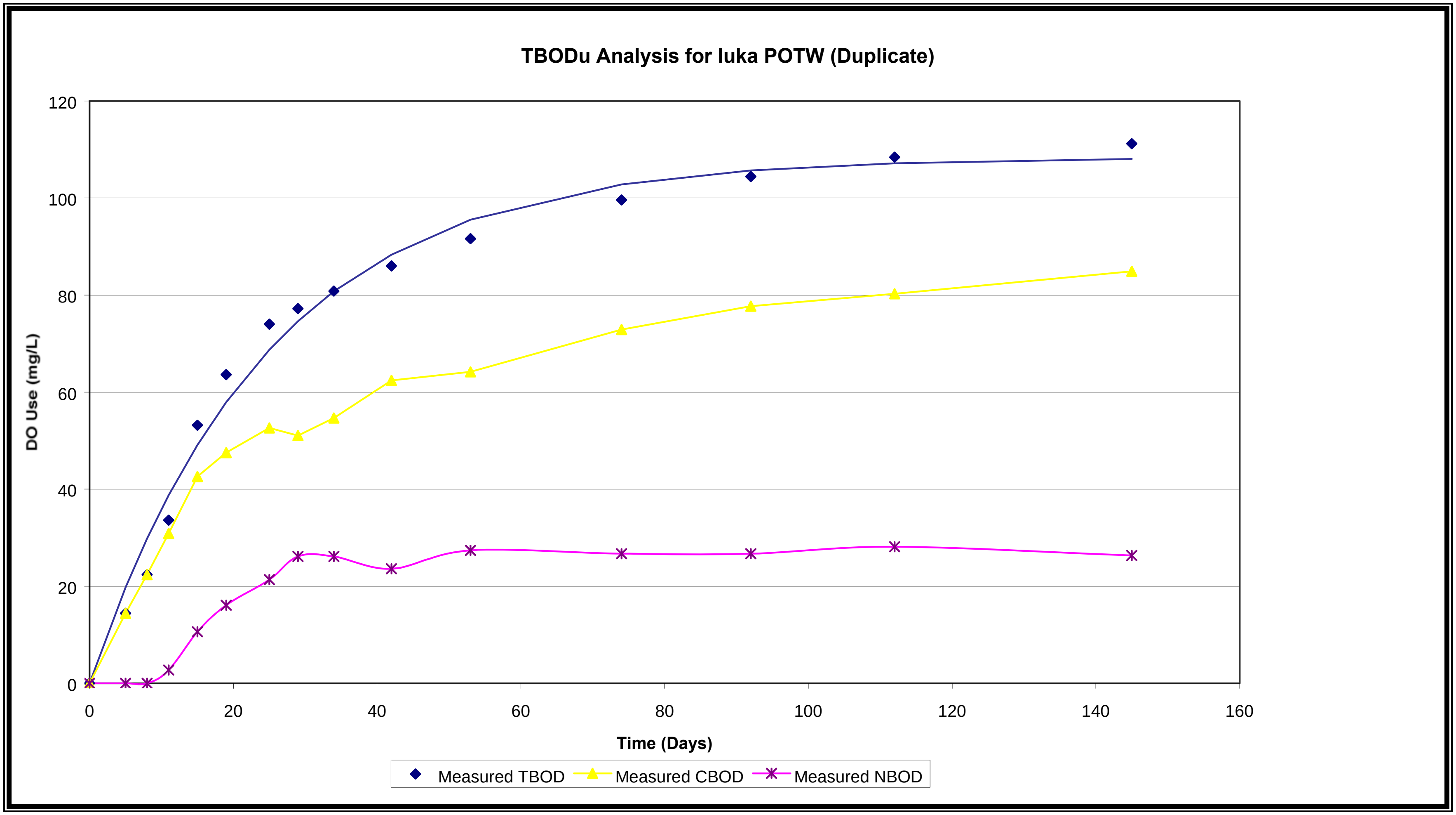

Figure A-13. TBODu Analysis of Duplicate Sample from Iuka POTW

Table A-8 presents a summary of the results of all of the TBODu analysis. The values of $TBOD_5$ and $CBOD_5$ were determined from the dissolved oxygen depletion reading taken at day five of the test. It is apparent from the data, that the instream TBODu increases greatly at IC-3 due to the high concentration of TBODu in the Iuka POTW effluent. In general, the duplicate TBODu tests, conducted for stations IC-3, IC-4, and IC-6 yielded comparable results. Thus, the data appears to be highly accurate and reliable for model calibration purposes.

Table A-8. TBODu Analysis Results

Station	Date	Time	$TBOD_5$ (mg/L)	$CBOD_5$ (mg/L)	TBODu (mg/L)	NBODu (mg/L)	CBODu (mg/L)
IC-2	9/14/98	15:58	1.20	1.20	4.30	0.96	3.34
IC-3	9/15/98	12:00	16.00	16.23	77.50	17.46	60.04
IC-3	9/15/98	12:00	16.00	15.54	74.20	19.74	54.46
IC-4	9/15/98	15:15	9.24	9.24	53.20	12.43	40.77
IC-4	9/15/98	15:15	8.20	8.20	50.20	13.12	37.08
IC-6	9/15/98	23:55	4.90	4.58	26.30	8.59	17.71
IC-6	9/15/98	23:55	4.90	3.85	26.40	9.05	17.35
IC-7	9/16/98	15:05	1.70	1.61	9.30	2.29	7.02

TBODu analysis of the effluent from the Iuka POTW was also conducted. Results of the laboratory analysis are shown in Figure A-12, Figure A-13, and Table A-9. The samples were collected as 24-hour composite samples from the lagoon, beginning at the time given in the table.

Table A-9. TBODu Analysis Results for the Iuka POTW Effluent

Station	Date	Time	$TBOD_5$ (mg/L)	$CBOD_5$ (mg/L)	TBODu (mg/L)	NBODu (mg/L)	CBODu (mg/L)
Iuka POTW	9/15/98	15:20	15.20	15.20	104.00	26.32	78.96
Iuka POTW	9/15/98	14:40	14.40	14.40	111.20	26.32	84.88

The TBODu analysis of the effluent was used to determine the ratio between the values of CBODu and $CBOD_5$. The CBODu to $CBOD_5$ ratio is used to calculate WQBELs for the Iuka POTW. To ensure accuracy of the ratio, the analysis of the POTW effluent was performed in duplicate. The CBODu to $CBOD_5$ ratio was calculated for each sample, yielding comparable results. The ratio was calculated as the average result of the duplicate tests, Table A-10. It should be noted that the literature value of the CBODu to $CBOD_5$ ratio for well-treated municipal/domestic wastewater is 2.30. This value is given in *Empirical Stream Model Assumptions for Conventional Pollutants and Conventional Water Quality Models* (MDEQ 1995). This value is recommended for use when actual field data is not available. However, since accurate field data were collected during the study, the ratio in Table A-10 will be used to calculate the WQBELs included in the TMDL for Indian Creek.

Table A-10. Calculation of the CBODu to $CBOD_5$ Ratio

Station	CBODu (mg/L)	$CBOD_5$ (mg/L)	CBODu to $CBOD_5$ Ratio
Iuka POTW	78.96	15.20	5.19
Iuka POTW	84.88	14.40	5.89
Average			**5.54**

Other chemical data collected during the Indian Creek study consisted of the in-situ parameters, DO, DO saturation, pH, temperature, and conductivity. In-situ parameters were measured on a continuous basis, with instruments deployed in the creek. The instruments were operated and maintained according to standard operating procedures. Calibrations were performed both before and after deployment of the instruments, and any discrepancies in the calibration data were noted. Collected data were stored in the memory of the instruments, in an electronic format, and checked for quality before evaluation.

During the Indian Creek study, the in-situ parameters were monitored in 30-minuite intervals for at least a 24-hour time period at each station. The monitoring periods were set up to correspond with the passage of the dye peak and collection of water samples at each monitoring station. Thus, in-situ data were collected at each station for at least 12 hours before and at least 12 hours after the passage of the dye peak. Descriptive statistics for each parameter are shown in Tables A-11 through A-15. The data show a much lower level of DO concentration and DO saturation at the monitoring stations that are downstream of the Iuka POTW. Specific conductivity shows a significant increase below the facility due to an increase in the level of dissolved ionic material in the effluent. The pH and temperature parameters exhibited less diurnal variation and were more consistent between monitoring stations above and below the Iuka POTW. Differences in the temperature observed at each station were minimal and can be primarily attributed to differences canopy coverage at each location.

