

# **TMDL for Organic Enrichment, Nutrients and Sediment for the Big Sunflower River**

## **Yazoo River Basin**

### **Sunflower, Coahoma, Washington, Humphreys, and Sharkey Counties, Mississippi**

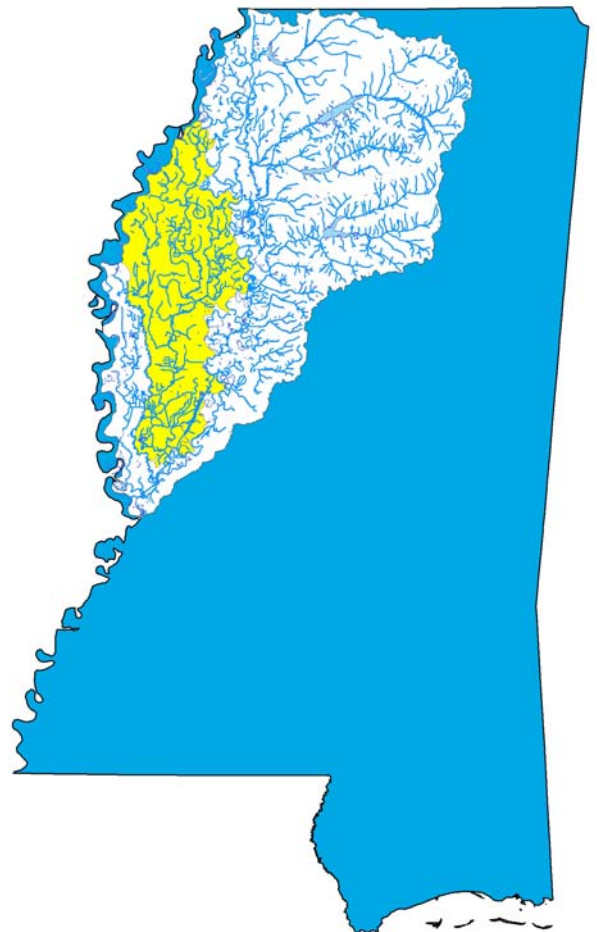
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# FOREWORD

This report has been prepared in accordance with the schedule contained within the federal consent decree dated December 22, 1998. The report contains one or more Total Maximum Daily Loads (TMDLs) for water body 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 implementation of the TMDLs contained herein will be prioritized within Mississippi's rotating basin approach.

The amount and quality of the data on which this report is based are limited. As additional information becomes available, the TMDLs may be updated. Such additional information may include water quality and quantity data, changes in pollutant loadings, or changes in landuse within the watershed. In some cases, additional water quality data may indicate that no impairment exists.

## Prefixes for fractions and multiples of SI units

Fraction	Prefix	Symbol	Multiple	Prefix	Symbol
10 <sup>-1</sup>	deci	d	10	deka	da
10 <sup>-2</sup>	centi	c	10 <sup>2</sup>	hecto	h
10 <sup>-3</sup>	milli	m	10 <sup>3</sup>	kilo	k
10 <sup>-6</sup>	micro	:	10 <sup>6</sup>	mega	M
10 <sup>-9</sup>	nano	n	10 <sup>9</sup>	giga	G
10 <sup>-12</sup>	pico	p	10 <sup>12</sup>	tera	T
10 <sup>-15</sup>	femto	f	10 <sup>15</sup>	peta	P
10 <sup>-18</sup>	atto	a	10 <sup>18</sup>	exa	E

## Conversion Factors

To convert from	To	Multiply by	To Convert from	To	Multiply by
Acres	Sq. miles	0.0015625	Days	Seconds	86400
Cubic feet	Cu. Meter	0.0283	Feet	Meters	0.3048
Cubic feet	Gallons	7.4805	Gallons	Cu feet	0.13368
Cubic feet	Liters	28.317	Hectares	Acres	2.471
cfs	Gal/min	448.83	Miles	Meters	1609.3
cfs	MGD	0.6463	mg/l	ppm	1
Cubic meters	Gallons	264.17	:g/l * cfs	Gm/day	2.45

## CONTENTS

TMDL Information .....	vii
EXECUTIVE SUMMARY .....	xi
<b>1. INTRODUCTION .....</b>	<b>1</b>
1.1 Background.....	1
1.2 Applicable Waterbody Segment Use .....	3
1.3 Applicable Waterbody Segment Standards .....	3
1.4 Selection of a Critical Condition.....	3
1.4.1 Organic Enrichment/Low DO.....	3
1.4.2 Sediment and Sedimentation.....	4
<b>2. TMDL ENDPOINTS .....</b>	<b>5</b>
2.1 Selection of a TMDL Endpoint and Critical Condition.....	5
2.2 Organic Enrichment and Dissolved Oxygen.....	5
2.3 Sediment .....	6
<b>3. SOURCE ASSESSMENT .....</b>	<b>7</b>
3.1 Assessment of Point Sources .....	7
3.2 Assessment of Nonpoint Sources.....	8
3.2.1 Organic Enrichment and Dissolved Oxygen.....	10
3.2.2 Sediment .....	11
<b>4. MODELING PROCEDURE: LINKING THE SOURCES TO THE ENDPOINT.....</b>	<b>12</b>
4.1 Modeling Framework Selection.....	12
4.1.1 Previous Modeling .....	12
4.1.2 Present Modeling .....	13
4.2 Model Application .....	13
4.3 Model Results .....	14
4.3.1 Total Suspended Solids.....	14
4.3.2 Ammonia and Dissolved Oxygen .....	15
<b>5. ALLOCATION.....</b>	<b>16</b>
5.1 Organic enrichment/low dissolved oxygen and nutrients.....	16
5.1.1. Segments MSBIGSUNRM and MSBIGSUNRM5 .....	16
5.1.2. Segment MSBIGSUNRM2.....	18
5.1.3. Segment MSBIGSUNRM4 and MSHBCUT .....	20
5.2 Sediment .....	23
5.2.1 Wasteload Allocations .....	23
5.2.2. Load Allocation .....	23
5.3 Incorporation of a Margin of Safety .....	23
5.4 Calculation of the TMDL.....	24
5.4.1. Dissolved Oxygen/Organic Enrichment/Nutrients .....	24
5.4.2. Sediment .....	25
5.5 Seasonality .....	25

6. CONCLUSION.....	26
6.1 Organic Enrichment/Dissolved Oxygen and Nutrients.....	26
6.2 Sediment .....	28
6.3 Future Monitoring.....	28
6.4 Public Participation.....	29
DEFINITIONS.....	30
ABBREVIATIONS .....	37
REFERENCES .....	39

### **List of Tables**

Table 1. Land use Distribution for the Big Sunflower River Watershed.....	2
Table 2. Modeled Point Sources Loadings .....	7
Table 3. Flows for several events .....	8
Table 4. Number of Water Quality Parameter Data Points. ....	9
Table 5. Water Quality Parameter Statistics (mg/l, except as noted). ....	10
Table 6. TSS Results for Listed Reaches.....	14
Table 7. Existing Sediment Yield.....	15
Table 8. Load scenario for MSBIGSUNRM and MSBIGSUMRM5, critical conditions	17
Table 9. Load scenario for MSBIGSUNRM2, critical conditions.....	18
Table 10. Wasteload Allocation, Segment BIGSUNRM2.....	19
Table 11. Load Allocation, segment BIGSUNRM2.....	20
Table 12. Load scenario for MSBIGSUNRM4 and MSHBCUT, critical conditions .....	21
Table 13. Load Allocation, segments MSBIGSUNRM4 and MSHBCUT .....	22
Table 14. Phase 1 TMDL for TBODu, for critical conditions in segments MSBIGSUNRM and MSBIGSUNRM5. ....	24
Table 15. Phase 1 TMDL for TBODu, for critical conditions in segments MSBIGSUNRM2.....	24
Table 16. Phase 1 TMDL for TBODu, for critical conditions in segments MSBIGSUNRM4 and MSHBCUT of the Big Sunflower River. ....	25
Table 17. TMDL Allocation for Sediment Yield, tonnes/km <sup>2</sup> -day .....	25

### **List of Figures**

Figure 1 Big Sunflower River Watershed 303d Listed Segments .....	1
Figure 2. Big Sunflower River Subwatersheds (adapted from Tetra Tech 1999) .....	2

### **List of Charts**

Chart 1. Section 1 of the Big Sunflower River for existing, critical condition simulations. .....	41
Chart 2. Section 2 of the Big Sunflower River for existing, critical condition simulations. .....	42
Chart 3. Section 2 of the Big Sunflower River following an equal reduction of all point and non-point sources (of from 50 to 80 percent).....	43

Chart 4. Section 3 of the Big Sunflower River (including Holly Bluff Cutoff) for existing, critical condition simulations. .... 44

Chart 5. Section 3 of the Big Sunflower River (including Holly Bluff Cutoff) for critical condition simulations following load reductions to Section 2..... 45

Chart 6. Section 3 of the Big Sunflower River , Old Sunflower Bendway, for existing, critical condition simulations. .... 46

Chart 7. Section 3 of the Big Sunflower River , Old Sunflower Bendway, for critical condition simulations following load reductions to Section 2..... 47

Chart 8. Section 3 of the Big Sunflower River, the Little Sunflower River, for existing, critical condition simulations. .... 48

Chart 9. Section 3 of the Big Sunflower River, the Little Sunflower River, for critical condition simulations following load reductions to Section 2..... 49

## TMDL Information

**Table i. Listing Information**

Water Body Name	Water Body ID	Counties	Monitored/ Evaluated	Cause
BOGUE PHALIA	MS392M	WASHINGTON SUNFLOWER	E	SEDIMENT/ SILTATION
LOCATION: AT LELAND FROM CONFLUENCE WITH CLEAR CREEK TO BIG SUNFLOWER RIVER				
BIG SUNFLOWER	MSBIGSUNRM	COAHOMA	E	NUTRIENTS ORGANIC ENRICHMENT/ LOW DO SUSPENDED SOLIDS TURBIDITY
LOCATION: AT CLARKSDALE FROM LYONS POTW TO HOPSON				
BIG SUNFLOWER	MSBIGSUNRM2	SUNFLOWER	M	NUTRIENTS ORGANIC ENRICHMENT/ LOW DO SUSPENDED SOLIDS TURBIDITY
LOCATION: AT SUNFLOWER FROM CONFLUENCE WITH JONES BAYOU TO CONFLUENCE WITH PORTER BAYOU				
BIG SUNFLOWER	MSBIGSUNRM3	SUNFLOWER WASHINGTON HUMPHREYS	E	SEDIMENT/ SILTATION
LOCATION: AT INDIANOLA FROM CONFLUENCE WITH PORTER BAYOU TO CONFLUENCE WITH BOGUE PHALIA				
BIG SUNFLOWER	MSBIGSUNRM4	WASHINGTON HUMPHREYS SHARKEY	M	NUTRIENTS ORGANIC ENRICHMENT/ LOW DO SUSPENDED SOLIDS TURBIDITY
LOCATION: NEAR ANGUILLA FROM CONFLUENCE WITH BOGUE PHALIA TO YAZOO RIVER				
BIG SUNFLOWER	MSBIGSUNRM5	COAHOMA	M	NUTRIENTS ORGANIC ENRICHMENT/ LOW DO SUSPENDED SOLIDS TURBIDITY
LOCATION: AT CLARKSDALE FROM CONFLUENCE WITH LITTLE SUNFLOWER RIVER TO LOWHEAD DAM ABOVE CLARKSDALE POTW				
HOLLY BLUFF CUTOFF	MSHBCUTM	WASHINGTON HUMPHREYS SHARKEY	E	NUTRIENTS ORGANIC ENRICHMENT/ LOW DO SEDIMENT/ SILTATION
LOCATION: NEAR ANGUILLA FROM CHAPPEL LANDING TO HOLLY BLUFF				

**Table ii. Water Quality Standard**

Parameter	Beneficial use	Water Quality Criteria
Dissolved Oxygen	Aquatic Life Support	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
Sediment	Aquatic Life Support	Waters shall be free from materials attributable to municipal, industrial, agricultural, or other dischargers producing color, odor, taste, total suspended solids, or other conditions in such degree as to create a nuisance, render the waters injurious to public health, recreation, or to aquatic life and wildlife, or adversely affect the palatability of fish, aesthetic quality, or impair the waters for any designated uses.

**Table iii. NPDES Facilities**

Permit	Facility Name	Subwatershed	Receiving Water
MS0020311	Clarksdale POTW	08030207012	Big Sunflower River
MS0001139	Clarksdale Pub Uti Wilkins Sta	08030207012	Big Sunflower River
MS0001139	Clarksdale Pub Uti Wilkins Sta	08030207012	Big Sunflower River
MS0001139	Clarksdale Pub Uti Wilkins Sta	08030207012	Big Sunflower River
MS0035823	Delta Pride Catfish, Indianola Plant	08030207	Big Sunflower River
MS0035823	Delta Pride Catfish, Indianola Plant	08030207	Big Sunflower River
MS0035823	Delta Pride Catfish, Indianola Plant	08030207	Big Sunflower River
MS0044458	Doddsville POTW	08030207009	Big Sunflower River
MS0000817	Entergy - Delta Station	08030207010	Big Sunflower River
MS0000817	Entergy - Delta Station	08030207010	Big Sunflower River
MS0000817	Entergy - Delta Station	08030207010	Big Sunflower River
MS0000817	Entergy - Delta Station	08030207010	Big Sunflower River
MS0000817	Entergy - Delta Station	08030207010	Big Sunflower River
MS0024619	Indianola POTW	08030207008	Big Sunflower River
MS0020591	Lyon POTW	08030207012	Big Sunflower River
MS0032085	Roundaway Elementary School	08030207012	Big Sunflower River
MS0043354	Southfish Farms, Llc	08030207	Big Sunflower River
MS0024384	Sunflower POTW	08030207010	Big Sunflower River
MS0042196	Alligator POTW	08030207010	Alligator Lake
MS0044032	America's Catch Incorporated	08030207009	Big Sunflower River
MS0020541	Anguilla POTW	08030207005	Drainage ditch to Big Sunflower River
MS0000833	Baxter Healthcare Corporation	08030207010	Tributary of Lead Bayou
MS0000833	Baxter Healthcare Corporation	08030207010	Tributary of Lead Bayou
MS0044148	Berryhill Mobile Home Park	08030207012	Big Sunflower River
MS0042285	Beulah POTW	08030207015	Laban Bayou
MS0021547	Cary POTW	08030207016	Trib to Big Sunflower River