Table A-11 contains an additional column with a comparison of the DO measured during the study and the instantaneous instream DO standard of 4.0 mg/L. The percent instantaneous violation column indicates the percentage of instantaneous DO measurements that violate the standard of 4.0 mg/L. Violations of the standard occurred downstream of the Iuka POTW at stations IC-4, IC-5, and IC-6.

Table A-11. Descriptive Statistics for Dissolved Oxygen Data

Station	Number of Observations	Minimum DO (mg/L)	Maximum DO (mg/L)	Mean DO (mg/L)	Median DO (mg/L)	Percent Instantaneous Violation
IC-1	53	5.88	8.41	6.91	7.00	0
IC-2	174	5.44	7.51	6.36	6.36	0
IC-3	172	4.66	6.97	5.43	5.39	0
IC-4	132	2.57	4.84	2.98	2.88	100.00
IC-5	131	2.66	4.41	3.23	3.08	100.00
IC-6	129	3.66	5.64	4.31	4.08	37.20
IC-7	83	5.70	7.37	6.21	5.95	0

Table A-12. Descriptive Statistics for DO Saturation Data

Station	Number of Observations	Minimum DO_{SAT} (%)	Maximum DO_{SAT} (%)	Mean DO_{SAT} (%)	Median DO_{SAT} (%)
IC-1	53	66.0	102.8	81.3	81.1
IC-2	174	63.8	91.2	75.2	74.1
IC-3	172	56.0	84.7	64.4	65.3
IC-4	132	31.1	59.3	36.0	34.7
IC-5	131	32.2	53.1	38.6	36.4
IC-6	129	43.4	67.9	50.9	47.6
IC-7	83	67.2	90	73.9	70.1

Table A-13. Descriptive Statistics for pH Data

Station	Number of Observations	Minimum pH	Maximum pH	Mean pH	Median pH
IC-1	53	6.53	6.87	6.67	6.64
IC-2	174	6.36	6.75	6.55	6.56
IC-3	172	6.47	6.98	6.62	6.60
IC-4	132	6.23	6.37	6.32	6.32
IC-5	131	6.30	6.82	6.37	6.37
IC-6	129	6.48	6.65	6.56	6.55
IC-7	83	6.10	6.27	6.15	6.14

Table A-14. Descriptive Statistics for Temperature Data

Station	Number of Observations	Minimum Temp (°C)	Maximum Temp (°C)	Mean Temp (°C)	Median Temp (°C)
IC-1	53	19.9	24.7	22.4	22.4
IC-2	174	20.8	24.3	22.8	22.8
IC-3	172	21.7	25.6	23.7	23.7
IC-4	132	22.4	25.6	24.1	24.2
IC-5	131	21.8	24.5	23.5	23.6
IC-6	129	22.0	25.0	23.7	23.8
IC-7	83	21.6	24.7	23.2	23.4

Table A-15. Descriptive Statistics for Specific Conductivity Data

Station	Number of Observations	Minimum SpCond (μS/cm)	Maximum SpCond (μS/cm)	Mean SpCond (μS/cm)	Median SpCond (μS/cm)
IC-1	53	60.9	71.5	66.4	66.1
IC-2	174	51.5	61.9	57.6	57.9
IC-3	172	92.4	102.3	97.6	97.3
IC-4	131	99.8	107.5	102.1	101.6
IC-5	131	96.4	101.5	98.5	98.1
IC-6	129	93.0	99.0	95.4	95.0
IC-7	83	77.7	79.4	78.4	78.3

Additional in-situ data were collected with profiling runs conducted during the study. Profile runs were generally conducted three times each day; immediately following sunrise, midday, and immediately following sunset. The profile runs were used to measure diurnal variation in water quality parameters at the monitoring stations and the Iuka POTW effluent discharge structure. Profiling data are given in Tables A-16 through A-23.

Table A-16. Profiling Data for Station IC-1

Date	Time	Temp (°C)	pH	SpCond (μS/cm)	DO (mg/l)	DO_{SAT} (%)	TDS (mg/L)
09/14/98	06:52	19.96	5.63	69.00	6.16	67.80	45.00
09/14/98	13:56	24.35	6.61	61.00	8.76	104.70	39.00
09/14/98	20:13	24.02	6.01	62.00	7.70	91.50	40.00
09/15/98	08:17	20.43	5.98	69.00	6.43	71.30	45.00
09/15/98	15:08	24.09	6.15	63.00	8.46	100.70	41.00
09/15/98	21:44	23.49	7.10	65.00	6.68	78.50	42.00
09/16/98	06:50	20.92	6.30	66.00	6.30	70.70	43.00
09/16/98	16:20	24.25	6.67	59.30	8.70	105.00	38.00
09/16/98	20:28	23.83	6.48	62.60	7.14	86.10	40.10
09/17/98	09:00	21.20	6.32	62.70	6.78	76.00	40.00

Table A-16. Profiling Data for Station IC-2

Date	Time	Temp (°C)	pH	SpCond (μS/cm)	DO (mg/l)	DO_{SAT} (%)	TDS (mg/L)
09/14/98	07:05	20.90	5.85	61.00	6.58	73.80	39.00
09/14/98	14:13	22.93	6.71	59.00	7.83	91.10	38.00
09/14/98	20:23	23.89	6.21	61.00	6.83	80.90	40.00
09/15/98	08:06	21.35	6.02	61.00	6.24	70.40	40.00
09/15/98	15:30	23.88	6.20	60.00	7.48	88.70	39.00
09/15/98	21:32	23.95	7.25	63.00	6.12	72.60	41.00
09/16/98	07:01	21.91	6.28	63.00	5.81	66.40	41.00
09/16/98	16:08	24.33	6.59	56.40	7.42	89.30	36.00
09/16/98	20:45	24.25	6.53	58.20	6.34	76.70	37.20
09/17/98	09:10	21.89	6.18	57.60	6.24	72.00	36.00

Table A-16. Profiling Data for Station IC-3

Date	Time	Temp (°C)	pH	SpCond (μS/cm)	DO (mg/l)	DO_{SAT} (%)	TDS (mg/L)
09/14/98	07:28	21.87	6.77	96.00	5.58	63.60	62.00
09/14/98	14:31	25.10	7.84	94.00	7.17	87.00	61.00
09/14/98	20:40	24.40	7.85	93.00	5.85	70.00	61.00
09/15/98	07:42	22.37	6.60	94.00	5.05	58.20	61.00
09/15/98	14:50	25.78	6.28	91.00	6.36	78.10	60.00
09/15/98	21:06	24.79	7.20	93.00	5.17	62.30	61.00
09/16/98	07:18	22.95	6.80	96.00	5.12	59.60	62.00
09/16/98	15:50	25.57	6.56	94.20	6.68	80.90	60.30
09/16/98	21:09	24.88	6.45	97.40	5.28	64.70	62.70
09/17/98	08:00	23.09	6.27	95.20	5.30	63.60	61.00

Table A-16. Profiling Data for Station IC-4

Date	Time	Temp (°C)	pH	SpCond (μS/cm)	DO (mg/l)	DO_{SAT} (%)	TDS (mg/L)
09/14/98	07:36	21.79	5.85	98.00	3.11	35.40	64.00
09/14/98	14:36	24.22	7.09	99.00	4.08	48.70	64.00
09/14/98	20:46	24.67	6.76	96.00	2.64	31.70	62.00
09/15/98	07:32	22.28	6.05	96.00	2.72	31.30	63.00
09/15/98	14:44	24.82	6.15	97.00	3.27	39.40	63.00
09/15/98	21:20	24.88	7.20	95.00	2.44	29.50	62.00
09/16/98	07:24	22.92	6.67	96.00	2.77	32.30	62.00
09/16/98	15:42	25.33	6.43	96.30	3.20	39.10	61.50
09/16/98	21:21	25.03	6.43	98.10	2.82	34.40	62.80
09/17/98	07:51	23.08	6.15	97.00	2.93	34.80	62.00

Table A-16. Profiling Data for Station IC-5

Date	Time	Temp (°C)	pH	SpCond (μS/cm)	DO (mg/l)	DO_{SAT} (%)	TDS (mg/L)
09/14/98	07:44	21.51	5.61	97.00	3.29	37.10	63.00
09/14/98	14:42	24.06	6.62	95.00	4.45	52.90	62.00
09/14/98	20:53	23.73	6.57	99.00	3.15	37.20	64.00
09/15/98	07:25	22.1	6.1	95.00	2.89	33.10	62.00
09/15/98	14:28	24.4	6.1	94.00	3.90	46.70	61.00
09/15/98	20:55	24.5	7.2	96.00	2.48	29.70	62.00
09/16/98	07:30	22.7	6.52	95.00	3.05	35.30	61.00
09/16/98	15:29	24.6	6.4	93.10	3.74	45.30	59.70
09/16/98	21:31	24.67	6.39	96.30	2.9	35.40	61.80
09/17/98	07:40	22.8	6.22	95.80	3.43	38.10	61.00