*Big Sunflower River TMDLs for Organic Enrichment, Nutrients, and Sediment*

<b>Permit</b>	<b>Facility Name</b>	<b>Subwatershed</b>	<b>Receiving Water</b>
MS0020567	Cleveland POTW	08030207010	Lead Bayou
MS0001147	Clarksdale Pub Uti Third Street Sta	08030207012	Mill Creek
MS0044237	Coahoma POTW	08030207012	Mill Creek
MS0039659	Confish Incorporated	08030207005	Lake Dawson into Big Sunflower
MS0038164	Delta City Utility District	08030207005	Sunflower River
MS0038814	Delta Pride Catfish Inc	08030207010	Big Sunflower River
MS0038814	Delta Pride Catfish Inc	08030207010	Big Sunflower River
MS0038814	Delta Pride Catfish Inc	08030207010	Big Sunflower River
MS0026417	Drew POTW	08030207008	Dougherty Bayou
MS0042234	Duncan POTW	08030207010	Hushpuckena River
MS0022683	East Park Sub Division	08030207012	Oxbow Bayou
MS0029262	Goose Pond Sub Division	08030207009	Stalen Brake
MS0042943	Gunnison POTW	08030207015	Bogue Phalia
MS0036722	Inverness Compression Station	08030207007	Lake Dawson
MS0020320	Inverness POTW	08030207008	Mound Bayou
MS0020109	Isola POTW	08030207005	Unnamed ditch to Lake Dawson
MS0021075	Jonestown POTW	08030207012	Swan Lake
MS0041998	Lake Bolivar State Park	08030207012	Lake Bayou
MS0032166	Lane Acres Sub Division	08030207012	Lake Bayou
MS0044512	Louise POTW	08030207004	Drainage Ditch A
MS0045080	Lurand POTW (Coahoma County)	08030207012	Hopson Bayou
MS0022225	Mascot Housing Development Co	08030207012	Harris Bayou
MS0025127	Merigold POTW	08030207010	Jones Bayou
MS0024961	Moorhead POTW	08030207010	Moorhead Bayou
MS0020842	Mound Bayou POTW	08030207010	Little Mound Bayou
MS0029009	Ms/Ms State Pen POTW # 1	08030207011	Black Bayou
MS0045331	Ms/Ms State Pen POTW # 2	08030207011	Black Bayou
MS0024937	Ms/Valley State University	08030207009	Gin Bayou
MS0022900	Oakhurst Company Incorporated	08030207012	Harris Bayou
MS0036544	Pace POTW	08030207015	Bogue Phalia
MS0042871	Riven Oaks Headstart Center	08030207004	Silver Creek
MS0001210	Rosedale Fabricators Llc	08030207015	Goff's Bayou
MS0020630	Rosedale POTW	08030207015	Ditch,Lane Bayou, Bogue Phalia
MS0036005	Schlater POTW	08030207009	McNutt Lake
MS0024953	Shaw POTW	08030207010	Porter Bayou
MS0025089	Shelby POTW	08030207010	Mound Bayou
MS0044709	Silver City POTW	08030207004	Big Cedar Creek
MS0039667	Southern Farm Fish Processors	08030207009	Roundaway Bayou to Quiver River
MS0039667	Southern Farm Fish Processors	08030207009	Roundaway Bayou to Quiver River
MS0035726	Sumner POTW	08030207009	Stalen Brake



*Big Sunflower River TMDLs for Organic Enrichment, Nutrients, and Sediment*

Permit	Facility Name	Subwatershed	Receiving Water
MS0000761	Tennessee Gas Pipeline Company	08030207005	Cole Lake
MS0025054	Tutwiler POTW	08030207012	Hopson Bayou
MS0026450	Winstonville POTW	08030207010	Little Mound Bayou

**Table v(a). Phase 1 TMDL for TBOD<sub>u</sub>, for critical conditions in segments MSBIGSUNRM and MSBIGSUNRM5.**

Condition	WLA (kg/day)	LA (kg/day)	MOS	TMDL (kg/day)
Base Flow	1738	472	Implicit	2210
Base Flow + 30 cfs	1738	472	Implicit	2210
Base Flow + 40 cfs	1738	472	Implicit	2210
Base Flow + 50 cfs	1738	472	Implicit	2210
Base Flow + 60 cfs	1738	472	Implicit	2210

**Table v(b). Phase 1 TMDL for TBOD<sub>u</sub>, for critical conditions in segments MSBIGSUNRM2**

Condition	WLA (kg/day)	LA (kg/day)	MOS	TMDL (kg/day)
Base Flow	19	123	Implicit	142
Base Flow + 30 cfs	33	544	Implicit	577
Base Flow + 40 cfs	43	738	Implicit	781
Base Flow + 50 cfs	47	860	Implicit	907
Base Flow + 60 cfs	47	899	Implicit	946

**Table v(c). Phase 1 TMDL for TBOD<sub>u</sub>, for critical conditions in segments MSBIGSUNRM4 and MSHBCUT of the Big Sunflower River.**

Condition	WLA (kg/day)	LA (kg/day)	MOS	TMDL (kg/day)
Base Flow	0	1518	Implicit	1518
Base Flow + 30 cfs	0	2588	Implicit	2588
Base Flow + 40 cfs	0	3210	Implicit	3210
Base Flow + 50 cfs	0	3571	Implicit	3571
Base Flow + 60 cfs	0	3653	Implicit	3653

**Table vi. Phase 1 TMDL for Sediment Yield, tonnes/km<sup>2</sup>-day**

WLA*	LA*	MOS	TMDL*
0.6 – 1.6	0.6 – 1.6	Implicit	0.6 – 1.6

Note: \* At the effective discharge. Since the allocation is expressed as a sediment yield per unit area of watershed, the WLA, LA, and TMDL are identical. See Section 5.2.

## EXECUTIVE SUMMARY

Three segments of the Big Sunflower River and its tributaries are on the monitored section of the Mississippi 1998 Section 303(d) List of Impaired Waterbodies. Four segments are on the evaluated section of the Mississippi 1998 Section 303(d) List of Waterbodies. The Big Sunflower River segments are in the Yazoo River Basin Hydrologic Unit Code (HUC) 08030207 in northwest Mississippi. These segments are listed due to organic enrichment/low dissolved oxygen, nutrients, turbidity, total suspended solids, and/or sediment/siltation. This TMDL is being completed for clean sediment because total suspended solids were delisted due to inappropriate analysis and because turbidity and siltation are represented by the same processes as clean sediment and controlled by the same best management practices (BMPs).

For organic enrichment/low dissolved oxygen and nutrients, the applicable state standard specifies that the 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. Mississippi currently does not have standards for allowable nutrient concentrations, so a TMDL specifically for nutrients will not be developed. However, since elevated levels of nutrients may cause low levels of dissolved oxygen, the TMDL developed for dissolved oxygen also addresses the potential impact of elevated nutrients in the Big Sunflower River watershed.

The State of Mississippi *Water Quality Criteria for Intrastate, Interstate and Coastal Waters* regulation does not include a numerical water quality standard for aquatic life protection due to sediment (2002). The narrative standard for the protection of aquatic life is sufficient for justification of TMDL development, but does not provide a quantifiable TMDL target. The Channel and Watershed Processes Research Unit (CWPRU) at the National Sedimentation Laboratory (NSL) was contracted by MDEQ and EPA Region 4 to develop reference sediment yields for each ecoregion within Mississippi. The reference yield, or TMDL target, was derived from the empirical analysis of historical flow and sediment-transport data for stable streams in each. From these studies, the reference yield of 0.6 to 1.6 T/d/km<sup>2</sup> was identified as the preliminary target yield for this analysis. The methods used to develop these values are described by Simon, Bingner, and Langendoen (2002) and Simon, Kuhnle, and Dickerson (2002).

The modeling framework employed in the present study consisted of five integrated efforts – characterization of: hydrologic flows, non-point source loadings, point source flows and loadings, in-stream hydraulics, and in-stream water quality. Hydrologic models and methods, based on the HSPF model, were employed to estimate the non-point source flows, which were combined and assigned to hydraulic simulations at the terminus of major contributing tributaries. Point source loadings flowing directly into the Big Sunflower River were explicitly modeled. Steady-flow hydraulic models, utilizing the HEC-RAS simulation program, were employed to route the inflows and estimate resulting hydraulic characteristics (e.g. depths, velocities, volumes). A water quality model (WASP) was used, in a steady state mode, to integrate the existing flows and loadings and estimate the impacts of those flows and loadings on water quality. The

studies were based in part, on previous modeling studies by Mississippi State University as reported by Shindala et al. (1998) and hydraulic studies provided by the USACE District-Vicksburg. A detailed description of the model applications is given by Martin et al. (2003).

The models, once calibrated to available data, were used to develop steady-state responses between loadings of nutrients/organic materials and dissolved oxygen concentrations and between sediment loads and in-stream concentrations for comparison with applicable standards and determination of the TMDL for each impaired segment.

### **Organic Enrichment/Dissolved Oxygen And Nutrients**

For organic enrichment/dissolved oxygen and nutrients, impairments were predicted in two of the five segments evaluated (MSBIGSUNRM4 and MSHBCUT), and TMDLs were established to remove the predicted impairments in these segments. In addition to evaluating load reductions, flow augmentation was considered as an alternative. Presently, flows in the Big Sunflower are augmented by an inflow (of approximately 30 cfs which is considered hereafter the base flow critical condition) to MSBIGSUNRM5 as needed in order to maintain a minimum flow of approximately 50 cfs in the Big Sunflower River at Sunflower, MS (USGS Gage No. 07288500). Flows evaluated included a no-flow augmentation, with additional augmentations to 40, 50 and 60 cfs. Model predictions suggested that flow augmentation alone was insufficient to remove the predicted impairment, so that TMDLs for maintaining or decreasing existing loads were established for each of the potential flow conditions. However, model predictions also suggested that reducing or eliminating the loads to upstream-impaired segments alone was insufficient to remove the predicted impairment. That is the majority of the TBODu loads from upstream sources occurred between the upstream segments and those predicted to be impaired (such as from the Quiver River). As a result, reductions of these NPS loads located between, for example MSBIGSUNRM2 and MSBIGSUNRM4 alone or in conjunction with upstream load reductions would be required to remove the predicted impairment. Federal regulations require that effluent limits developed to protect water quality criteria be consistent with the assumptions and requirements of any available wasteload allocation for the discharge prepared by the state and approved by EPA. Due to economic and environmental considerations in the watershed, MDEQ will stage the implementation of this TMDL. This TMDL recommends a 5-year compliance schedule be included in the NPDES permit of each NPDES Permitted facility in the WLAs. The compliance schedule should require each facility to meet permit limits during the first four years of the permit. Prior to the end of the fifth year of the permit, the compliance schedule will require each facility to meet limits as determined by the state necessary to meet whatever applicable water quality standards that are in place at that time.

For organic enrichment/dissolved oxygen and nutrients, the DO predicted impairments for the two segments MSBIGSUNRM4 and MSHBCUT resulted in part from hydraulic control structures located within these segments. For example, in MSBIGSUNRM4 a weir located below Highway 12 results in increased predicted depths and decreased

velocities (decreased reaeration), and increased retention time (greater impacts of sediment oxygen demand). The combined impact in MSBIGSUNRM4, for the base flow critical condition, was a predicted utilization of approximately 75 % of the available DO deficit in the absence of external TBODu loads, providing little remaining assimilative capacity for those external loads. A weir located in the Holly Bluff Cutoff (MSHBCUT) similarly impacts flows and DO depletions in that segment. Since the utilization of the majority of the available DO deficit results, in part, from the presence of the hydraulic control structures, or man-induced channel modifications, the man-induced channel modifications can be considered a type of pollution. The term pollution is used to describe man-induced activities that may cause a water body to occasionally not attain water quality standards such as weirs and channelization. A pollutant is a particular substance that causes impairment of a water body, such as nutrients or organic material. TMDL development is not required for water bodies impaired due to pollution. It is recommended that the cause of impairment for these segments be reclassified as a pollution cause for this water body.

The evaluations conducted indicated a need for additional studies related to MSBIGSUNRM4 and MSHBCUT. The flows in these reaches are complicated by the presence of weirs and operation of a downstream control structure (the Little Sunflower control structure). In addition, below the Highway 12 weir, the river consists of a series of hydraulically connected channels, including the Big Sunflower River, Holly Bluff cutoff, the six-mile cutoff, the Old Sunflower Bendway and Little Sunflower River. The interactions of these connected channels under low flow conditions needs further investigation. In addition, under low flow conditions, simulations indicate that the upper portion of the Little Sunflower River is not hydraulically connected to the other river reaches (as a result of a sill located near the head of this section of river). As a result, under low flow conditions this section of river would only be impacted by downstream backwater conditions, which could lead to stagnation and DO depletions. The impact of this was not adequately analyzed in the present modeling study and requires further investigation to determine the degree of impairment and causal factors.

### **Sediment and Sedimentation**

Analysis of data and modeling showed that existing sediment yields in areas of the reaches listed as impaired by sedimentation, siltation, and/or turbidity range from 0.3 to 10.5 (metric) tonnes/km<sup>2</sup>-day, which overlays the range of target yields identified for stable streams in the region. It is expected that all values within this range will result in attainment of water quality standards. The unstable yield range is approximately the same as the target yield range, which indicates a reduction should not be necessary.

# 1. 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 TMDL process is designed to restore and maintain the quality of those impaired waterbodies through the establishment of pollutant specific allowable loads. The pollutants of concern for this TMDL are materials contributing to low dissolved oxygen and sediment impairment.

Three segments of the Big Sunflower River and its tributaries are on the monitored section of the Mississippi 1998 Section 303(d) List of Impaired Waterbodies. Four segments are on the evaluated section of the Mississippi 1998 Section 303(d) List of Impaired Waterbodies. These segments were listed based on current and historical data. The 303d listed segments are shown in Figure 1.

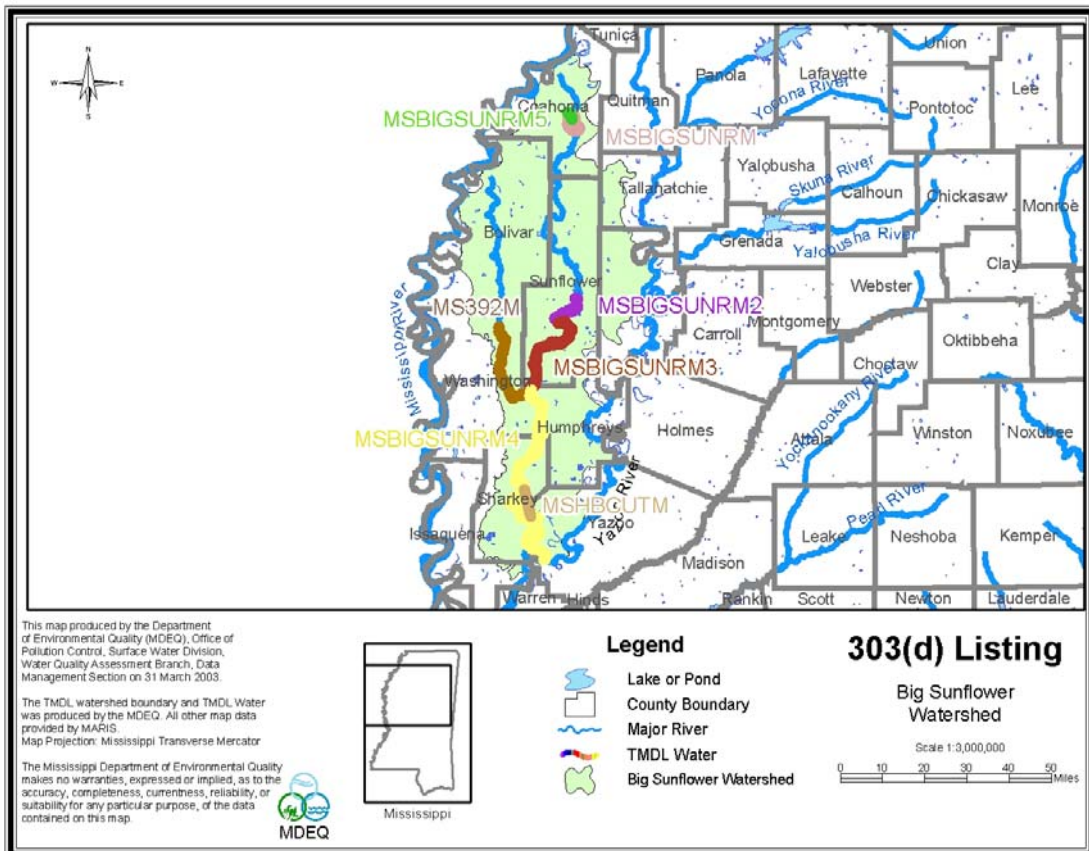


Figure 1 Big Sunflower River Watershed 303d Listed Segments

The Big Sunflower River segments are in the Yazoo River Basin Hydrologic Unit Code (HUC) 08030207 in northwest Mississippi. The watershed covers approximately 1,992,000 acres; and lies within portions of Bolivar, Coahoma, Humphreys, Leflore, Sunflower, Tallahatchie, Sharkey, and Washington Counties. The watershed is primarily rural, but includes many small municipalities. Cropland is the dominant land use within the watershed as shown by the land distribution summary in Table 1.

**Table 1. Land use Distribution for the Big Sunflower River Watershed**

Measure	Urban	Agriculture	Barren	Wetland	Forest	Water	Total
Area (acres)	6,739	1,546,404	0	88,454	246,972	103,431	1,992,000
Area (%)	0.4%	77.6%	0%	4.4%	12.4%	5.2%	100.0%

The watershed has been divided into seven subwatersheds based on the major tributaries and topography.

Figure 2 shows the subwatersheds with a three-digit Reach File 1 segment identification number. Each subwatershed is assigned a corresponding identification number, which is a combination of the eight-digit HUC and the three-digit Reach File 1 segment identification number. The identification number of the most downstream reach of the watershed is 08030207006.

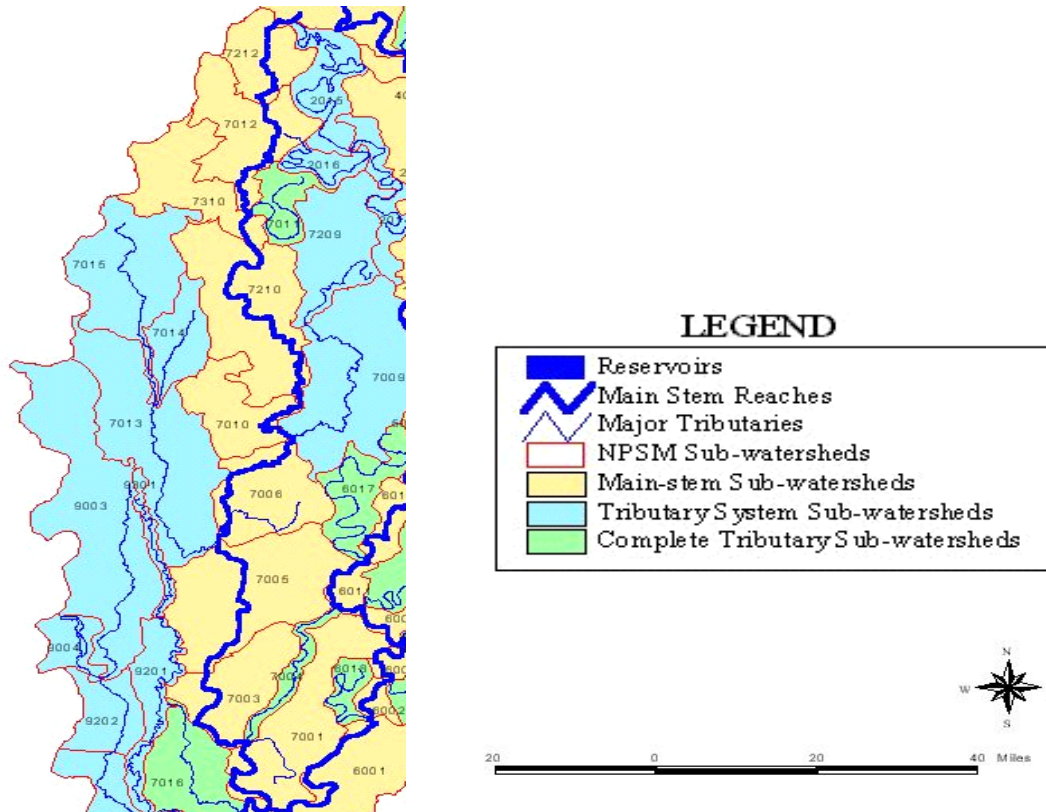


Figure 2. Big Sunflower River Subwatersheds (adapted from Tetra Tech 1999)

## 1.2 Applicable Waterbody Segment Use

The water use classification for the listed segments of the Big Sunflower River, as established by the State of Mississippi in the *Water Quality Criteria for Intrastate, Interstate and Coastal Waters* regulation, is Fish and Wildlife Support. The designated beneficial uses for the Big Sunflower River are Secondary Contact and Aquatic Life Support.

## 1.3 Applicable Waterbody Segment Standards

The water quality standard applicable to the use of the waterbody and the pollutants of concern is defined in the *State of Mississippi Water Quality Criteria for Intrastate, Interstate, and Coastal Waters* (2002). The applicable standard specifies that the dissolved oxygen (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.

Ammonia must not only be considered due to its effect on dissolved oxygen in the receiving water, but also its toxicity potential. Ammonia nitrogen concentrations can be evaluated using the criteria given in 1999 Update of Ambient Water Quality Criteria for Ammonia (EPA-822-R-99-014). The maximum allowable instream ammonia nitrogen (NH<sub>3</sub>-N) concentration at a pH of 7.0 and stream temperature of 26°C is 2.82 mg/l.

The *State of Mississippi Water Quality Criteria for Intrastate, Interstate, and Coastal Waters* do not include a water quality standard applicable to aquatic life protection due to sediment, siltation, suspended solids, or turbidity (2002). A narrative standard for the protection of aquatic life was interpreted to determine an applicable target for this TMDL. The narrative standard is that waters shall be free from materials attributable to municipal, industrial, agricultural, or other dischargers producing color, odor, taste, total suspended solids, or other conditions in such degree as to create a nuisance, render the waters injurious to public health, recreation, or to aquatic life and wildlife, or adversely affect the palatability of fish, aesthetic quality, or impair the waters for any designated uses. The interim target is for a maximum allowable sediment yield of 0.6 to 1.6 (metric) tonnes/km<sup>2</sup>/day at the effective discharge.

## 1.4 Selection of a Critical Condition

### 1.4.1 Organic Enrichment/Low DO

Low DO typically occurs during seasonal low-flow, high-temperature periods that occur during the late summer and early fall. Elevated oxygen demand is of primary concern during low-flow periods because the effects of minimum dilution and high temperatures combine to produce the worst-case potential effect on water quality (USEPA, 1997). The flow at critical conditions is typically defined as the 7Q10 flow, which is the lowest flow for seven consecutive days expected during a 10-year period. 7Q10 flows, however, have not been established for streams in the Mississippi Alluvial Plain. In addition, recent decreases in base flows have been a concern, and Big Sunflower River flows have been

augmented to maintain a minimum in-stream flow of 50 cfs at Sunflower. This augmented flow is considered the base flow critical condition for the TMDL. However, since additional flow augmentation is being considered, augmentation flows of 40, 50, and 60 cfs were also evaluated. A no augmentation scenario was evaluated for comparison purposes only.

#### **1.4.2 Sediment and Sedimentation**

Sediment transport generally increases with increasing discharge. The commonly used condition to characterize typical sediment transport in a stream is the flow with a statistical recurrence interval of 1.5 years (Simon, Bingner, and Langendoen, 2002).



## **2. TMDL ENDPOINTS**

### **2.1 Selection of a TMDL Endpoint and Critical Condition**

One of the major components of a TMDL is the establishment of in-stream 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 implementing the load and waste load reductions specified in the TMDL. The endpoints allow for a comparison between observed in-stream conditions and conditions that are expected to restore designated uses.

While the endpoint of a TMDL calculation is similar to a standard for a pollutant, the endpoint is not the standard.

### **2.2 Organic Enrichment and Dissolved Oxygen**

The in-stream DO target for this TMDL is a daily average of not less than 5.0 mg/l. The instantaneous minimum portion of the DO standard was considered when establishing the in-stream target for this TMDL. However, it was determined that using the daily average standard with the conservative modeling assumptions would be sufficiently protective of the instantaneous minimum standard. The conservative assumptions, including a constant minimum flow, resulted in a prediction of the minimum DO concentration expected in the Big Sunflower for the conditions simulated. A process that could potentially result in difference in the average and instantaneous concentration that was not included in the modeling framework was algal respiration. However, there are presently insufficient data available to either model or estimate the impact of algal growth and respiration on diel variations in oxygen concentrations in the Big Sunflower River.

The maximum impact of oxidation of organic material is generally not at the location of the sources, but at some distance downstream, where the maximum DO deficit occurs. The DO deficit is defined as the difference between the DO concentration at 100% saturation and the actual DO. The point of maximum DO deficit, also called the DO sag, will be used to define the endpoint required for this TMDL. The endpoint for this TMDL will be based on a daily average of not less than 5.0 mg/l at the DO sag during a typical low flow period on the Big Sunflower.

Ammonia must not only be considered due to its effect on dissolved oxygen in the receiving water, but also its toxicity potential. Ammonia nitrogen concentrations can be evaluated using the criteria given in 1999 Update of Ambient Water Quality Criteria for Ammonia (EPA-822-R-99-014). The maximum allowable in-stream ammonia nitrogen (NH<sub>3</sub>-N) concentration at a pH of 7.0 and stream temperature of 26°C is 2.82 mg/l.

The critical low flow period, most often occurring in August through October, was modeled to define a characteristic base flow of 15 ft<sup>3</sup>/sec at Sunflower plus low flow

augmentation of 30 ft<sup>3</sup>/sec provided by the Yazoo-Mississippi Delta Joint Water Management District from wells near Clarksdale (Martin et al., 2003).

## **2.3 Sediment**

The terms sediment, siltation, suspended solids, and turbidity (defined in the DEFINITIONS section of this document) are not synonymous. For example, turbidity can be caused by dissolved substances, such as tannin from leaves, and unrelated to suspended sediment. However, for purposes of this TMDL, listed impairments by sediment, siltation, suspended solids, and turbidity are taken to be represented by total suspended solids (TSS), measured in mg/l and the suspended sediment yield, measured in metric tonnes/km<sup>2</sup>-day, that corresponds to that TSS.

Sediment transport (load) in flowing water can be compartmentalized in several ways, including suspended load plus bedload. The analyses presented here are based on measurements of total suspended solids, which can be used to estimate suspended load, and modeling of suspended load. Bedload, which is sediment hopping, sliding, or rolling along the bed, is difficult or impossible to measure and is not included.

Sediment impairment of waterbodies usually arises from excessive sediment in the water column or excessive deposition to the bed; however, too little sediment can also cause impairment (EPA, 1999). Adverse effects of excess sediment on cold water fish species are well-documented, but effects on warm water fish are poorly understood (Waters, 1995). It is known that excessive sediment in suspension can lead to clogging of gills and excessive sediment deposition can damage benthic organisms, but quantitative relationships to define harmful levels for warm water species are not generally available. It is also known that too little sediment in transport can lead to bed and bank erosion and subsequent harm to benthic communities, such as that sometimes occurring below dams, and deprivation of downstream areas of needed sediment (e.g., Boesch, et al., 1994).

Since aquatic life impairment has not been quantitatively linked to sediment concentrations or deposition rates for warm water species, a reference condition approach is used for this TMDL, and it is expressed as an acceptable range of sediment loadings at the effective discharge. For purposes of this TMDL, the narrative standard and the stable stream concept for the region has been interpreted to mean an allowable sediment yield of between 0.6 and 1.6 (metric) tons/km<sup>2</sup>-day at the effective discharge. (Simon, Bingner, and Langendoen, 2002 and Simon, Kuhnle, and Dickerson, 2002)

Sediment transport generally increases with increasing discharge, but the highest (flood) discharges occur only occasionally. The commonly used condition to characterize typical sediment transport in a stream is the effective discharge – a flow with a statistical recurrence interval of 1.5 years (Simon, Bingner, and Langendoen, 2002). If the sediment target applicable for sediment in the Big Sunflower River is maintained during typical conditions of effective discharge, then the health of the stream should improve.

### 3. SOURCE ASSESSMENT

The TMDL evaluation summarized in this report examined all known potential impairment-causing sources in the Big Sunflower River Watershed. The source assessment is provided as an indication of what sources might be reduced to reach the reduction goals outlined in this report.

#### 3.1 Assessment of Point Sources

Point sources considered under this TMDL are listed in Table iv. Those discharging directly into the modeled portions of the Big Sunflower River were assumed to be discharging at their permitted rates and loadings; whereas, loadings from those sources discharging into tributaries were assumed to be included in the tributary loadings as described below. (Martin et al., 2003)

Directly modeled point sources and their loading rates are listed in Table 2. Locations are shown by model section.

The Total Suspended Solids (TSS) contribution from NPDES permitted facilities was considered negligible in the development of this TMDL. The TSS component of any NPDES permitted facility is not the pollutant addressed within this TMDL. The TSS material of concern for this TMDL is sediment from land runoff and in-channel processes.

**Table 2. Modeled Point Sources Loadings**

		Clarksdale POTW	Doddsville POTW	Indianola POTW	Delta Pride Cattfish, Indianola Plant	Roundway Elementary School	Southfish Farms, LLC	Sunflower POTW
	Section	1	2	2	2	1	2	2
NH3	kg/day	94.67	0.53	3.79	87.01	NA	0.47	0.04
NO3	kg/day	2.15	0.01	0.74	0.11	NA	0.02	0.01
PO4	kg/day	8.31	1.21	27.93	26.29	NA	0.23	0.73
CHI-a	kg/day	0.00	0.00	0.00	0.00	NA	0.00	0.00
CBODU	kg/day	1306.48	19.60	326.62	881.87	NA	229.94	94.07
DO	kg/day	113.61	0.00	0.00	0.00	NA	0.00	0.00
Org-N	kg/day	29.12	4.16	54.38	3.22	NA	0.73	3.27

### 3.2 Assessment of Nonpoint Sources

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

The hydrologic model HSPF used in the present study has the capability of predicting loadings of water quality constituents, but that capability was not used in determining this TMDL because sufficient data did not exist to allow an adequate calibration of such a model. Instead, available data were evaluated to determine typical yields and flow response relationships, which along with the predicted hydrologic flows were used to compute non-point source loadings. Table 3 shows the computed flows.