Table A-16. Profiling Data for Station IC-6

Date	Time	Temp (°C)	pH	SpCond (μS/cm)	DO (mg/l)	DO_{SAT} (%)	TDS (mg/L)
09/14/98	07:50	21.42	5.43	96.00	3.97	44.40	63.00
09/14/98	14:50	24.78	6.50	95.00	5.32	64.00	62.00
09/14/98	20:59	23.56	6.57	97.00	3.62	42.70	63.00
09/15/98	07:17	22.07	6.10	95.00	3.42	39.30	62.00
09/15/98	14:21	24.84	6.08	93.00	4.83	58.20	61.00
09/15/98	20:38	24.20	7.30	95.00	3.34	39.80	62.00
09/16/98	07:37	22.60	6.58	95.00	3.49	40.40	61.00
09/16/98	15:19	25.00	6.51	91.80	4.61	55.80	58.60
09/16/98	21:38	24.44	6.34	95.50	3.39	41.00	61.00
09/17/98	07:28	22.79	6.21	96.30	3.76	43.70	61.00

Table A-16. Profiling Data for Station IC-7

Date	Time	Temp (°C)	pH	SpCond (μS/cm)	DO (mg/l)	DO_{SAT} (%)	TDS (mg/L)
09/14/98	08:06	20.46	5.43	78.00	6.32	69.80	51.00
09/14/98	15:10	24.50	6.31	78.00	7.80	93.50	50.00
09/14/98	21:14	23.03	6.64	78.00	6.23	72.60	51.00
09/15/98	06:59	21.10	5.82	80.00	5.70	64.00	52.00
09/15/98	14:02	24.58	6.28	78.00	7.38	88.70	51.00
09/15/98	20:18	23.73	7.50	78.00	5.78	68.30	50.00
09/16/98	07:57	21.53	6.53	78.00	5.72	64.90	51.00
09/16/98	15:01	24.35	6.31	75.90	6.84	81.10	48.80
09/16/98	21:57	23.63	6.28	76.30	5.73	68.20	48.70
09/17/98	07:05	21.89	5.72	77.10	5.78	66.60	49.00

Table A-16. Profiling Data for Iuka POTW Effluent Discharge Structure

Date	Time	Temp (°C)	pH	SpCond (μS/cm)	DO (mg/l)	DO_{SAT} (%)	TDS (mg/L)
09/14/98	07:24	24.57	6.65	59.00	7.67	91.30	24.00
09/14/98	14:25	26.85	8.16	59.00	8.47	106.10	38.00
09/14/98	20:36	26.53	8.29	55.00	8.21	101.70	36.00
09/15/98	07:39	25.25	6.65	164.00	7.27	88.40	101.00
09/15/98	14:55	27.61	8.50	77.00	7.75	98.30	50.00
09/15/98	21:11	27.45	8.42	190.00	7.54	95.20	120.00
09/16/98	07:14	25.89	6.89	168.00	6.68	82.20	109.00
09/16/98	15:55	26.72	6.83	190.00	7.65	96.60	129.00
09/16/98	20:59	26.86	7.15	205.00	7.67	97.40	133.00
09/17/98	08:04	25.84	6.56	205.00	7.53	93.40	129.00

Light and dark bottles, for measuring photosynthesis and respiration in the water column, were deployed in the stream at all of the monitoring stations. The method consisted of placing a sample of creek water in two plastic bottles of equal volume and placing them back in the creek. The light bottle is a clear bottle that will allow light penetration. Thus, both photosynthesis and respiration can occur in the light bottle. The dark bottle does not allow light penetration, so that only respiration can occur in the bottle. After the water samples were collected, the initial DO concentration in each bottle was measured. Then the bottles were capped and mounted in the stream at a depth within the photic zone. The bottles were left in the stream for a period of approximately six hours. The final concentration of DO in each bottle was then determined. There are some differences in the photosynthesis and respiration measured with the light and dark bottles and the actual values of these parameters. Because the water samples in the light and dark bottle tests are enclosed in a bottle, they are not subject to the natural currents of water movement in the waterbody. Also, the light and dark bottle tests do not include the effects of oxygen demand due to sediments, attached periphyton, and other irregular substances.

The results of the light and dark bottle tests were used to calculate the rates of net photosynthesis, water column respiration, and gross primary productivity in units of mg/L/day. Net photosynthesis refers to the total change in DO due to the combined effect of photosynthesis and respiration in the water column. A positive rate of net photosynthesis indicates that the rate of oxygen produced by photosynthesis is greater than the rate of respiration in the water column. The net photosynthesis rate is calculated by subtracting the final DO concentration in the light bottle from the initial DO concentration. This result is then divided by the incubation time, Equation A-4. The rate of water column respiration is determined by subtracting the initial DO concentration from the final DO in the dark bottle. The DO change is then divided by the incubation time, Equation A-5. The gross primary productivity refers to the total rate of oxygen production by photosynthesis. Gross primary productivity is equal to the sum of the net photosynthesis and the water column respiration. It is calculated by subtracting the final DO concentration in the light bottle from the final DO concentration in the dark bottle. This result is divided by the incubation time to give the gross primary productivity rate, Equation A-6. The light and dark bottle tests were conducted al least twice at all of the stations included in the Indian Creek study. The photosynthesis, respiration, and productivity rates were calculated by taking an average of the two replicates. The results of the light and dark bottle tests are given in Table A-16.

$$\mathbf{NP = (DO_{\mathit{lf}} - DO_{\mathit{i}}) / t} \qquad \text{(Equation A-4)}$$

Where
NP is the net community productivity, mg/L/day
DO_{lf} is the final DO concentration in the light bottle, mg/L
DO_{i} is the initial DO concentration, mg/L
t is the incubation time, days

$$\mathbf{R = (DO_{\mathit{i}} - DO_{\mathit{df}}) / t} \qquad \text{(Equation A-5)}$$

Where
R is the water column respiration, mg/L/day
DO_{i} is the initial DO concentration, mg/L
DO_{df} is the final DO concentration in the dark bottle, mg/L
t is the incubation time, days

$$\mathbf{GPP = (DO_{\mathit{lf}} - DO_{\mathit{df}}) / t} \qquad \text{(Equation A-6)}$$

Where
GPP is the gross photosynthetic production, mg/L/day
DO_{lf} in the final DO concentration in the light bottle, mg/L
DO_{df} in the final DO concentration in the dark bottle, mg/L
t is the incubation time, days

Table A-16 Light and Dark Bottle Test Results

Station	Date	DO_i (mg/L)	DO_{lf} (mg/L)	DO_{df} (mg/L)	Incubation Period (hours)	NP (mg/L/day)	Average NP (mg/L/day)	R (mg/L/day)	Average R (mg/L/day)	GPP (mg/L/day)	Average GPP (mg/L/day)
IC-1	09/16/98	7.2	6.9	7.1	5.5	-1.31	-1.31	0.44	0.65	-0.87	-0.65
IC-1	09/16/98	7.2	6.9	7.0	5.5	-1.31		0.87		-0.44	
IC-2	09/16/98	6.2	6.2	6.3	5.5	0.00	-0.22	-0.44	-0.22	-0.44	-0.44
IC-2	09/16/98	6.2	6.1	6.2	5.5	-0.44		0.00		-0.44	
IC-3	06/16/98	6.3	5.5	5.2	6.3	-3.05	-2.29	4.19	2.67	1.14	0.38
IC-3	09/16/98	5.7	5.3	5.4	6.3	-1.52		1.14		-0.38	
IC-4	09/15/98	3.0	3.2	2.5	6.3	0.77	0.19	1.92	1.92	2.69	2.11
IC-4	09/15/98	3.0	2.9	2.5	6.3	-0.38		1.92		1.54	
IC-5	09/16/98	3.4	4.0	3.4	5.5	2.62	2.18	0.00	0.65	2.62	2.84
IC-5	09/16/98	3.3	3.7	3.0	5.5	1.75		1.31		3.05	
IC-5	09/15/98	3.3	3.3	3.1	6.3	0.00	0.38	0.77	0.77	0.77	1.15
IC-5	09/15/98	3.3	3.5	3.1	6.3	0.77		0.77		1.54	
IC-6	09/15/98	4.4	4.3	3.9	6.0	-0.40	-0.20	2.00	1.60	1.60	1.40
IC-6	09/15/98	4.3	4.3	4.0	6.0	0.00		1.20		1.20	
IC-7	09/16/98	6.1	6.5	5.8	5.3	1.81	1.81	1.36	1.13	3.17	2.94
IC-7	09/16/98	6.0	6.4	5.8	5.3	1.81		0.91		2.72	
IC-7	09/15/98	6.4	6.2	5.9	7.5	-0.64	-0.64	1.60	1.44	0.96	0.80
IC-7	09/15/98	6.3	6.1	5.9	7.5	-0.64		1.28		0.64	
IC-7P	09/15/98	6.0	6.1	5.9	7.0	0.34	-0.17	0.34	0.51	0.69	0.34
IC-7P	09/15/98	6.3	6.1	6.1	7.0	-0.69		0.69		0.00	

A.5 Discussion

Following the intensive study, a thorough analysis of all data was conducted. The analysis and interpretation of the data was necessary in order to characterize significant instream hydrological and chemical processes for representation in the QUAL2E model. These processes include stream flow, reaeration, CBODu decay, sediment oxygen demand, and algae growth. Each of these processes was characterized on a reach specific basis for the model.

In the QUAL2E model, there are two options available for defining the hydraulic characteristics of a stream. The first option utilizes a functional representation, whereas the second option utilizes a geometric interpretation. After analyzing the two options and the hydrological data available from the study, the functional representation was chosen for the Indian Creek model. With this option, the headwater flow and incremental inflow in each reach are input by the user. Discharge coefficients, which define the relationship between flow, stream velocity, and water depth are also entered for each reach. The model calculates stream velocity and depth in each computational element according to Equation A-7 and Equation A-8 (USEPA 1987).

$$\mathbf{u = aQ^b} \qquad \text{(Equation A-7)}$$

Where
u = stream velocity, ft/second
Q = flow, cfs
a = coefficient for velocity
b = exponent for velocity

$$\mathbf{d = eQ^f} \qquad \text{(Equation A-8)}$$

Where
d = stream depth, ft
Q = flow, cfs
e = coefficient for depth
f = exponent for depth

The coefficients and exponents for each equation were calculated using values water velocity, depth, and the average flow in each reach measured during the study. Assuming that the channel cross-section was rectangular, the values of the exponents were set at 0.40 for velocity and 0.60 for depth for calculating the coefficients. In order to validate the assumed exponents, the modeled velocities and depths were compared to the values of these parameters measured during the study. Average water depth is difficult to measure because is varies throughout the length and cross-section. Width generally has less variation, and was estimated by taking several width measurements at cross-sections along each reach. Depth was then calculated for each reach by dividing the average flow by the product of the velocity and average width. Small adjustments were made to the value of the coefficients until the modeled velocity and water depth matched the measured values of these parameters. The coefficients and exponents entered into the model are given in Table A-17 and Table A-18.

Table A-17. Velocity Coefficients and Exponents

Reach	u (ft/second)	Q (cfs)	b	a
R-3	0.267	1.97	0.40	0.20
R-4	0.138	2.32	0.40	0.10
R-5	0.141	2.50	0.40	0.10
R-6	0.094	2.78	0.40	0.06
R-7	0.094	3.10	0.40	0.06

Table A-18. Depth Coefficients and Exponents

Reach	d (ft)	Q (cfs)	f	e
R-3	0.691	1.97	0.60	0.46
R-4	1.462	2.32	0.60	0.88
R-5	1.604	2.50	0.60	0.93
R-6	2.202	2.78	0.60	1.26
R-7	1.931	3.10	0.60	0.98

The modeled instream concentration of CBODu, is dependent on the oxidation rate and setting rate of CBODu. The oxidation rate of CBODu was calculated from data collected during the study, while the CBODu settling rate was estimated through model literature values and model calibration. The oxidation of carbonaceous material can be described mathematically using first order kinetics according to Equation A-9.

$$\mathbf{L = Lo(e^{(-k1*t)})} \qquad \text{(Equation A-9)}$$

Where
L = amount of CBODu remaining at time t, mg/L
Lo = CBODu, or the total oxygen depletion due to oxidation of carbonaceous material at time 0, mg/L
k_1 = first-order CBODu decay rate in base e, day^{-1}
t = elapsed time, days

The first-order decay rate, k_1, depends on both the characteristics of the effluent and the instream conditions after the release of the effluent. Based on equation A-9, the value of k_1 was determined graphically by plotting the natural log of the CBODu load versus travel time downstream. Assuming that the CBODu decay is first order, this graph will produced a straight line with a slope equal to k_1. Although there are many other methods are available for estimating the CBODu decay rate, this method is recommended for use in streams impaired by a single, continuous point source such as the Iuka POTW in *Rates, Constants, and Kinetics Formulations in Surface Water Quality Modeling* (USEPA 1985).

The data used to determine k_1 are given in Table A-19. CBODu loads were calculated by multiplying the measured CBODu concentrations by the flow and a unit conversion factor. The travel times given in the table were measured during the dye study. Figure A-14 shows a plot of the data. The linear regression function in a spreadsheet was used to determine the slope of the line, using the least squares method to fit a line through a series of observations. The slope, -1.27, indicates that the CBODu decay rate in base e is 1.27 day^{-1} at a temperature of 20°C. As shown in the figure, the R-squared value is 0.97. This reflects an extremely favorable correlation between the two data sets.

Table A-19. Determination of First-Order k_1 Value

Station	Travel Time (days)	CBODu Load (lbs/day)	Natural Log of Load
IC-3	0.00	544.12	6.30
IC-4	0.14	420.39	6.04
IC-6	0.40	245.17	5.50
IC-7	1.18	116.00	4.75

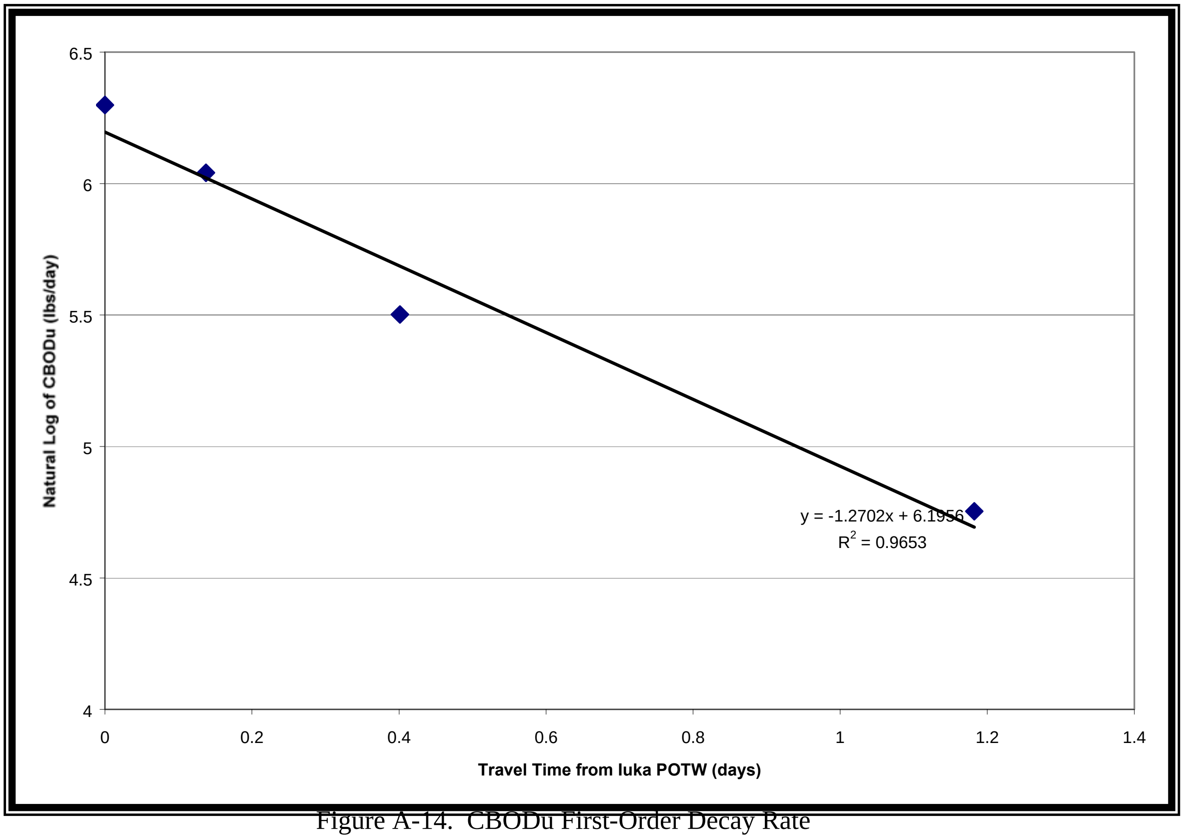

Figure A-14. CBODu First-Order Decay Rate

Sediment oxygen demand (SOD) can account for a large portion of the total oxygen demand in a waterbody, especially where the settling rate of organic material is high, allowing the formation of sludge beds. SOD is a representation of the oxygen demanding processes of the bottom substances, attached periphyton, and other irregular substances. The major factors effecting SOD are temperature, available oxygen at the sediment-water interface, makeup of the biological community, organic and physical characteristics of the sediment, and the velocity of the currents flowing over the sediments. Techniques have been developed for investigating and quantifying the impact of these individual factors on SOD. However, the most accurate and cost effective way to evaluate SOD is to measure SOD directly rather than measuring the underlying factors that control the process of SOD (USEPA 1985).