**Table 3. Flows for several events**

	Areas (Acres)	Discharge, ft <sup>3</sup> /s				Base Flow
		5-year	2-year	1.5-year	1.25-year	
Storm at Sunflower ->		8640.00	6383.00	5440.00	4650.00	15.50
Black B.	40522	562.96	287.74	198.18	147.07	1.80
Mound B.	80570	1557.83	1025.42	812.83	674.96	1.08
Jones B.	28894	558.75	367.79	291.54	242.09	0.39
Dougherty + Burrel B.	62611	1210.65	796.89	631.68	524.54	0.84
Lead B.	6478	125.26	82.45	65.36	54.27	0.09
Hushpuckena R.	87386	981.12	874.28	820.04	779.08	3.65
Harris + Clark B.	19761	336.51	299.64	280.93	266.81	1.37
Clarksdale	115302	1627.05	1448.77	1358.31	1290.03	6.63
Quiver R.	333811	4902.30	2912.06	2180.39	1729.82	182.00
Bogue Phalia R.	411289	5387.41	2879.06	2032.67	1538.58	20.20

Available water quality data and associated flows were compiled from several sources, including the DEQ, USACE, and web- and print-published literature (U. S. Geological Survey, 2003b; FTN, 2001; Tetra Tech, 1999; NRCS, 1998; Shindala et al., 1998; USACE, 1996; and Parker and Robinson, 1972.) Table 4 lists the parameters extracted from these sources along with the number of data points for each. The data were analyzed by standard procedures in order to obtain information suitable for use in the water quality modeling described in Part 4 of this report. Simple statistical parameters of mean, standard deviation, etc. were computed using built-in EXCEL spreadsheet functions. For details, see Martin et al. (2003). Summary results are given in Table 5.

Table 4. Number of Water Quality Parameter Data Points.

Parameter	Abbreviation	Number of Samples			
		All	Big Sunflower	Bogue Phalia	Quiver
Temperature	Temp	923	712	58	58
Dissolved Oxygen	DO	876	686	53	53
Biological Oxygen Demand	BOD	169	18	57	57
Chemical Oxygen Demand	COD	298	148	54	54
Total Kjeldahl Nitrogen	TKN	908	647	81	81
Total Phosphorous	TP	633	390	79	79
Dissolved Phosphorous	P Dissolved	362	218	55	55
Phosphate	OPO4	169	100	26	26
Nitrate	NO3	594	401	63	63
Ammonia	NH3	427	199	75	75
Total Organic Carbon	TOC	292	102	58	58
Turbidity	NTU	314	255	41	18
Suspended Solids	TSS	593	372	91	81

**Table 5. Water Quality Parameter Statistics (mg/l, except as noted).**

Parameter	All Samples		Big Sunflower		Bogue Phalia		Quiver	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Temp (deg C)	19.7	8.0	19.5	8.0	22.3	8.5	22.3	7.3
DO	7.6	3.5	7.6	3.6	8.3	3.2	6.5	3.2
BOD	7.6	6.7	18.5*	9.5*	5.5	3.6	6.6	7.1
COD	23.8	11.8	22.3	11.4	21.0	9.8	25.5	11.1
TKN	1.65	0.97	1.57	0.87	1.85	1.21	2.03	1.26
TP	0.61	0.65	0.66	0.77	0.48	0.30	0.54	0.43
P Diss	0.24	0.27	0.19	0.22	0.28	0.16	0.30	0.37
OPO4	0.20	0.16	0.16	0.10	0.18*	0.15*	0.19*	0.14*
NO3	0.60	0.68	0.75	0.77	0.32	0.31	0.26	0.17
NH3	0.44	0.58	0.32	0.33	0.54	0.72	0.56	0.76
TOC	8.9	5.1	8.7	6.5	9.8	5.1	9.2	3.2
NTU	262	341	273	359	200	254	235*	224*
TSS	151	183	128	168	160	181	236	236

Note: \* Small sample size makes value less reliable.

### 3.2.1 Organic Enrichment and Dissolved Oxygen

Nonpoint loading of nutrients and biochemical oxygen demand in a water body results from the transport of the pollutants into receiving waters by overland surface runoff and groundwater infiltration. Land use activities within the drainage basin, such as agriculture and urbanization contribute to nonpoint source loading. Other nonpoint pollution sources include atmospheric deposition and natural weathering of rocks and soil.

For the modeling described in Part 4, the parameter values in Table 5 for the Big Sunflower River were used for the upper end of the modeled river and for all tributaries other than the Bogue Phalia and Quiver Rivers. The BOD value of 18.5 was used, even though it is based on only 18 samples and is more than twice as large as the overall average, since the critical period is late summer to early fall and those values were representative of that period.

### 3.2.2 Sediment

Nonpoint loading of sediment in a water body results from the transport of the material into receiving waters by the processes of mass wasting, head cutting, gullying, and sheet and rill erosion. Sources of sediment include in-stream sources (bank and bottom erosion) plus surface erosion from areas with:

- Agriculture
- Silviculture
- Rangeland
- Construction sites
- Roads
- Urban areas
- Mass wasting areas
- Gullies
- Surface mining

Given the land use distribution shown in Table 1, surface erosion and gully erosion from agricultural lands are the most probable sources of nonpoint sediment supply. Cropland sediment yields for the Big Sunflower basin are reported to average about 3 tonnes/km<sup>2</sup>-day for conventional tillage and 0.2 tonnes/km<sup>2</sup>-day for conservation tillage (Schreiber, et al., 2001). Forested areas that are subject to silviculture activities may exhibit elevated sediment contributions if Voluntary Best Management Practices for Forestry in Mississippi are not implemented. Martin et al. (2003) showed that the relationship between TSS and river discharge in the Big Sunflower Basin could be represented by:

#### Equation 1

$$TSS = 372.48 \left( \frac{Q}{Q_r} \right)^{0.4024}$$

where  $TSS$  is in mg/l,  $Q$  = river discharge in cfs, and  
 $Q_r$  = reference river discharge, given by:

#### Equation 2

$$Q_r = 35A^{5/6}$$

where  $A$  is the area (in sq mi) of the drainage basin tributary to the measurement point.

These equations were used to specify tributary contributions of TSS at every inflow point in the model described in Part 4 for the critical flow (1.5-year recurrence interval). Analysis of the error between observations and values predicted by these equations showed a root mean square error of 178 mg/l, and a relative root mean square error of 1.69 times the predicted value. (Martin et al., 2003) Bank erosion was determined to be a negligible contributor to TSS in the Big Sunflower River (Martin et al., 2003).

## **4. MODELING PROCEDURE: LINKING THE SOURCES TO THE ENDPOINT**

Establishing the relationship between the in-stream 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 water body 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**

The modeling framework employed in the present study consisted of five integrated efforts – characterization of: hydrologic flows, non-point source loadings, point source flows and loadings, in-stream hydraulics, and in-stream water quality. A brief overview is provided below, and each effort and its implementation are described in detail in following sections.

Hydrologic models and methods were employed to estimate the non-point source flows, which were combined and assigned to hydraulic simulations at the terminus of major contributing tributaries. Point source loadings flowing directly into the Big Sunflower River were explicitly modeled.

#### **4.1.1 Previous Modeling**

Mississippi State University (MSU) completed a hydrodynamic and water quality modeling study of the Big Sunflower in 1998 for MDEQ (Shindala et al., 1998). The DYNHYD hydrodynamic model and WASP water quality model were applied to three reaches of the Big Sunflower extending from above Clarksdale (IRM 190) to a low-head dam (at URM 54.01) approximately one-half mile south the Highway 12 bridge between Belzoni and Hollandale. The model segmentation included selected tributary segments (including Bogue Phalia, which is listed as impaired) as well as the main-stem river. The hydrodynamic and water quality models were validated against data collected during 1997. The hydrodynamic model was also applied and tested using conditions occurring in 1993. The water quality model was validated to existing data for eight state variables

Recently, the U. S. Army Corps of Engineers updated an existing one-dimensional HEC-RAS (HEC, 2001) model of the Big Sunflower for use in flood damage reduction studies.

A previous hydrologic modeling effort (Tetra Tech, 1999) produced a discretized nonpoint source model of the Big Sunflower watershed using the Hydrological Simulation Program-Fortran (HSPF)



#### **4.1.2 Present Modeling**

In this effort the modeling was based upon the refinement and application of these existing models and data, including:

- The existing non-point source model as developed by Tetra-Tech and applied to the Big Sunflower watersheds
- Existing data for development of flow response relationships for tributary loadings
- Existing non-point source data
- Existing hydraulic models as developed by the U.S. Corps of Engineers District-Vicksburg and as part of previous studies by Mississippi State University
- Existing water quality models developed as part of previous studies by Mississippi State University

Descriptions of the models are given by Martin et al. (2003).

#### **4.2 Model Application**

The existing models and data were used to develop steady-state responses between loadings of nutrients/organic materials and dissolved oxygen concentrations and between sediment loads and in-stream concentrations for comparison with applicable standards and determination of the TMDL for each impaired segment.

Water quality variations are integrally linked with hydraulic variations, such as variations in flows, depths, and velocities. For the present study, a hydraulic model was employed to predict variations in hydraulic characteristics as a function of inflows, geometric characteristics and bottom roughness characteristics. The model was used to predict hydraulic characteristics as a function of steady state flow conditions.

A water quality model was employed to integrate the flows, loads, hydraulic characteristics and kinetic interactions and to relate the impact of loads, and changes in those loads, on in-stream water quality.

The present modeling differed from the previous work by Shindala et al. (1998) in that a steady-state framework was employed. Constant non-point and point-source flows and loads were computed. A steady-flow hydraulic model was employed to compute hydraulic characteristics for a series of flow conditions ranging from a base flow to a two-year event. The water quality model was run dynamically, with constant flows and forcings, until steady state predictions were obtained. The steady-state predictions were then used to evaluate existing conditions for comparison with water quality criteria and for determination of the TMDLs.

The models developed in this study were used to develop relationships between flows and loads for two recognized impairments of the Big Sunflower River: sedimentation and organic/nutrient enrichment as related to dissolved oxygen concentrations. The specific

details of the model components and the implementation of the modeling framework are described by Martin et al. (2003).

The Big Sunflower River was modeled in three separate sections, with outflow conditions in one section serving as inflow conditions for the next downstream section. The sections were:

- Section 1: from Clarksdale, River Mile (RM: 190.00) to the culverts bridge (RM: 164.15) near Roundaway.
- Section 2: from the culverts bridge (RM:164.15) to the inactive Lock and Dam (weir) near Highway 12 bridge (RM:54.01)
- Section 3: from Lock and Dam (RM:54.01) to the Little Sunflower River below the confluence of the Little Sunflower and old Sunflower Bendway (to the control structure on the Little Sunflower).

Note that some caution needs to be exercised in interpreting the locations of the reaches. Two river mile conventions are in use on the Big Sunflower: improved and unimproved. For consistency with the previous study by Shindala et al. (1998), the unimproved river mile convention is used for sections 1 and 2, while the “improved” river mile convention is adapted for section 3, for consistency with the modeling by the Corps of Engineers District-Vicksburg.

### 4.3 Model Results

#### 4.3.1 Total Suspended Solids

Model results for TSS exhibit mean concentrations between about 225 mg/l and 325 mg/l. Table 6 shows the results for the impaired reaches.

**Table 6. TSS Results for Listed Reaches**

Listed Reach			Estimated Mean TSS, mg/l		
Name	RM Start	RM End	Start	End	Average
MSBIGSUNRM	193	183.4	331	326	328
MSBIGSUNRM2	110.4	93	264	261	262
MSBIGSUNRM3	93	61	261	241	251
MSBIGSUNRM4	61	0	241	228	234
MSBIGSUNRM5	189.3	186.2	331	328	330
MSHBCUTM	36.6	19.6	234	232	233
MS392M	--	61	--	218	218

The TSS model results of Table 6 can be converted to a corresponding suspended sediment yield by the expression:

**Equation 3**

$$Y_{1.5} = TSS_{1.5} \left( \frac{Q_{1.5}}{A_B} \right)$$

Where  $Y$  is the suspended sediment yield in mass per unit area per time,  $TSS$  is the sediment concentration,  $Q$  is the effective discharge, and  $A_B$  is the drainage area tributary to the location, and the subscript 1.5 indicates values for the effective 1.5 year event discussed earlier.

An estimate of the range of existing conditions sediment yield range for each impaired reach under the 1.5 year event is shown in Table 7. The high and low estimates correspond to the magnitude of the relative root-mean-square errors found in the analysis of TSS data by Martin et al. (2003) and are rounded to the nearest tenth.

**Table 7. Existing Sediment Yield**

Listed Segment	Discharge cfs	Basin Area sq km	Unit Yield, tonnes/km <sup>2</sup> -day		
			Mean	Low Estimate	High Estimate
MSBIGSUNRM	1358	280	3.9	2.1	10.5
MSBIGSUNRM2	5440	1987	1.8	0.9	4.7
MSBIGSUNRM3	7620	3337	1.4	0.7	3.8
MSBIGSUNRM4	9650	5001	1.1	0.6	3.0
MSBIGSUNRM5	1358	280	3.9	2.1	10.5
MSHBCUTM	9653	7177	0.8	0.4	2.1
MS392M	2033	1664	0.7	0.3	1.8

**4.3.2 Ammonia and Dissolved Oxygen**

Model results for ammonia and DO are shown in Charts 1 - 9 for the augmented base flow condition. They show that lowest predicted dissolved oxygen concentrations occurred in lower portions of Section 2 and in Section 3 along the Big Sunflower in the vicinity of Holly Bluff Cutoff. The lower concentrations in these sections reflect, in part, the influence of the weirs in these sections of the river. Lowest predicted dissolved oxygen concentrations occurred under the low or base flow condition. Predicted dissolved oxygen concentrations for the 1.25 to 2-year events remained relatively high and constant throughout the River. (Martin et al. 2003)

In Section 1 total ammonia predictions were less than 2.5 mg/l for all but the non-augmented base flow. For Section 2 total ammonia predicted concentrations remained below 1.8 mg/l for all conditions simulated. In Section 3 of the Big Sunflower, which did not receive loadings except from the upstream boundary (the outflow from Section 2), concentrations of ammonia decreased in a downstream direction so that the predicted concentrations approached zero by the end of the Section (at the Little Sunflower control structure).

## **5. ALLOCATION**

The allocation for this Phase 1 TMDL involves a wasteload allocation for point sources and a load allocation for nonpoint sources necessary for attainment of water quality standards in segments MS392M, MSBIGSUNRM, MSBIGSUNRM2, MSBIGSUNRM3, MSBIGSUNRM4, MSBIGSUNRM5, and MSHBCUT. Allocations were developed for dissolved oxygen as impacted by organic enrichment and nutrients as well as total suspended solids.