The continuous in-situ data collected at each monitoring station were analyzed to assess the oxygen producing and demanding processes in the sediments of Indian Creek using a modified method developed by Odum and Hoskin (1958) described in *Comparative Studies in the Metabolism of Marine Waters*. This method, which is commonly referred to as the diel curve method, involves a graphical analysis of DO changes over a period of 24-hours or longer. This method assumes that with appropriate corrections, the diel rise and fall of DO concentrations remains proportional to activities of plants and animals residing in a water body. Any chemical oxidation occurring in the waterbody is treated as biological respiration. This method can be described mathematically with Equation A-10.

$$\mathbf{Q = GPP - R + D} \qquad \text{(Equation A-10)}$$

Where
Q = net rate of change in DO, mg-oxygen/L/day
GPP = rate of change in GPP, mg-oxygen/L/day
R = rate of change in respiration, mg-oxygen/L/day
D = rate of change in atmospheric diffusion, mg-oxygen/L/day

The diel curve method was used to determine the value of GPP and R. The Tsivoglou formulation was used to determine the value of D for each reach in Indian Creek. A continuous data set of 24-hours of in-situ data were used for the calculations. Like the chemical data collected in the study, the in-situ data used for the study were chosen relative to the dye peak. The data collected in the 12 hours prior to and 12 hours following the dye peak were used for the calculations. The first step in the process was to calculate and graph the uncorrected DO rate of change using a 4-hour running interval, Equation A-11.

$$\mathbf{\text{Uncorrected DO Rate of Change} = (DO_{t-2} - DO_{t+2}) / 4} \qquad \text{(Equation A-11)}$$

Where
DO_{t-2} = DO concentration two hours proceeding time t, mg/L
DO_{t+2} = DO concentration two hours following time t, mg/L

The value of D was then used to adjust the uncorrected DO rate of change positively (upward) or negatively (downward) depending on the oxygen saturation deficit or credit. If the DO concentration is above saturation, then the oxygen that is actually produced by GPP, but is lost to the atmosphere (and thus not able to be measured by in-situ oxygen monitors), must be accounted for by adjusting the curve upward. This gives credit to the GPP for all photosynthetically produced oxygen. The reverse is true for conditions when the DO concentration is below saturation. In such cases, the waterbody is gaining oxygen from the atmosphere at a rate equivalent to the reaeration rate, adjusted for the oxygen saturation deficit. Since this oxygen came from the atmosphere and was not actually produced through primary production, the curve must be adjusted downward so as not to credit GPP for oxygen production that actually came by way of atmospheric diffusion into the water (Odum and Hoskin 1958).

At all of the monitoring stations in Indian Creek, the DO nearly always remained below saturation throughout the study. Thus, the rate DO addition through atmospheric diffusion was calculated by Equation A-12. Then, the corrected DO rate of change was calculated by subtracting the diffusion rate from the uncorrected rate of change.

$$\mathbf{D = k_2*(DO_{SAT} - DO)} \qquad \text{(Equation A-12)}$$

Where
D = diffusion rate, mg-oxygen/L/day
k_2 = reaeration coefficient, day^{-1}
DO_{SAT} = dissolved oxygen at 100% saturation, mg/L
DO = measured dissolved oxygen concentration, mg/L

When calculating respiration, the simplifying assumption must be made that the respiration rate at night is the same as the respiration rate measured during the day. Although this assumption is probably not entirely correct, it introduces only minimal error into the diurnal curve calculations while simplifying the process considerably (Odum and Hoskin 1958). The respiration rates were calculated by averaging the values of corrected DO rate of change that were measured after sunset. This nighttime value of corrected DO rate of change was extrapolated as a constant throughout the 24-hour period. The area between the corrected DO rate of change curve and nighttime respiration line that occurs during daylight hours is equal to the GPP.

The DO rate of change and associated GPP and respiration components are shown graphically for each monitoring station in Indian Creek in Figures A-15 through A-22. A summary of GPP and R for each station is presented in Table A-20. The values of GPP and R are initially calculated from the graphical analysis in units of mg-oxygen/L/day. Conversion of these values to a square-feet basis is achieved through the use of an average depth throughout the reach. Table A-20 also shows the calculated values of SOD for each station. The SOD values were calculated by first determining community respiration via the diel curve method, and then subtracting the water column respiration derived from the light and dark bottle tests. The difference between the value of community respiration and water column respiration is attributable to SOD. The value of SOD in each reach was calculated by averaging the values of SOD measured at the monitoring stations on the upstream and downstream ends of each reach.

Station	Reach	L/D Bottle GPP (mg/L/day)	Diurnal Curve GPP (mg/L/day)	L/D Bottle R (mg/L/day)	Diurnal Curve R (mg/L/day)	SOD (diurnal curve R – L/D bottle R) (mg/L/day)	Average Reach Depth (ft)	SOD (g/ft^2/day)	Diurnal curve k_2 value
IC-1	R-1	-0.65	4.37	0.65	10.17	9.52	1.21	0.45	0.145
IC-2		-0.44	2.27	0.00	6.40	6.40	3.10		0.083
IC-2	R-2	-0.44	2.27	0.00	6.40	6.40	3.10	0.40	0.083
IC-3		0.38	2.38	2.67	13.50	10.83	0.74		0.150
IC-3	R-3	0.38	2.38	2.67	13.50	10.83	0.74	0.41	0.150
IC-4		2.11	0.80	1.92	15.8	13.88	1.50		1.220
IC-4	R-4	2.11	0.80	1.92	15.8	13.88	1.50	0.85	1.220
IC-5		2.00	1.88	0.71	25.15	24.44	1.58		0.190
IC-5	R-5	2.00	1.88	0.71	25.15	24.44	1.58	0.96	0.190
IC-6		1.40	2.40	1.60	17.33	15.75	1.85		0.148
IC-6	R-6	1.40	2.40	1.60	17.33	15.75	1.85	0.50	0.148
IC-7		1.36	1.57	1.02	3.90	2.88	1.98		0.047

Table A-20. Summary of Photosynthesis, Respiration, and SOD Data

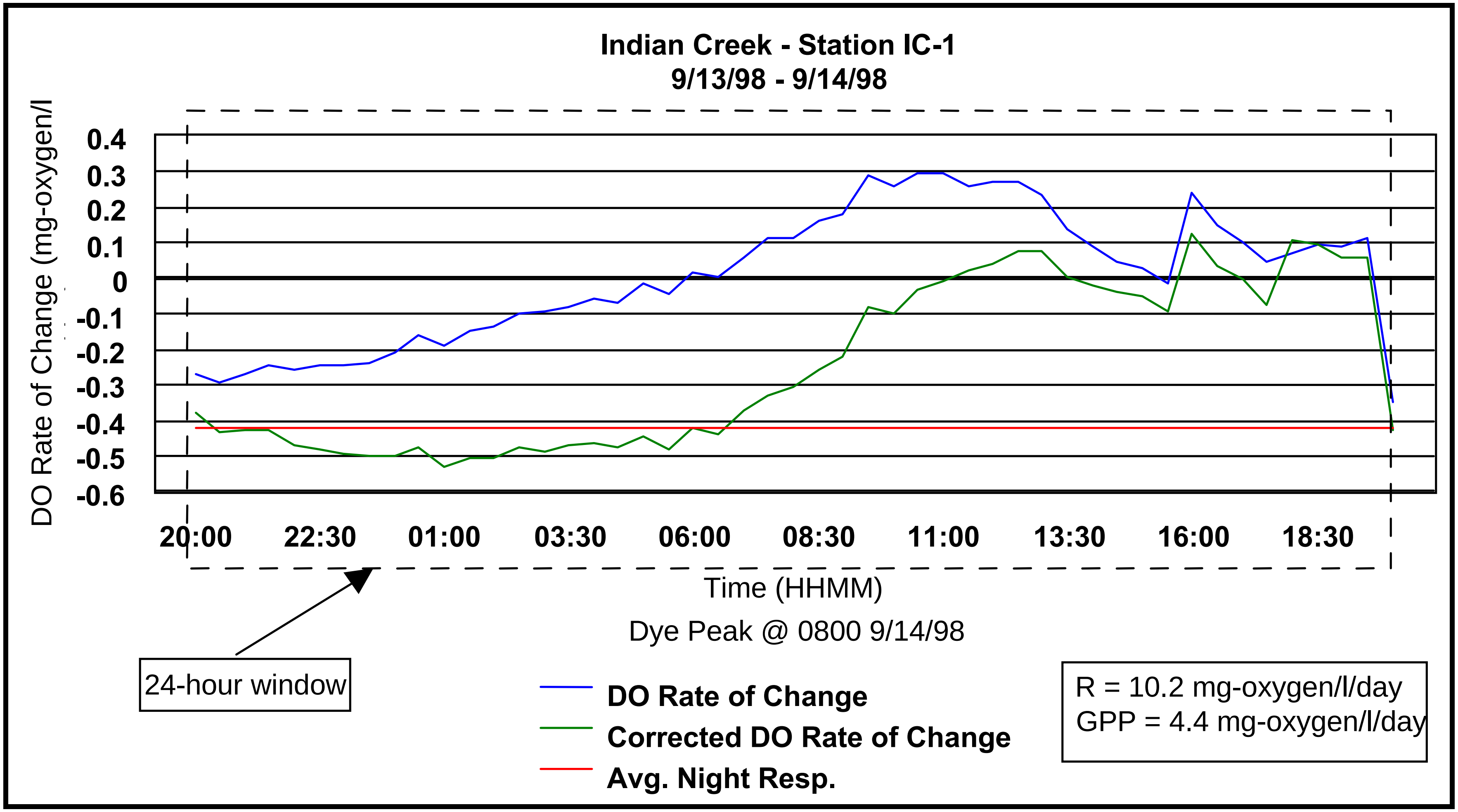

Figure A-15. Diurnal Curve Analysis for IC-1

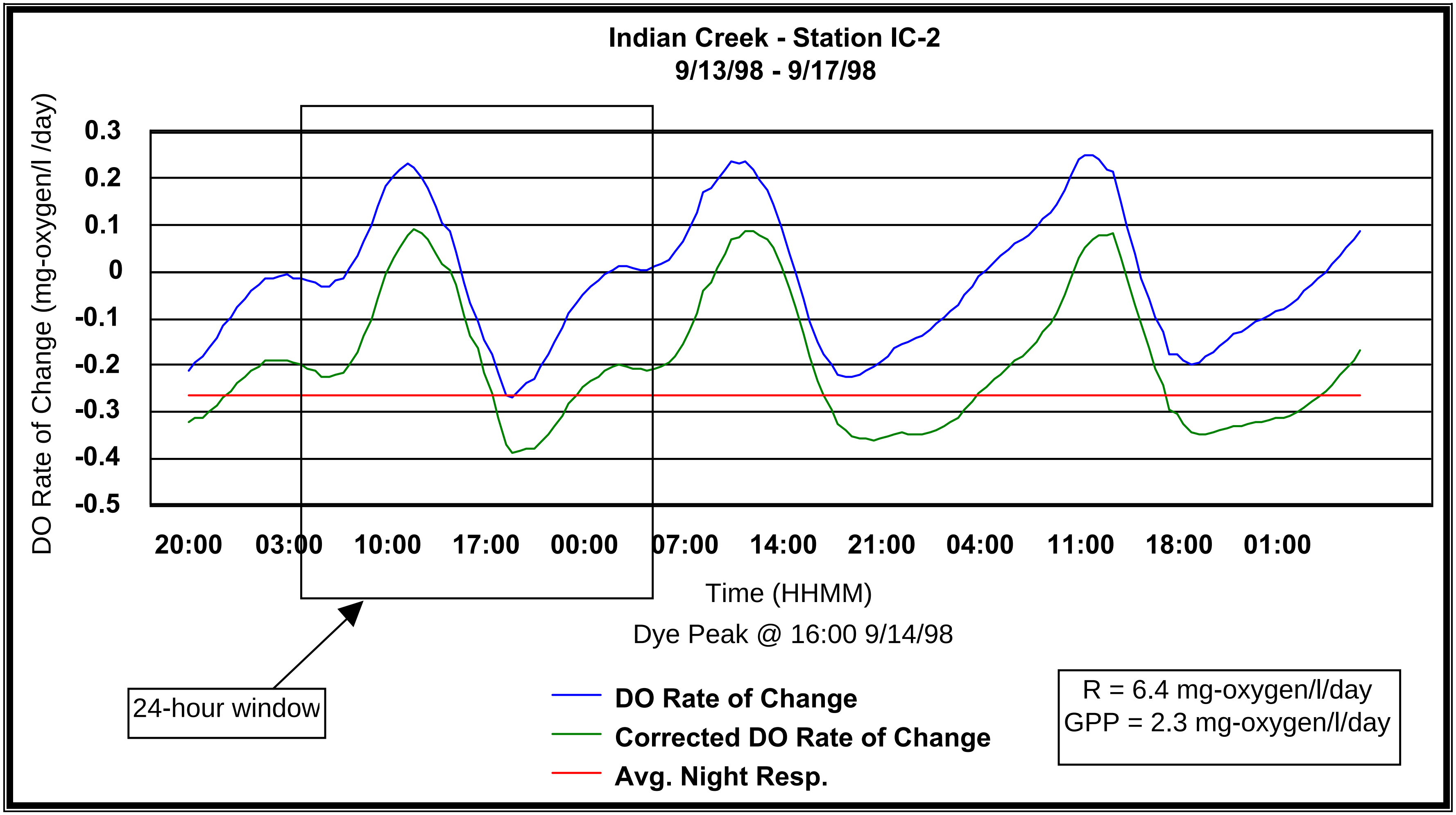

Figure A-16. Diurnal Curve Analysis for IC-2