### **5.1 Organic enrichment/low dissolved oxygen and nutrients**

The assessment of the impact of organic enrichment/nutrients on dissolved oxygen concentrations in impaired segments of the Big Sunflower was based upon the assumed critical condition, which included the present flow augmentation of 30 cfs. In addition, conditions were evaluated including no flow augmentation and an augmentation of 40, 50 and 60 cfs in order to estimate the combined impact of flow augmentation and load reductions on dissolved oxygen concentrations. Therefore, wasteload and load allocations as described below were developed for each of these flow augmentation strategies for each of the impaired segments listed above. As indicated previously, dissolved oxygen impairment was only predicted in segments MSBIGSUMRM2 and MSHBCUT.

#### **5.1.1. Segments MSBIGSUNRM and MSBIGSUNRM5**

The impaired segments considered here include: MSBIGSUNRM, extending from the Lyons POTW to Hopson, and MSBIGSUNRM5, extending from the confluence of the Big Sunflower River with the Little Sunflower River to the lowhead dam above the Clarksdale POTW. Since these two segments overlap and both are included in the modeled Section 1, they will be evaluated together.

Neither of these segments were predicted to be impaired, in that predicted dissolved oxygen concentrations remained above 5 mg/l for all scenarios simulated. However, the output loadings from these segments can impact the predicted DO concentrations in the lower river such as the low DO predictions above the Highway 12 weir, which is the basis for the wasteload and load allocations described herein.

Discharges to segment MSBIGSUNRM and MSBIGSUNRM5 include the headwater to this segment and a two NDPEs permitted facilities, the Clarksdale POTW and the Clarksdale wells, which are used in providing the flow augmentations evaluated in the modeling study, as tabulated in Table 8. Note that the present model did not extend to above RM 190 at Clarksdale, so that the specific impact of the Lyons POTW and Little Sunflower could not be explicitly evaluated, and these sources are assumed to be implicitly included in the headwater loads.

**Table 8. Load scenario for MSBIGSUNRM and MSBIGSUMRM5, critical conditions**

	Base Flow	Base + 30 cfs	Base + 40 cfs	Base + 50 cfs	Base + 50 cfs
Headwater Inflow (cfs)	6.6	6.6	6.6	6.6	6.6
Headwater Inflow (cms)	0.19	0.19	0.19	0.19	0.19
NH3 (mg/L)	0.32	0.32	0.32	0.32	0.32
NBODu (mg/l)	1.46	1.46	1.46	1.46	1.46
CBODu (mg/L)	27.7	27.7	27.7	27.7	27.7
NBODu (kg/day)	23.6	23.6	23.6	23.6	23.6
CBODu (kg/day)	448.0	448.0	448.0	448.0	448.0
Clarksdale Wells (cfs)	0.0	30.0	40.0	50.0	60.0
Clarksdale Wells (cms)	0.00	0.85	1.13	1.42	1.70
NH3 (mg/L)	0.0	0.0	0.0	0.0	0.0
NBODu (mg/l)	0.0	0.0	0.0	0.0	0.0
CBODu (mg/L)	0.0	0.0	0.0	0.0	0.0
NBODu (kg/day)	0.0	0.0	0.0	0.0	0.0
CBODu (kg/day)	0.0	0.0	0.0	0.0	0.0
Clarksdale POTW flow (mgd)	5.0	5.0	5.0	5.0	5.0
NH3 (kg/day)	94.60	94.60	94.60	94.60	94.60
NBODu (kg/day)	432.3	432.3	432.3	432.3	432.3
CBODu (kg/day)	1305.60	1305.60	1305.60	1305.60	1305.60
TBODu (kg/day)	2209.6	2209.6	2209.6	2209.6	2209.6

**5.1.1.1. Wasteload Allocation**

The present recommendation is for no overall load reductions, or load increases, for the NPDES Permitted facilities discharging to this impaired segment. There was no predicted impairment in this segment. However, it is recommended that these predictions be reevaluated in the future to insure that model predictions accurately reflect existing conditions. For example, the hydraulic model did not include the lowhead dam as described for MSBIGSUMRM5, which could potentially impact the retention time, and dissolved oxygen characteristics of this section of the river.

Loads from this segment are predicted to impact downstream impaired segments, such as MSBIGSUNRM4. While the contribution of these permitted sources to the predicted dissolved oxygen deficit in that segment is small (less than 0.1 mg/l DO), the contribution increases with flow rate. Therefore, increases in loading rates could potentially increase the impact of these loads, which should be evaluated in the context of all contributing loadings to this segment and flow augmentation strategies. It is concluded that major changes to loads should not be made until further study of the condition of Big Sunflower River during critical conditions can be conducted, and strategies developed for implementing load reductions for all sources. At the present time it is recommended that the existing facilities take steps to ensure that they remain in compliance with their permit limits.

**5.1.1.2. Load Allocation**

For reasons cited above, it is recommended that no overall load reductions, or load increases, be implemented for non-point sources discharging to this segment.

**5.1.2. Segment MSBIGSUNRM2**

Segment MSBIGSUNRM2, extending on the Big Sunflower River from the confluence with Jones Bayou (RM 110.4) to the confluence with Porter Bayou (RM 93) was not predicted to be impaired, in that predicted dissolved oxygen concentrations remained above 5 mg/l for all scenarios simulated. However, the output loadings from this segment impact the predicted DO concentrations in the lower river such as the low DO predictions above the Highway 12 weir (MSBIGSUNRM4). Since loads from a river segment should not result in impairment in a downstream impaired reach, load reductions are required.

Discharges to segment MSBIGSUNRM2 include the headwater to this segment, the Jones Bayou tributary, and a single NPDES permitted discharge, from the Sunflower POTW. Inflows and loads to this segment for each of the critical flow conditions evaluated are tabulated in Table 9.

**Table 9. Load scenario for MSBIGSUNRM2, critical conditions**

	Base Flow	Base +30 cfs	Base +40 cfs	Base +50 cfs	Base +50 cfs
Headwater Inflow (cfs)	23.2	53.2	63.2	73.2	83.2
Headwater Inflow (cms)	0.66	1.51	1.79	2.07	2.36
NH3 (mg/L)	0.36	0.29	0.27	0.25	0.23
NBODu (mg/l)	1.7	1.3	1.2	1.1	1.1
CBODu (mg/L)	12.0	9.2	8.3	7.6	6.9
NBODu (kg/day)	94.1	173.6	191.1	204.4	215.6
CBODu (kg/day)	677.6	1202.0	1289.6	1358.8	1409.1
Jones Bayou Inflow (cfs)	0.4	0.4	0.4	0.4	0.4
Jones Bayou Inflow (cms)	0.01	0.01	0.01	0.01	0.01
NH3 (mg/L)	0.32	0.32	0.32	0.32	0.32
NBODu (mg/l)	1.5	1.5	1.5	1.5	1.5
CBODu (mg/L)	27.74	27.74	27.74	27.74	27.74
NBODu (kg/day)	1.4	1.4	1.4	1.4	1.4
CBODu (kg/day)	26.4	26.4	26.4	26.4	26.4
Sunflower POTW flow (mgd)	0.24	0.24	0.24	0.24	0.24
NH3 (kg/day)	0.04	0.04	0.04	0.04	0.04
NBODu (kg/day)	0.2	0.2	0.2	0.2	0.2
CBODu (kg/day)	94.07	94.07	94.07	94.07	94.07
TBODu (kg/day)	893.7	1497.7	1602.6	1685.1	1746.7

**5.1.2.1. Wasteload Allocation**

A single NPDES Permitted facility is located in this segment and included in the wasteload allocation, as shown in Table 10. The loads given in Table 10 are equal to the load reduction scenarios for the critical condition, along with four alternative flow augmentations. An overall reduction ranging from 50 to 80% of the permitted TBODu load, as a function of flow augmentation is needed in order for the model to show compliance with the TMDL endpoint at the downstream segment (MSBIGSUNRM4), if all other sources are similarly reduced.

**Table 10. Wasteload Allocation, Segment BIGSUNRM2**

Sunflower POTW flow (mgd)	0.24	0.24	0.24	0.24	0.24
NH3 (kg/day)	0.04	0.04	0.04	0.04	0.04
NBODu (kg/day)	0.2	0.2	0.2	0.2	0.2
CBODu (kg/day)	18.81	32.92	42.33	47.03	47.03
TBODu (kg/day)	19.0	33.1	42.5	47.2	47.2
% Reduction	80%	35%	45%	50%	50%

Federal regulations require that effluent limits developed to protect water quality criteria be consistent with the assumptions and requirements of any available wasteload allocation for the discharge prepared by the state and approved by EPA. Due to economic and environmental considerations in the watershed, MDEQ will stage the implementation of this TMDL. This TMDL recommends a 5-year compliance schedule be included in the NPDES permit of each NPDES Permitted facility in the watershed. The compliance schedule should require each facility to meet permit limits during the first four years of the permit. Prior to the end of the fifth year of the permit, the compliance schedule will require each facility to meet limits as determined by the state necessary to meet whatever applicable water quality standards that are in place at that time. Load reductions from this facility in isolation are insufficient to remove the predicted impairment in the downstream segment (MSBIGSUNRM4). For example, the predicted contribution to the deficit in that reach due to this facility alone is less than 0.1 mg/l. At the present time it is recommended that the existing facility take steps to ensure that they remain in compliance with their permit limits.

**5.1.2.2. Load Allocation**

Non-point sources to this segment include headwater loads at the upper extremity of the segment and the contributions of Jones Bayou, both of which are included in the load allocation tabulated in Table 11. The loads given in Table 11 are equal to the load reduction scenarios for the critical condition, along with four alternative flow augmentations. An overall reduction ranging from 46 to 85% of the non-point source load is needed in order for the model to show compliance with the TMDL endpoint at the downstream segment (MSBIGSUNRM4), if all other sources are similarly reduced.

**Table 11. Load Allocation, segment BIGSUNRM2**

	Base Flow	Base + 30 cfs	Base + 40 cfs	Base + 50 cfs	Base + 50 cfs
Headwater Inflow (cfs)	23.2	53.2	63.2	73.2	83.2
Headwater Inflow (cms)	0.66	1.51	1.79	2.07	2.36
NH3 (mg/L)	0.36	0.29	0.27	0.25	0.23
NBODu (mg/l)	1.64	1.33	1.23	1.14	1.06
CBODu (mg/L)	0.40	2.77	3.46	3.58	3.29
NBODu (kg/day)	93.2	173.4	190.9	204.2	215.5
CBODu (kg/day)	22.9	360.2	534.1	641.0	668.9
Jones Bayou Inflow (cfs)	0.4	0.4	0.4	0.4	0.4
Jones Bayou Inflow (cms)	0.01	0.01	0.01	0.01	0.01
NH3 (mg/L)	0.32	0.32	0.32	0.32	0.32
NBODu (mg/l)	1.5	1.5	1.5	1.5	1.5
CBODu (mg/L)	5.55	9.71	12.48	13.87	13.87
NBODu (kg/day)	1.4	1.4	1.4	1.4	1.4
CBODu (kg/day)	5.3	9.2	11.9	13.2	13.2
TBODu (kg/day)	122.8	544.2	738.3	859.8	899.0
% Reduction	85%	61%	51%	46%	46%

Federal regulations require that effluent limits developed to protect water quality criteria be consistent with the assumptions and requirements of any available wasteload allocation for the discharge prepared by the state and approved by EPA. Due to economic and environmental considerations in the watershed, MDEQ will stage the implementation of this TMDL. This TMDL recommends a 5-year compliance schedule be included in the NPDES permit of each NPDES Permitted facility in the watershed. The compliance schedule should require each facility to meet permit limits during the first four years of the permit. Prior to the end of the fifth year of the permit, the compliance schedule will require each facility to meet limits as determined by the state necessary to meet whatever applicable water quality standards that are in place at that time. Load reductions from these sources in isolation are insufficient to remove the predicted impairment in the downstream segment (MSBIGSUNRM4). For example, the elimination of loads from the upstream source and Jones Bayou alone are not sufficient to remove the predicted impairment.

### 5.1.3. Segment MSBIGSUNRM4 and MSHBCUT

Two impaired segments are located on the lower portion of the Big Sunflower River,

- MSBIGSUNRM4, extending from the confluence of the Bogue Phalia to the Yazoo, and
- MSHBCUT, extending from near Anguilla from Chappel landing to Holly Bluff.

Note that in actuality, as discussed in Martin et al. (2003), the Big Sunflower does not discharge directly into the Yazoo River. For the purposes of this study, the lower reach



extended through the Little Sunflower control structure (Section 3, Martin et al. 2003). This reach includes sections of the Big Sunflower River, Little Sunflower, Old Sunflower Bendway and Holly Bluff cutoff (MSHBCUT), all of which are hydraulically connected. There are no permitted point sources discharging directly to this section of river, and no contributing tributaries with significant flows during low flow periods.

Modeling studies of the Big Sunflower River included sections extending from above Clarksdale (RM 190) to the Little Sunflower Control Structure. Of the sections of the river simulated, the only sections predicted to have dissolved oxygen concentrations below 5 mg/L were within these two impaired segments. For the critical conditions simulated, dissolved oxygen concentrations of less than 5 mg/l were predicted for the portion of the MSBIGSUMRM4 extending from below the confluence with the Bogue Phalia to the control structure (weir) located below Highway 12 (RM 54.01). For the critical conditions, dissolved oxygen concentrations of less than 5 mg/L were also predicted for the Holy Bluff cutoff (MSHBCUT). Since these sections of the river share the same upstream boundary source and are hydraulically connected they are considered together in this analysis. The upstream source loadings and loadings from the Bogue Phalia are tabulated in Table 12.

**Table 12. Load scenario for MSBIGSUNRM4 and MSHBCUT, critical conditions**

	Base Flow	Base + 30 cfs	Base + 40 cfs	Base + 50 cfs	Base + 60 cfs
Headwater Inflow (cfs)	205.6	235.6	245.6	255.6	265.6
Headwater Inflow (cms)	5.82	6.67	6.95	7.24	7.52
NH3 (mg/L)	0.39	0.38	0.37	0.37	0.36
NBODu (mg/l)	1.78	1.74	1.71	1.68	1.65
CBODu (mg/L)	7.6	7.8	7.7	7.6	7.5
NBODu (kg/day)	895.7	1001.5	1026.5	1049.0	1070.3
CBODu (kg/day)	3830.5	4486.8	4624.0	4746.3	4853.0
Bogue Phalia Inflow (cfs)	20.2	20.2	20.2	20.2	20.2
Bogue Phalia Inflow (cms)	0.57	0.57	0.57	0.57	0.57
NH3 (mg/L)	0.54	0.54	0.54	0.54	0.54
NBODu (mg/l)	2.5	2.5	2.5	2.5	2.5
CBODu (mg/L)	8.31	8.31	8.31	8.31	8.31
NBODu (kg/day)	122.2	122.2	122.2	122.2	122.2
CBODu (kg/day)	410.7	410.7	410.7	410.7	410.7
TBODu (kg/day)	5259.1	5488.4	5650.4	5795.3	5923.3

The influence of the control structures in this section of the river should be noted. The portion of MSBIGSUN4 predicted to be impaired is immediately upstream of a weir. The weir (located below the Highway 12 bridge at RM 54.01) produces a backwater with deeper water, lower velocities, and longer retention times, which contributes to DO depletions (less reaeration and longer exposure to sediment demands). For example, for the base + 30 cfs case, the predicted DO deficit immediately above the Highway 12 weir was approximately 3.0 mg/l for the case where there were no ammonia or CBODu loads to the River. The predicted saturation DO concentration was 9.1 mg/l. That is, in the absence of ammonia and CBODu loads, the predicted DO concentration would be

approximately 6.1 mg/l (9.1-3.0 mg/l), leaving only a remaining deficit of 1.1 mg/l above the standard or 5 mg/l. The Quiver River contributes approximately 1.2 mg/l to the deficit and the Bogue Phalia 0.1 mg/l, with a total deficit of approximately 1.8 mg/l for all ammonia and CBODu sources (point and non-point). The result is that disproportionately large reductions in point and non-point sources are required to remove the impairment, since the available deficit is small, due largely to the impact of the control structure. Similarly, the weir located at the bottom section of the Holly Bluff Cutoff (MSHBCUT) contributes to low water velocities and greater DO depletions in this impaired segment.