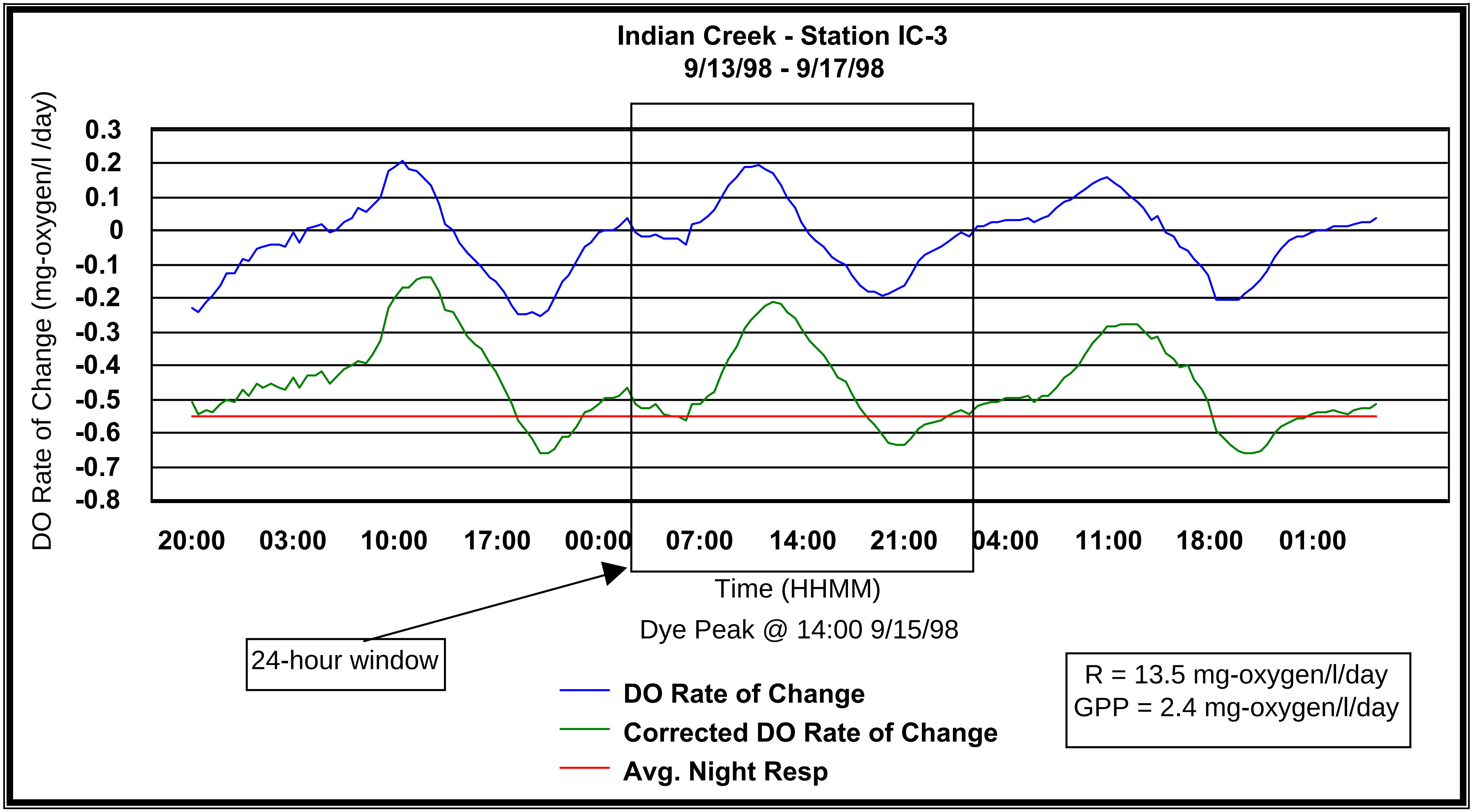

Figure A-17. Diurnal Curve Analysis for IC-3

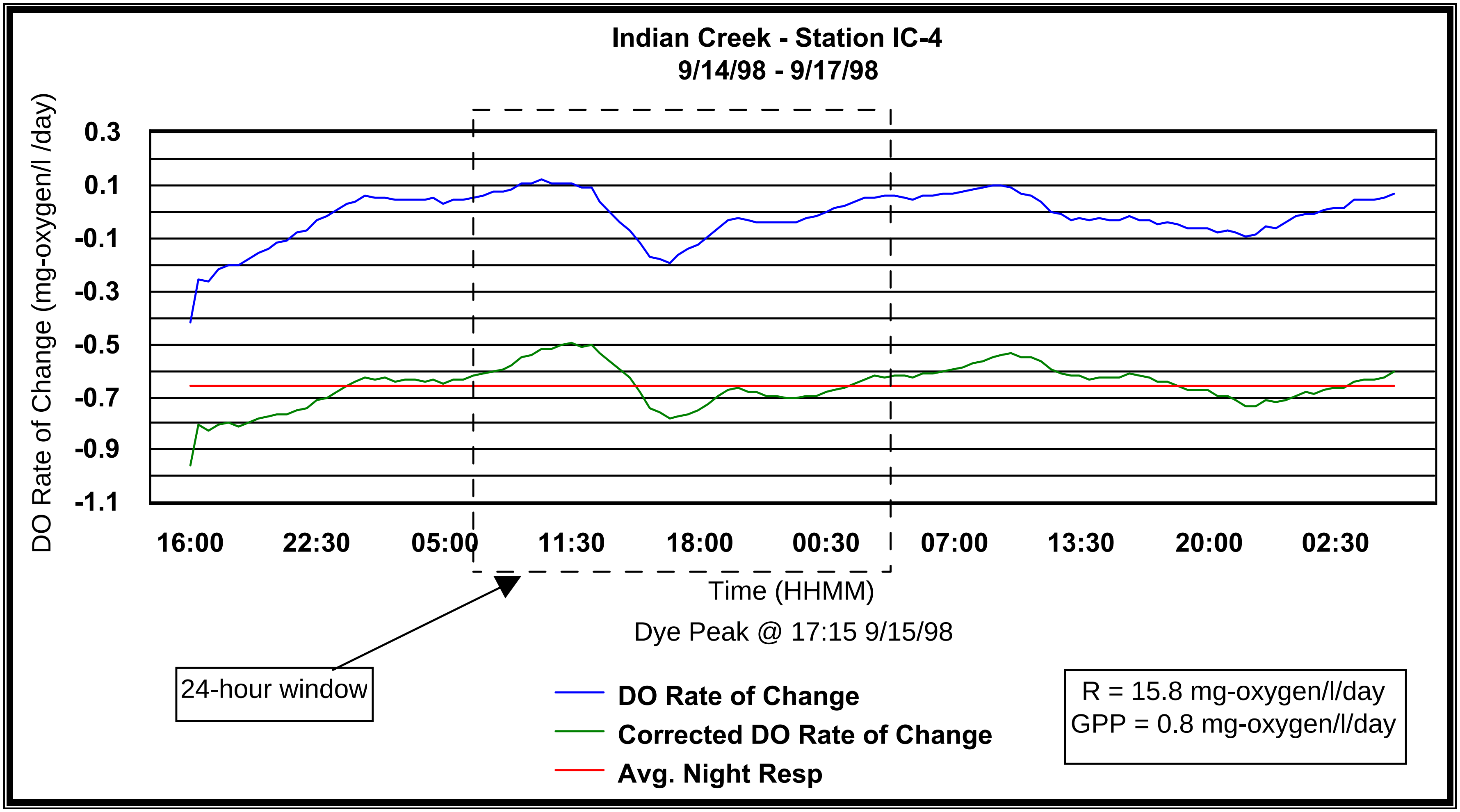

Figure A-18. Diurnal Curve Analysis for IC-4

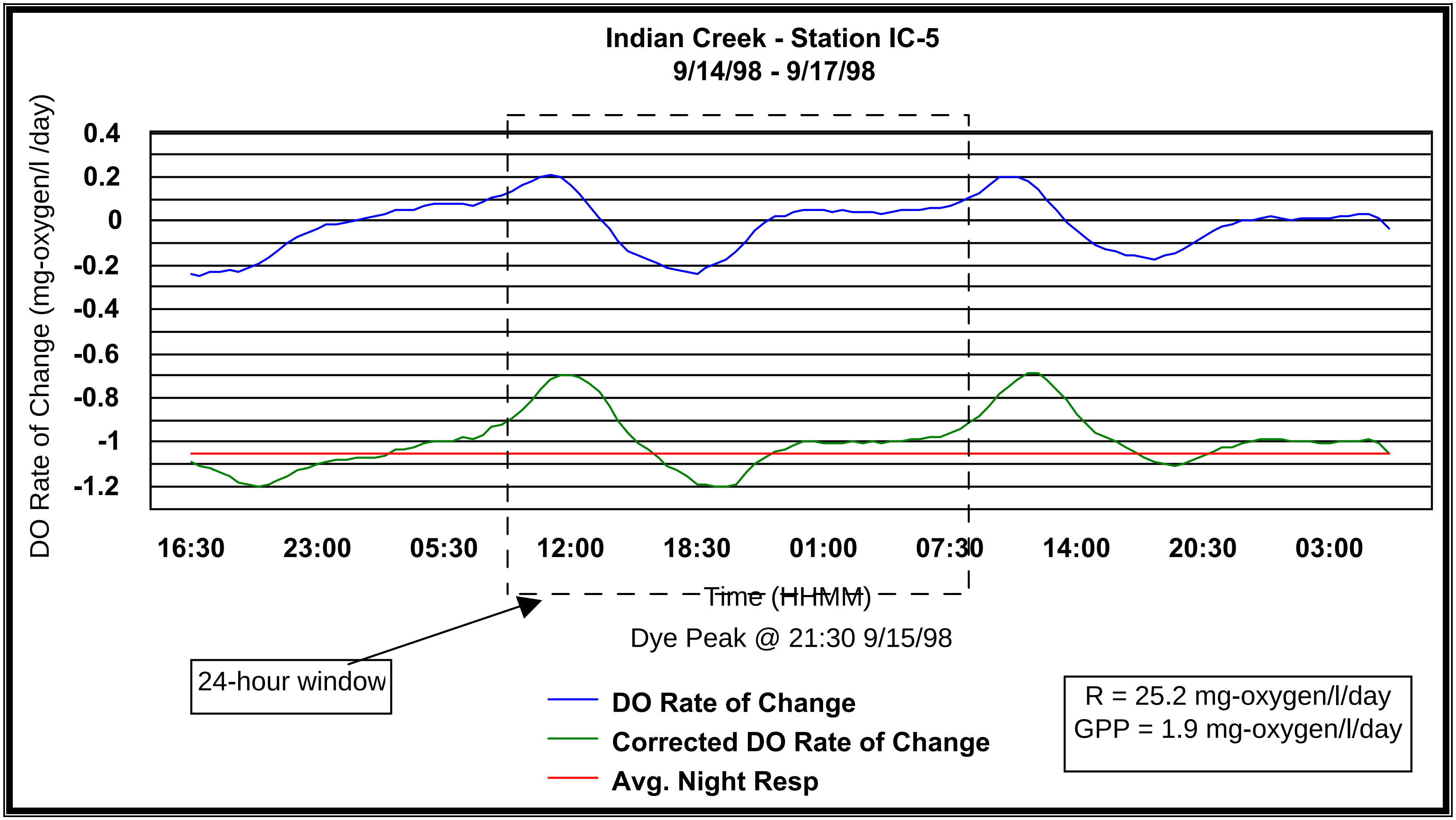

Figure A-19. Diurnal Curve Analysis for IC-5

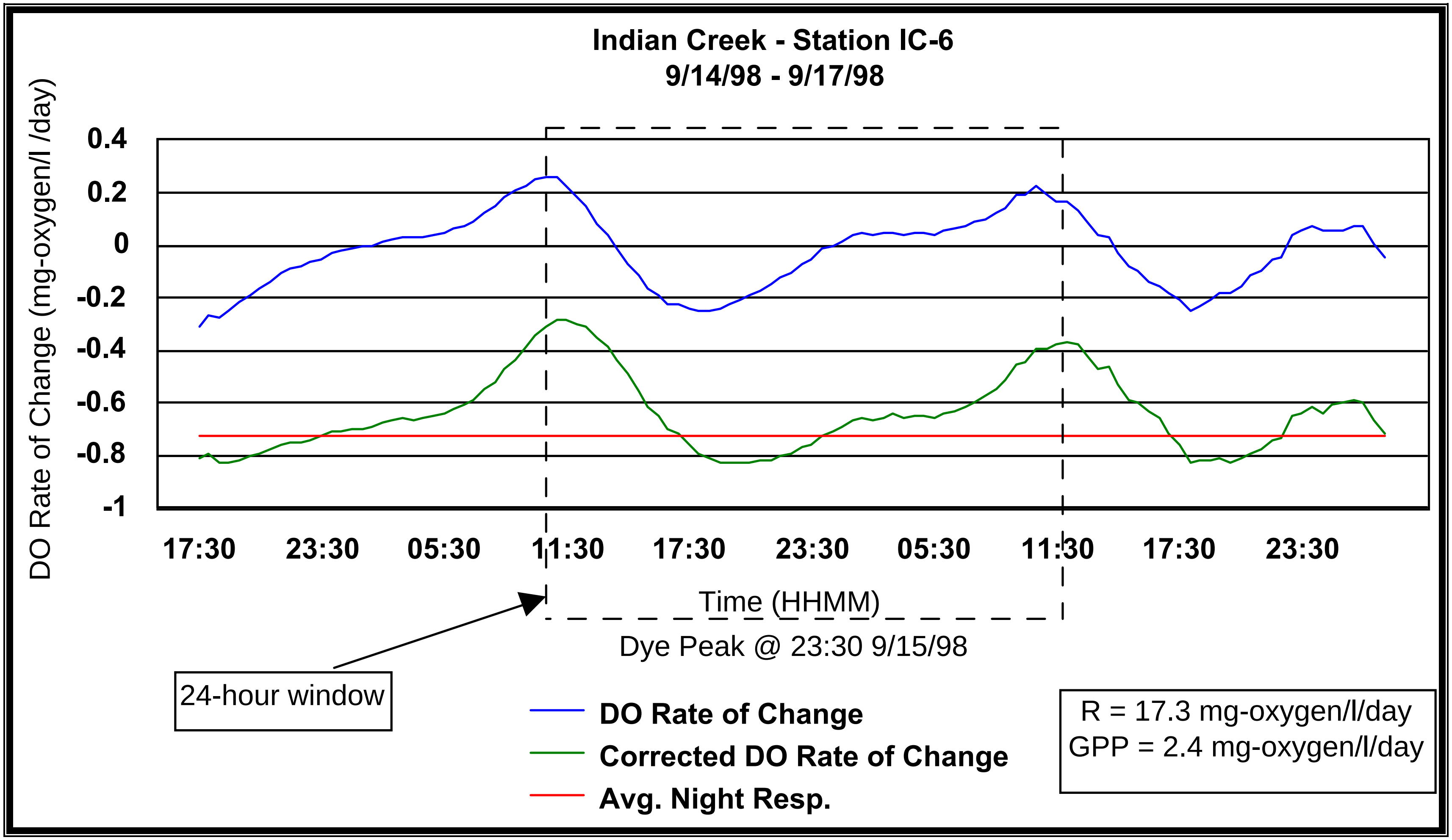

Figure A-20. Diurnal Curve Analysis for IC-6

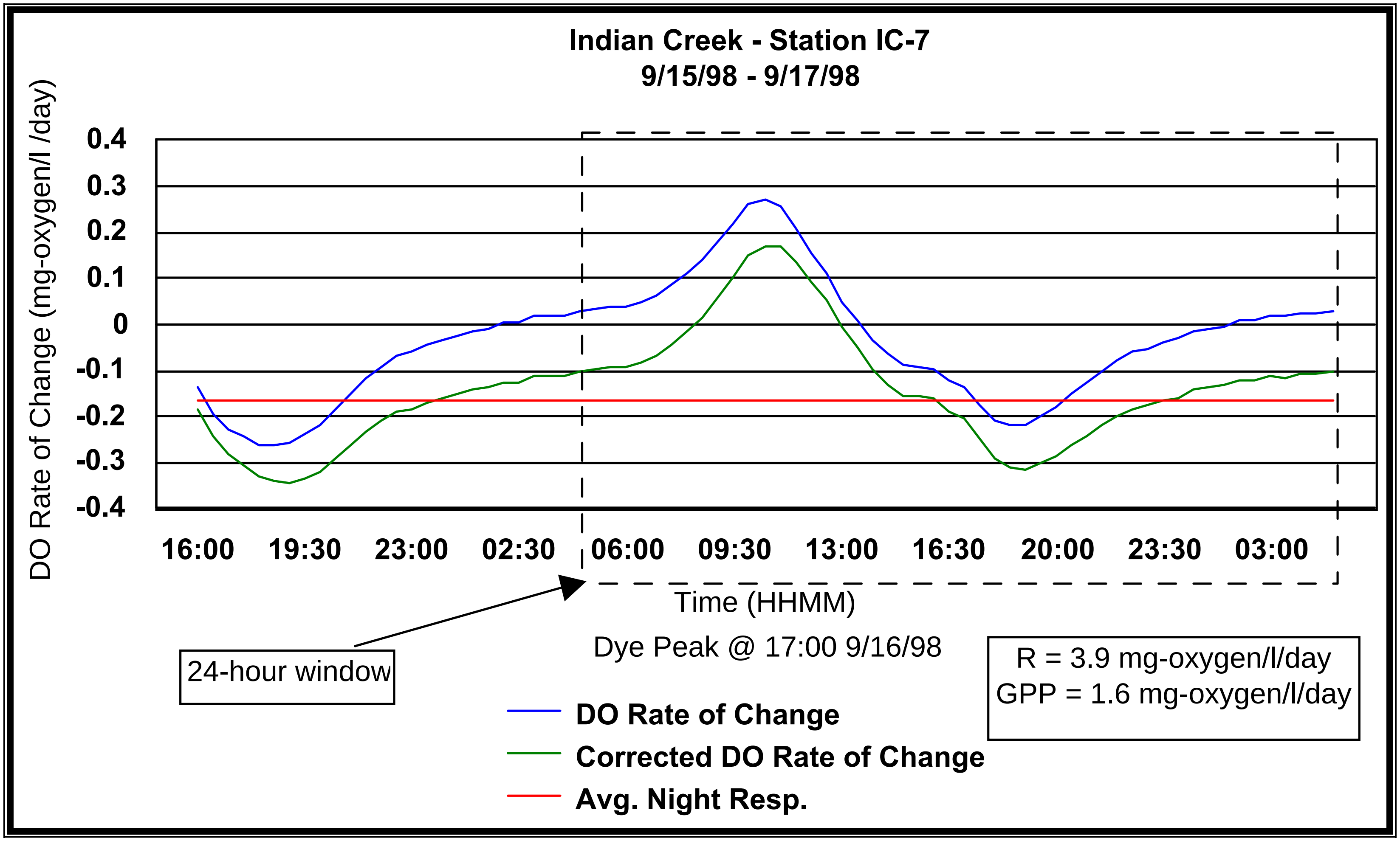

Figure A-21. Diurnal Curve Analysis for IC-7