#### 5.1.4.1 Wasteload Allocation

No point sources discharging directly to these two segments were identified. Therefore, there is no wasteload allocation. However, there are point sources located upstream of MSBIGSUNRM4 which contribute to the headwater loadings.

#### 5.1.4.2. Load Allocation

Non-point sources to these segments include only the loads above the confluence of the Big Sunflower with the Bogue Phalia, both of which are included in the load allocation tabulated in Table 13. The loads given in Table 13 are equal to the load reduction scenarios for the critical condition, along with four alternative flow augmentations. An overall reduction ranging from 38 to 71% of the non-point source load is needed in order for the model to show compliance with the TMDL endpoint in segments MSBIGSUNRM4 and MSHBCUT.

**Table 13. Load Allocation, segments MSBIGSUNRM4 and MSHBCUT**

	Base Flow	Base + 30 cfs	Base + 40 cfs	Base + 50 cfs	Base + 60 cfs
Headwater Inflow (cfs)	205.6	235.6	245.6	255.6	265.6
Headwater Inflow (cms)	5.82	6.67	6.95	7.24	7.52
NH3 (mg/L)	0.39	0.38	0.37	0.37	0.36
NBODu (mg/l)	1.76	1.73	1.70	1.67	1.64
CBODu (mg/L)	0.85	2.30	3.13	3.52	3.48
NBODu (kg/day)	885.9	995.7	1021.9	1045.2	1066.9
CBODu (kg/day)	427.3	1326.2	1881.2	2198.3	2258.1
Bogue Phalia Inflow (cfs)	20.2	20.2	20.2	20.2	20.2
Bogue Phalia Inflow (cms)	0.57	0.57	0.57	0.57	0.57
NH3 (mg/L)	0.54	0.54	0.54	0.54	0.54
NBODu (mg/l)	2.5	2.5	2.5	2.5	2.5
CBODu (mg/L)	1.66	2.91	3.74	4.16	4.16
NBODu (kg/day)	122.2	122.2	122.2	122.2	122.2
CBODu (kg/day)	82.1	143.8	184.8	205.4	205.4
TBODu (kg/day)	1517.5	2587.9	3210.2	3571.0	3652.5
% Reduction	71%	53%	43%	38%	38%

Federal regulations require that effluent limits developed to protect water quality criteria be consistent with the assumptions and requirements of any available wasteload

allocation for the discharge prepared by the state and approved by EPA. Due to economic and environmental considerations in the watershed, MDEQ will stage the implementation of this TMDL. This TMDL recommends a 5-year compliance schedule be included in the NPDES permit of each NPDES Permitted facility in the watershed. The compliance schedule should require each facility to meet permit limits during the first four years of the permit. Prior to the end of the fifth year of the permit, the compliance schedule will require each facility to meet limits as determined by the state necessary to meet whatever applicable water quality standards that are in place at that time. In addition, consideration is recommended to attributing the predicted impairment in these segments to the presence of the hydraulic control structures, a source of pollution.

## **5.2 Sediment**

### **5.2.1 Wasteload Allocations**

The contribution from NPDES permitted facilities was considered negligible in the development of this TMDL. The Total Suspended Solids (TSS) component of any NPDES permitted facility is different from the pollutant addressed within this TMDL. The pollutant of concern for this TMDL is sediment from landuse runoff and in-channel processes.

Sediment loadings from NPDES regulated construction activities and Municipal Separate Storm Sewer Systems (MS4s) are considered point sources of sediment to surface waters. These discharges occur in response to storm events and are included in the WLA of this TMDL as the same target yield as the TMDL of 0.6 to 1.6 tonnes/km<sup>2</sup>-day at the effective discharge.

### **5.2.2. Load Allocation**

The load allocation for sediment is that sediment yield which, when combined with the margin of safety, will limit sediment yield equal to the required endpoint less a margin of safety. For an implicit margin of safety, the sediment yield load allocation is equal to the endpoint, or 0.6 to 1.6 tonnes/km<sup>2</sup>-day at the effective discharge. The estimated existing yield range of Table 8 overlaps this range. The unstable yield range is approximately the same as the target yield range, which indicates a reduction should not be necessary.

## **5.3 Incorporation of a Margin of Safety**

The margin of safety is a required component of a TMDL and accounts for the uncertainty about the relationship between pollutant loads and the quality of the receiving water body. 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 TMDL is implicit for DO and suspended sediment yield.

The implicit MOS for DO is based on conservative assumptions which place a higher demand of DO on the water body than may actually be present. For example, the assumed critical condition for which flows are low and constant (the base flow condition) through the entire waterbody is considered part of the margin of safety. Modeling the water body at this flow provides protection during the worst-case scenario.

The implicit MOS for sediment yield is based on the use of the reference reach concept for the targeted endpoint.

## 5.4 Calculation of the TMDL

The TMDL was calculated based on Equation 4.

### Equation 4

$$\text{TMDL} = \text{WLA} + \text{LA} + \text{MOS}$$

Where WLA is the wasteload allocation, LA is the load allocation, and MOS is the margin of safety.

### 5.4.1. Dissolved Oxygen/Organic Enrichment/Nutrients

#### 5.4.1.1. Segments MSBIGSUNRM and MSBIGSUNRM5

**Table 14. Phase 1 TMDL for TBODu, for critical conditions in segments MSBIGSUNRM and MSBIGSUNRM5.**

	WLA (kg/day)	LA (kg/day)	MOS	TMDL (kg/day)
Base Flow	1738	472	Implicit	2210
Base Flow + 30 cfs	1738	472	Implicit	2210
Base Flow + 40 cfs	1738	472	Implicit	2210
Base Flow + 50 cfs	1738	472	Implicit	2210
Base Flow + 60 cfs	1738	472	Implicit	2210

#### 5.4.1.2. Segment MSBIGSUNRM2

**Table 15. Phase 1 TMDL for TBODu, for critical conditions in segments MSBIGSUNRM2.**

	WLA (kg/day)	LA (kg/day)	MOS	TMDL (kg/day)
Base Flow	19	123	Implicit	142
Base Flow + 30 cfs	33	544	Implicit	577
Base Flow + 40 cfs	43	738	Implicit	781
Base Flow + 50 cfs	47	860	Implicit	907
Base Flow + 60 cfs	47	899	Implicit	946

**5.4.1.3. Segments MSBIGSUNRM4 and MSHBCUT**

**Table 16. Phase 1 TMDL for TBODu, for critical conditions in segments MSBIGSUNRM4 and MSHBCUT of the Big Sunflower River.**

	WLA (kg/day)	LA (kg/day)	MOS	TMDL (kg/day)
Base Flow	NA	1518	Implicit	1518
Base Flow + 30 cfs	NA	2588	Implicit	2588
Base Flow + 40 cfs	NA	3210	Implicit	3210
Base Flow + 50 cfs	NA	3571	Implicit	3571
Base Flow + 60 cfs	NA	3653	Implicit	3653

**5.4.2. Sediment**

The TMDL calculations for sediment yield at the effective discharge are shown in Table 17.

**Table 17. TMDL Allocation for Sediment Yield, tonnes/km<sup>2</sup>-day**

WLA*	LA*	MOS	TMDL
0.6 – 1.6	0.6 – 1.6	Implicit	0.6 – 1.6

Note: \* At the effective discharge and See section 5.2

**5.5 Seasonality**

The use of data collected throughout the year at many stations in the ecoregion to set the target addresses seasonal variation. Instantaneous flow and suspended sediment data were used to develop the TMDL targets for each ecoregion. These data were collected throughout the year and would account for all seasons of the calendar year, changing atmospheric conditions (including rainy and dry seasons and high and low temperatures), and the periods representative of critical conditions.

## **6. CONCLUSION**

This TMDL is based on a modeling framework consisting of five integrated efforts—characterization of: hydrologic flows, non-point source loadings, point source flows and loadings, in-stream hydraulics, and in-stream water quality. Hydrologic models and methods, based on the HSPF model, were employed to estimate the non-point source flows, which were combined and assigned to hydraulic simulations at the terminus of major contributing tributaries. Point source loadings flowing directly into the Big Sunflower River were explicitly modeled. Steady-flow hydraulic models, utilizing the HEC-RAS simulation program, were employed to route the inflows and estimate resulting hydraulic characteristics (e.g. depths, velocities, volumes). A water quality model (WASP) was used, run to steady-state, to integrate the existing flows and loadings and estimate the impacts of those flows and loadings on water quality. The studies were based in part, on previous modeling studies by Mississippi State University as reported by Shindala et al. (1998) and hydraulic studies provided by the USACE District-Vicksburg. A detailed description of the model applications is given by Martin et al. (2003).

While the modeling framework is applicable to simulating dynamic conditions, it was only applied in this effort to predict steady-state conditions. The primary constraint on the application, and reason for the steady-state application, was due to the limited available data. The method by which the modeling framework was applied also places constraints upon its use. For example, without further data and model calibration, the present modeling system cannot be used to evaluate the impact of alternative management practices on non-point source loadings. The modeling framework can readily be extended to a dynamic model application should it become necessary, and should data become available to support such an application. Such an application would aid in ensuring that the overall loads of sediments and TBOD<sub>u</sub> placed in this waterbody from point and non-point sources do not exceed the water body's assimilative capacity.

### **6.1 Organic Enrichment/Dissolved Oxygen and Nutrients**

For organic enrichment/dissolved oxygen and nutrients, impairments were predicted in two of the five segments evaluated (MSBIGSUNRM4 and MSHBCUT), and TMDLs were established to remove the predicted impairments in these segments.

In addition to evaluating load reductions, flow augmentation was considered as an alternative. Presently, flows in the Big Sunflower are augmented by an inflow of approximately 30 cfs to MSBIGSUNRM5 in order to maintain a minimum flow of approximately 50 cfs at Sunflower, MS (USGS Gage No. 07288500). Flows evaluated included a no-flow augmentation, with additional augmentations to 40, 50 and 60 cfs. Model predictions suggested that flow augmentation alone was insufficient to remove the predicted impairment.

While TMDLs for maintaining or decreasing existing loads were established for each of the potential flow conditions, model predictions further suggested that reducing or

eliminating the loads to upstream-impaired segments alone was insufficient to remove the predicted impairment. That is the majority of the TBODu loads from upstream sources occurred between the upstream segments and those predicted to be impaired (such as from the Quiver River). As a result, reductions of these NPS loads located between, for example MSBIGSUNRM2 and MSBIGSUNRM4 alone or in conjunction with upstream load reductions would be required to remove the predicted impairment. Federal regulations require that effluent limits developed to protect water quality criteria be consistent with the assumptions and requirements of any available wasteload allocation for the discharge prepared by the state and approved by EPA. Due to economic and environmental considerations in the watershed, MDEQ will stage the implementation of this TMDL. This TMDL recommends a 5-year compliance schedule be included in the NPDES permit of each NPDES Permitted facility in the watershed. The compliance schedule should require each facility to meet permit limits during the first four years of the permit. Prior to the end of the fifth year of the permit, the compliance schedule will require each facility to meet limits as determined by the state necessary to meet whatever applicable water quality standards that are in place at that time.

For organic enrichment/dissolved oxygen and nutrients, the DO predicted impairments for the two segments evaluated (MSBIGSUNRM4 and MSHBCUT) resulted in part from hydraulic control structures located within these segments. For example, in MSBIGSUNRM4 a weir (located below Highway 12) results in increased predicted depths and decreased velocities (decreased reaeration), and increased retention time (greater impacts of sediment oxygen demand). The combined impact in MSBIGSUNRM4, for the base flow critical condition, was a predicted utilization of approximately 75 % of the available DO deficit in the absence of external TBODu loads, providing little remaining assimilative capacity for those external loads.

A weir located in the Holly Bluff Cutoff (MSHBCUT) similarly impacts flows and DO depletions in that segment. Since the utilization of the majority of the available DO deficit results, in part, from the presence of the hydraulic control structures, or man-induced channel modifications, the man-induced channel modifications can be considered a type of pollution. The term pollution is used to describe man-induced activities that may cause a water body to occasionally not attain water quality standards such as weirs and channelization. A pollutant is a particular substance that causes impairment of a water body, such as nutrients or organic material. TMDL development is not required for water bodies impaired due to pollution. It is recommended that the cause of impairment for these segments be reclassified as a pollution cause for this waterbody.

The model studies also indicated a need for future modeling efforts to address potential impacts of algal growth in the river. Although known to impact water quality in the Big Sunflower, sufficient data were not available to support such an application at this time. It is suggested that the modeling framework developed in this study be expanded to include simulation of algae should data become available to support such an application.

The modeling studies indicated a need for additional studies related to MSBIGSUNRM4 and MSHBCUT. The flows in these reaches are complicated by the presence of weirs

and operation of a downstream control structure (the Little Sunflower control structure). In addition, below the Highway 12 weir, the river consists of a series of hydraulically connected channels, including the Big Sunflower River, Holly Bluff cutoff, the six-mile cutoff, the Old Sunflower Bendway and Little Sunflower River. The interactions of these connected channels under low flow conditions needs further investigation. In addition, under low flow conditions, simulations indicate that the upper portion of the Little Sunflower River is not hydraulically connected to the other river reaches (as a result of a sill located near the head of this section of river). As a result, under low flow conditions this section of River would only be impacted by downstream backwater conditions, which could lead to stagnation and DO depletions. The impact of this was not adequately analyzed in the present modeling study and required further investigation to determine the degree of impairment and causal factors.

## **6.2 Sediment**

Analysis of data and modeling showed that existing sediment yields in areas tributary to the reaches listed as impaired by sedimentation, siltation, and/or turbidity range from 0.3 to 10.5 (metric) tonnes/km<sup>2</sup>-day, which overlays the range of target yields identified for stable streams in the ecoregion. The unstable yield range is approximately the same as the target yield range, which indicates a reduction should not be necessary.

## **6.3 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 year-long cycle, MDEQ's resources for water quality monitoring will be focused on one of the basin groups. During the next monitoring phase in the Yazoo Basin, the Big Sunflower River Watershed will receive additional monitoring to identify any change in water quality.

Additional monitoring will also be conducted in Big Sunflower in order to provide an improved data set for calibration of the water quality model used to develop the phase 1 TMDL, or for implementation of a dynamic (continuous) simulation model extended to include river reaches upstream of Clarksdale. Parameters such as flow, water velocity, and background concentrations of TSS, CBOD<sub>u</sub>, NH<sub>3</sub>-N, and other nutrients during the critical modeling period would be beneficial, for both in-stream samples and NPS sources. Algae were not simulated in the present modeling study (due to a lack of data), although they are known to impact water quality in the River, Measurements of rates of CBOD<sub>u</sub> decay, algal photosynthesis and respiration, chlorophyll-a or algal biomass and sediment oxygen demand over a growing season or more would allow for a more accurate model.

Finally, additional characterization of the effluent from nonpoint sources, and point source facilities, such as determinations of CBOD<sub>u</sub> to CBOD<sub>5</sub> ratios, would increase the model's accuracy. The additional monitoring would allow confirmation of the assumptions used in the model used for calculating the TMDL. If additional data show



that the assumptions used in the phase 1 model were not accurate, the model and the TMDL will be updated.

## **6.4 Public Participation**

MDEQ held two stakeholder meetings to present and discuss the results of this TMDL report. 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. The public will be given an opportunity to review the TMDL and submit comments. MDEQ also distributes all TMDLs at the beginning of the public notice to those members of the public who have requested to be included on a TMDL mailing list. TMDL mailing list members may request to receive the TMDL reports through either, email or the postal service. Anyone wishing to become a member of the TMDL mailing list should contact Greg Jackson at (601) 961-5098 or [Greg\\_Jackson@deq.state.ms.us](mailto:Greg_Jackson@deq.state.ms.us).

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 submission of this TMDL to EPA Region 4 for final approval.

## **DEFINITIONS**

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

**Aggradation:** The raising of the bed of a watercourse by the deposition of sediment.

**Allocations:** That portion of a receiving water's loading capacity that is attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources.

**Ambient Stations:** A network of fixed monitoring stations established for systematic water quality sampling at regular intervals, and for uniform parametric coverage over a long-term period.

**Ammonia:** Inorganic form of nitrogen (NH<sub>3</sub>); product of hydrolysis of organic nitrogen and denitrification. Ammonia is preferentially used by phytoplankton over nitrate for uptake of inorganic nitrogen.

**Ammonia Nitrogen:** The measured ammonia concentration reported in terms of equivalent ammonia concentration; also called total ammonia as nitrogen (NH<sub>3</sub>-N)

**Ammonia Toxicity:** Under specific conditions of temperature and pH, the unionized component of ammonia can be toxic to aquatic life. The unionized component of ammonia increases with pH and temperature.

**Ambient Stations:** A network of fixed monitoring stations established for systematic water quality sampling at regular intervals, and for uniform parametric coverage over a long-term period.

**Anthropogenic:** Pertains to the [environmental] influence of human activities.

**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.

**Available DO Deficit:** The difference between DO saturation concentration and the DO standard (e.g., 5 mg/l).

**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 water body may be based upon a similar, unaltered or least impaired, water body or on historical pre-alteration data.

**Bank Full Stage:** Stage of flow at which a stream fills its channel up to level of its bank. Recurrence interval averages 1.5 to 2 years.

**Bedload Sediment:** Portion of sediment load transported downstream by sliding, rolling, bouncing along the channel bottom. Generally consists of particles >1 mm.

**Best Management Practices (BMPs):** Methods, measures, or practices that are determined to be reasonable and cost effective means for a landowner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.

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

**Calibration:** The process of adjusting model parameters within physically defensible ranges until the resulting predictions give a best possible good fit to observed data.

**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 water body.

**Channel:** A natural stream that conveys water; a ditch or channel excavated for the flow of water.

**Channel Improvement:** The improvement of the flow characteristics of a channel by clearing, excavation, realignment, lining, or other means in order to increase its capacity. Sometimes used to connote channel stabilization.

**Channel Stabilization:** Erosion prevention and stabilization of velocity distribution in a channel using jetties, drops, revetments, vegetation, and other measures.

**Clean Sediment:** Sediment that is not contaminated by chemical substances. Pollution caused by clean sediment refers to the quantity of sediment, as opposed to the presence of pollutant-contaminated sediment.

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

**Cross-Sectional Area:** Wet area of a waterbody normal to the longitudinal component of the flow.

**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 water body 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 water body depends on temperature, atmospheric pressure, and dissolved solids.

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

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

**Dissolved Solids:** Disintegrated organic and inorganic material in water. Excessive amounts will make water unfit to drink or use in industrial processes.

**Dynamic Model:** A mathematical formulation describing and simulating the physical behavior of a system or a process and its temporal variability.

**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.

**Ecoregion:** A physical region that is defined by its ecology, which includes meteorological factors, elevation, plant and animal speciation, landscape position, and soils.

**Effective Discharge:** The discharge which typifies sediment transport.

**Effluent:** Treated wastewater flowing out of the treatment facilities.

**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.

**Flood Plain:** The lowland that borders a river, usually dry but subject to flooding.

**Fluvial Geomorphology:** The effect of rainfall and runoff on the form and pattern of riverbeds and river channels.

**Geomorphology:** The study of the evolution and configuration of landforms.

**Gully Erosion:** The erosion process whereby water accumulates in narrow channels and, over short periods, removes soil from this narrow are to considerable depths, ranging from 1-2 feet to as much as 75-100 feet.

**Impaired Water body:** Any water body 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.

**Mass Wasting:** Downslope transport of soil and rocks due to gravitational stress.

**Narrative Criteria:** Nonquantitative guidelines that describe the desired water quality goals.

**Natural Waters:** Flowing water within a physical system that has developed without human intervention, in which natural processes continue to take place.

**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 NBOD<sub>u</sub>, the amount of oxygen consumed by microorganisms while stabilizing or degrading nitrogenous compounds under aerobic conditions over an extended time period.

**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; silviculture; surface mining; disposal of wastewater; hydrologic modifications; and urban development.

**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.

**Numeric Target:** A measurable value determined for the pollutant of concern, which, if achieved, is expected to result in the attainment of water quality standards in the listed water body.

**Phased Approach:** Under the phased approach to TMDL development, load allocations and wasteload allocations are calculated using the best available data and information recognizing the need for additional monitoring data to accurately characterize sources and loadings. The phased approach is typically employed when nonpoint sources dominate. It provides for the implementation of load reduction strategies while collecting additional data.

**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.

**Pollutant:** Dredged soil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt and industrial, municipal, and agricultural waste discharged into a water. (CWA Section 502(6))

**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 (POTW):** 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.

**Reference Sites:** Water bodies that are representative of the characteristics of the region and subject to minimal human disturbance.

**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.

**River Mile:** Location along a river from some arbitrary reference point.

**River Mile (Unimproved):** For the Big Sunflower River, unimproved river mile indicates the upstream distance following the path of the river before bendway cutoffs and straightening.

**River Mile (Improved):** For the Big Sunflower River, improved river mile indicates the upstream distance following the path of the river after bendway cutoffs and straightening.

**Runoff:** That part of precipitation, snowmelt, or irrigation water that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters.

**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.

**Scour:** To abrade and wear away. Used to describe the weathering away of a terrace or diversion channel or streambed. The clearing and digging action of flowing water, especially the downward erosion by stream water in sweeping away mud and silt on the outside of a meander or during flood events.

**Sediment:** Particulate organic and inorganic matter that is transported by flowing water or wind and accumulates on the bottom of waterways

**Sediment Delivery:** Contribution of transported sediment to a particular location or part of a landscape.

**Sediment Production:** Delivery of colluvium or bedrock from hillslope to stream channel. The production rate is evaluated as the sum of the rates of colluvial bank erosion and sediment transport across channel banks.

**Sediment Yield:** Quantity of sediment passing a particular point (e.g., discharge point of the basin) in a watershed per unit area of watershed per unit of time.

**Sedimentation:** Process of deposition of waterborne or windborne sediment or other material; also refers to the infilling of bottom substrate in a waterbody by sediment (siltation).

**Sheet Erosion:** Also Sheetwash. Erosion of the ground surface by unconcentrated (i.e. not in rills) overland flow.

**Sheetwash:** Also Sheet Erosion. Erosion of the ground surface by unconcentrated (i.e. not in rills) overland flow.

**Stage:** The height of a water surface above an established datum plane.

**Storm Runoff:** Rainfall that does not evaporate or infiltrate the ground because of impervious land surfaces or a soil infiltration rate than rainfall intensity, but instead flows into adjacent land or water bodies or is routed into a drain or sewer system.

**Stream Restoration:** Various techniques used to replicate the hydrological, morphological, and ecological features that have been lost in a stream due to urbanization, farming, or other disturbance.

**Surface Runoff:** Precipitation, snow melt, or irrigation water in excess of what can infiltrate the soil surface and be stored in small surface depressions; a major transporter of nonpoint source pollutants.

**Suspended Solids:** Organic and inorganic particles (sediment) suspended in and carried by a fluid (water). The suspension concentration is governed by the upward components of turbulence, and currents and downward settling of the particles.

**Topography:** The physical features of a geographic surface area including relative elevations and the positions of natural and man-made features.

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

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

**Turbidity:** A measure of opacity of a substance; the degree to which light is scattered or absorbed by a fluid.

**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

ARS	Agricultural Research Service
BASINS	Better Assessment Science Integrating Point and Nonpoint Sources
BMP	Best Management Practice
CBOD <sub>u</sub>	Carbonaceous Ultimate Biochemical Oxygen Demand
CWA	Clean Water Act
CWPRU	Channel and Watershed Processes Research Unit
DA	Drainage Area
DEM	Digital Elevation Model
DMR	Discharge Monitoring Report
DO	Dissolved Oxygen
EPA	Environmental Protection Agency
GIS	Geographic Information System
HEC-RAS	Hydrologic Engineering Center River Analysis System
HUC	Hydrologic Unit Code
HSPF	Hydrologic Simulation Program FORTRAN
IRM	Improved River Mile
LA	Load Allocation
MARIS	Mississippi Automated Resource Information Service
MDEQ	Mississippi Department of Environmental Quality
MFC	Mississippi Forestry Commission
MGD	Million Gallons per Day
MOS	Margin of Safety
NBOD <sub>u</sub>	Nitrogenous Ultimate Biochemical Oxygen Demand

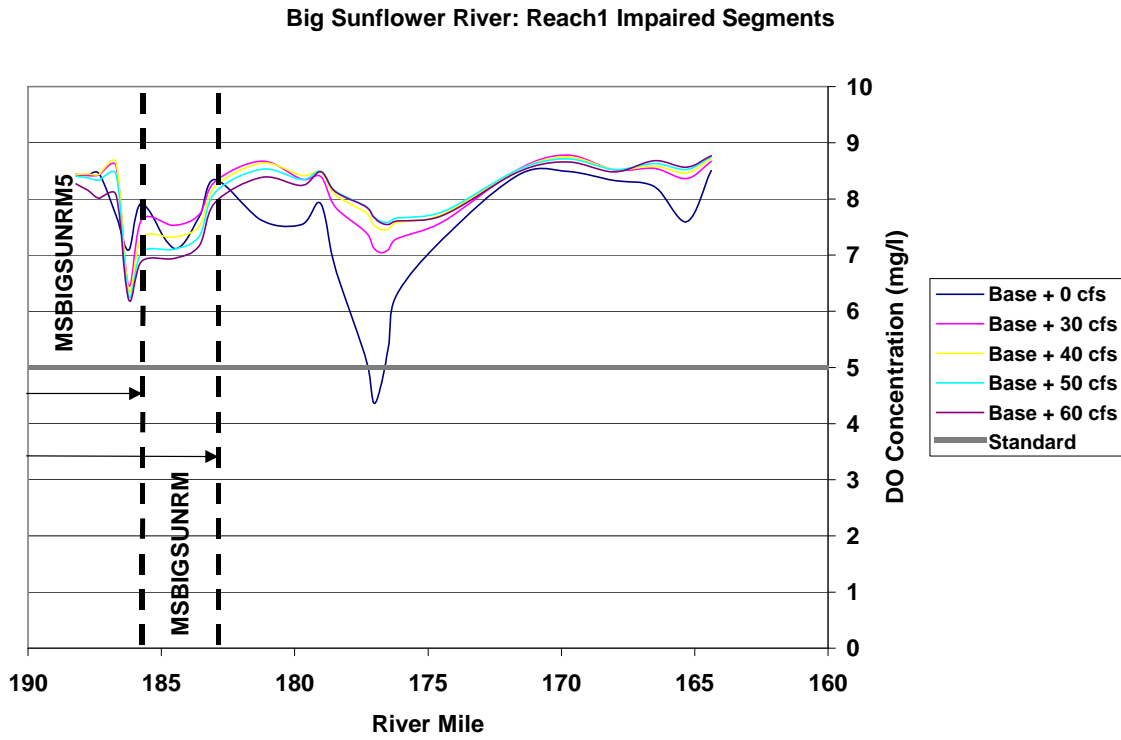
*Big Sunflower River TMDLs for Organic Enrichment, Nutrients, and Sediment*

NH <sub>3</sub> .....	Total Ammonia
NH <sub>3</sub> -N .....	Total Ammonia as Nitrogen
NO <sub>2</sub> + NO <sub>3</sub> .....	Nitrite Plus Nitrate
NPDES .....	National Pollution Discharge Elimination System
NPS .....	Non-Point Source
NRCS .....	Natural Resource Conservation Service
NSL .....	National Sedimentation Laboratory
RF3 .....	Reach File 3
RM .....	River Mile
TBOD <sub>u</sub> .....	Total Ultimate Biochemical Oxygen Demand
TSS .....	Total Suspended Solids
TN .....	Total Nitrogen
URM .....	Unimproved River Mile
USACE .....	U. S. Army Corps of Engineers
USGS .....	United States Geological Survey
USLE .....	Universal Soil Loss Equation
WASP .....	Water Analysis Simulation Program
WLA .....	Waste Load Allocation

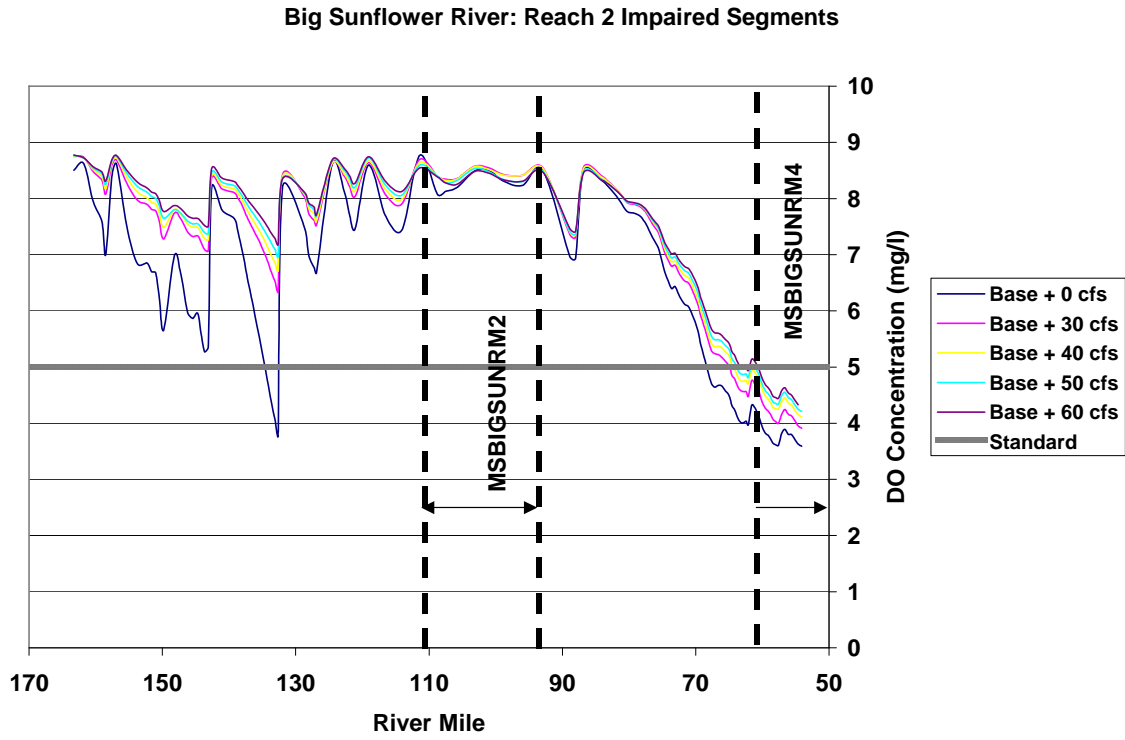
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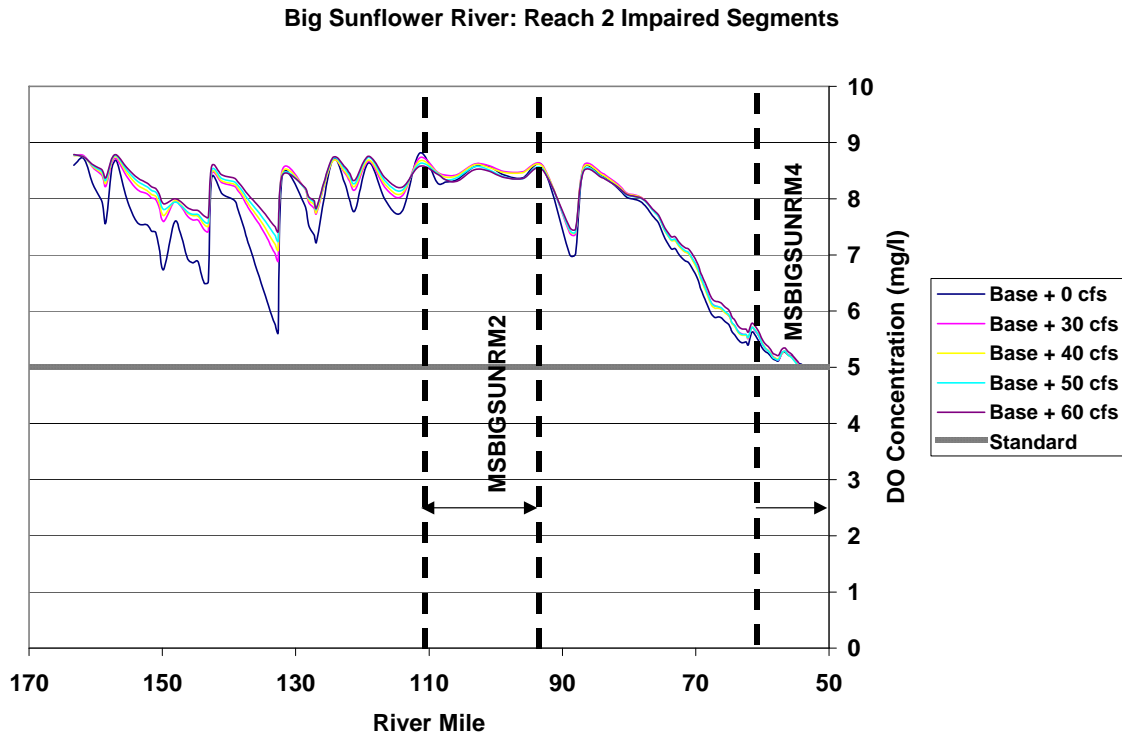




**Chart 1. Section 1 of the Big Sunflower River for existing, critical condition simulations.**

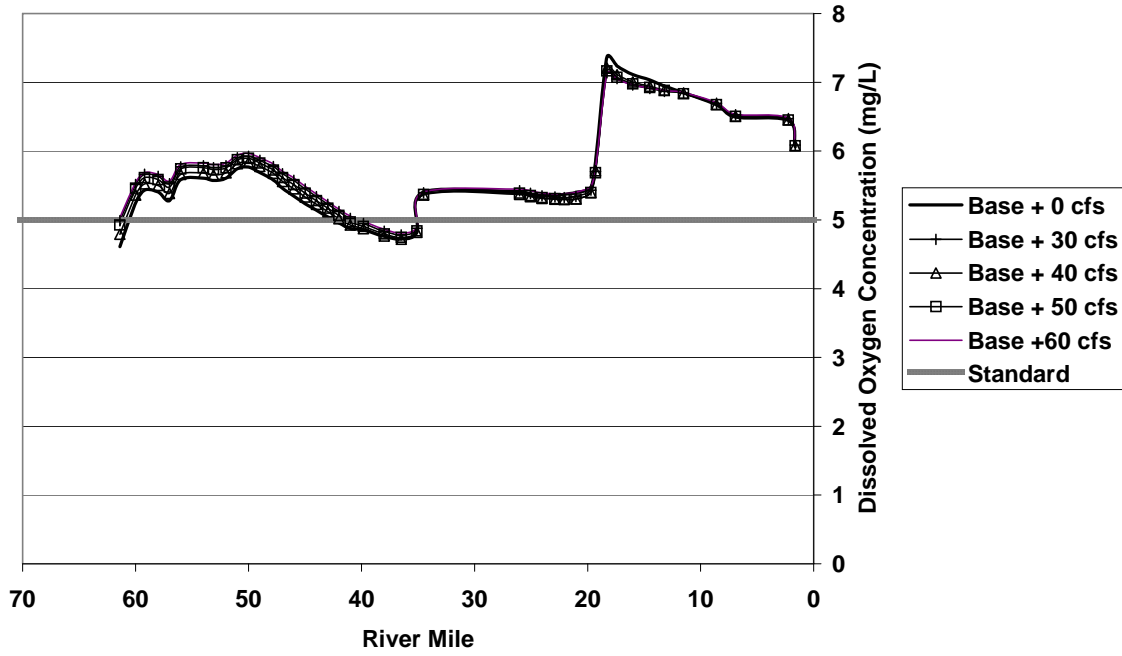


**Chart 2. Section 2 of the Big Sunflower River for existing, critical condition simulations.**



**Chart 3. Section 2 of the Big Sunflower River following an equal reduction of all point and non-point sources (of from 50 to 80 percent).**

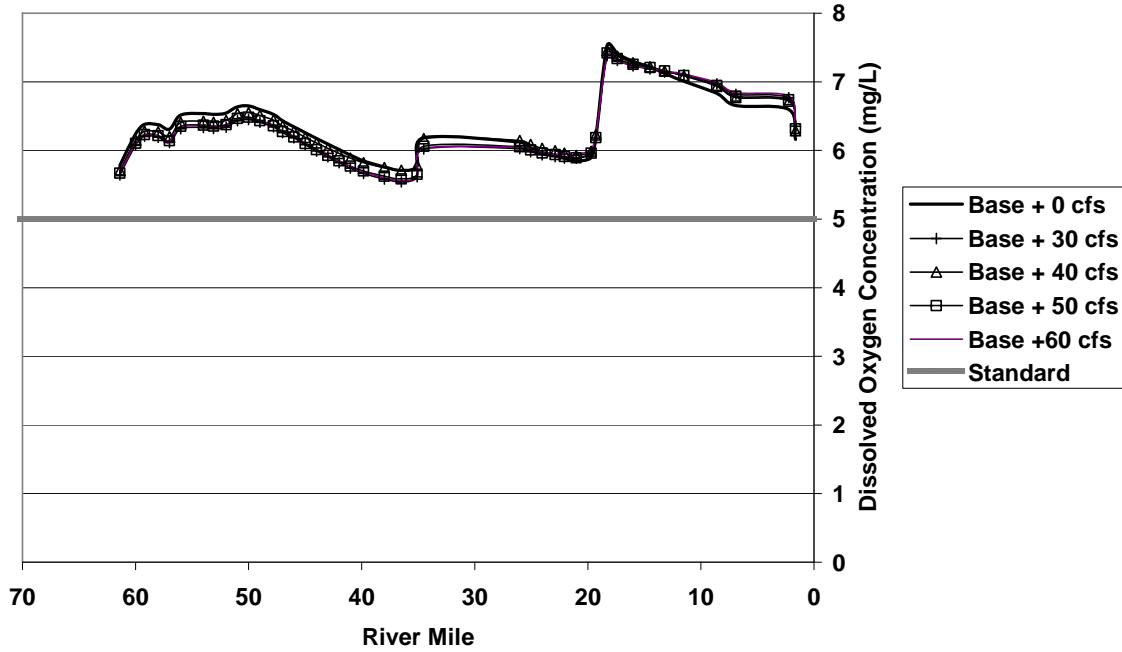
### Section 3: Big Sunflower River



**Chart 4. Section 3 of the Big Sunflower River (including Holly Bluff Cutoff) for existing, critical condition simulations.**

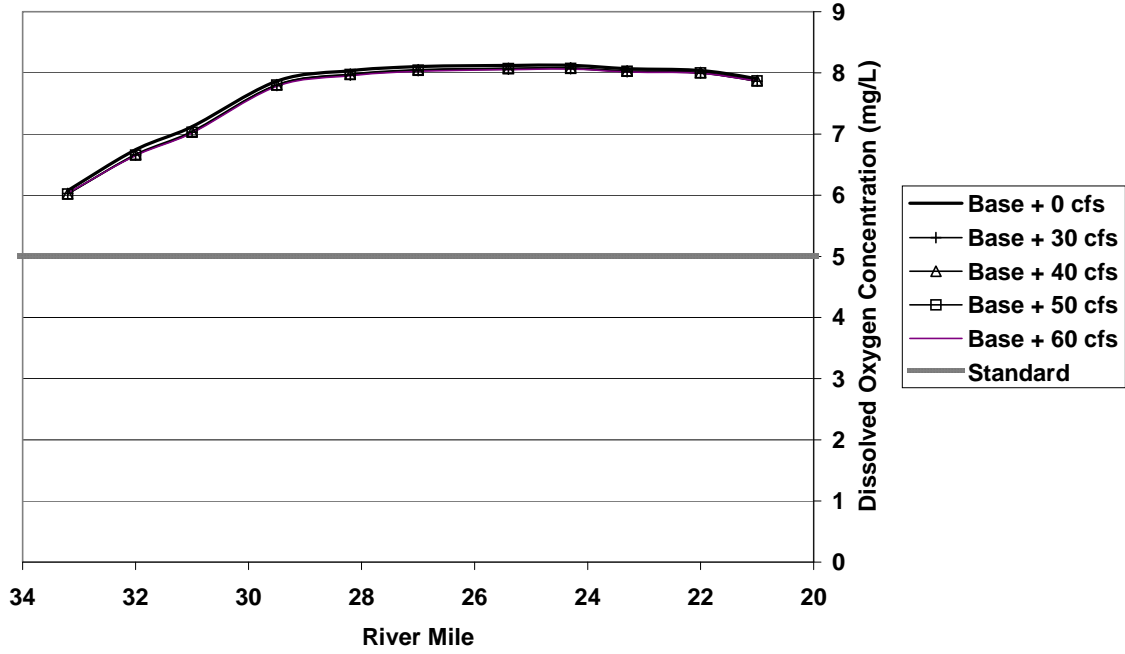


### Section 3: Big Sunflower River



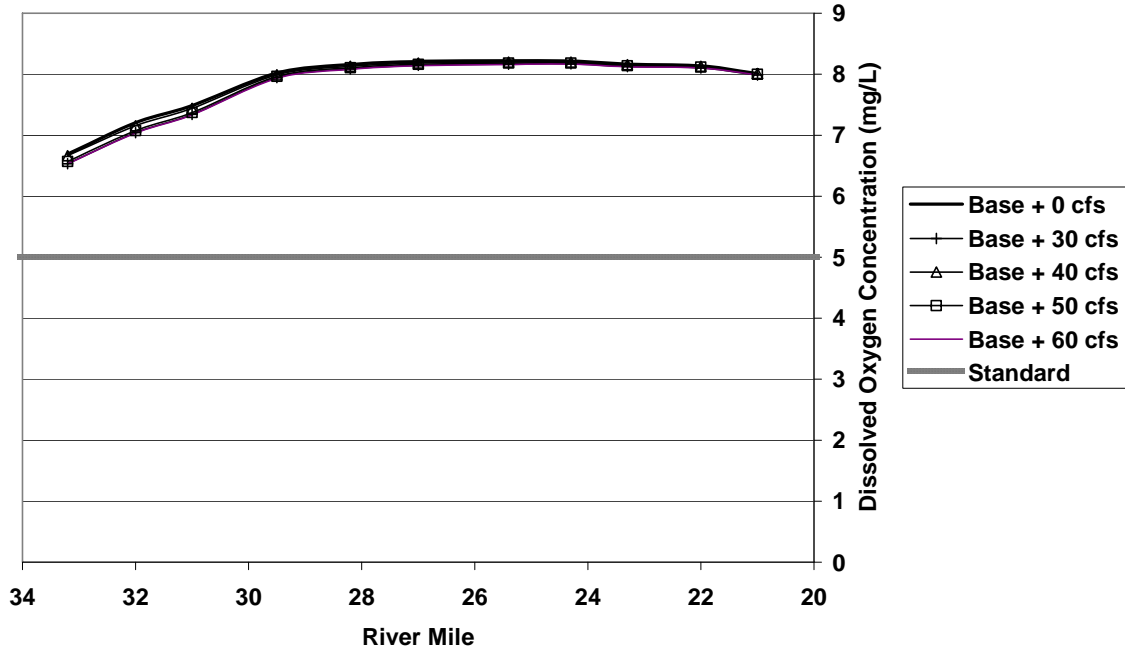
**Chart 5. Section 3 of the Big Sunflower River (including Holly Bluff Cutoff) for critical condition simulations following load reductions to Section 2.**

### Section 3: Old Sunflower Bendway



**Chart 6. Section 3 of the Big Sunflower River , Old Sunflower Bendway, for existing, critical condition simulations.**

### Section 3: Old Sunflower Bendway



**Chart 7. Section 3 of the Big Sunflower River , Old Sunflower Bendway, for critical condition simulations following load reductions to Section 2.**

Section 3: Little Sunflower River

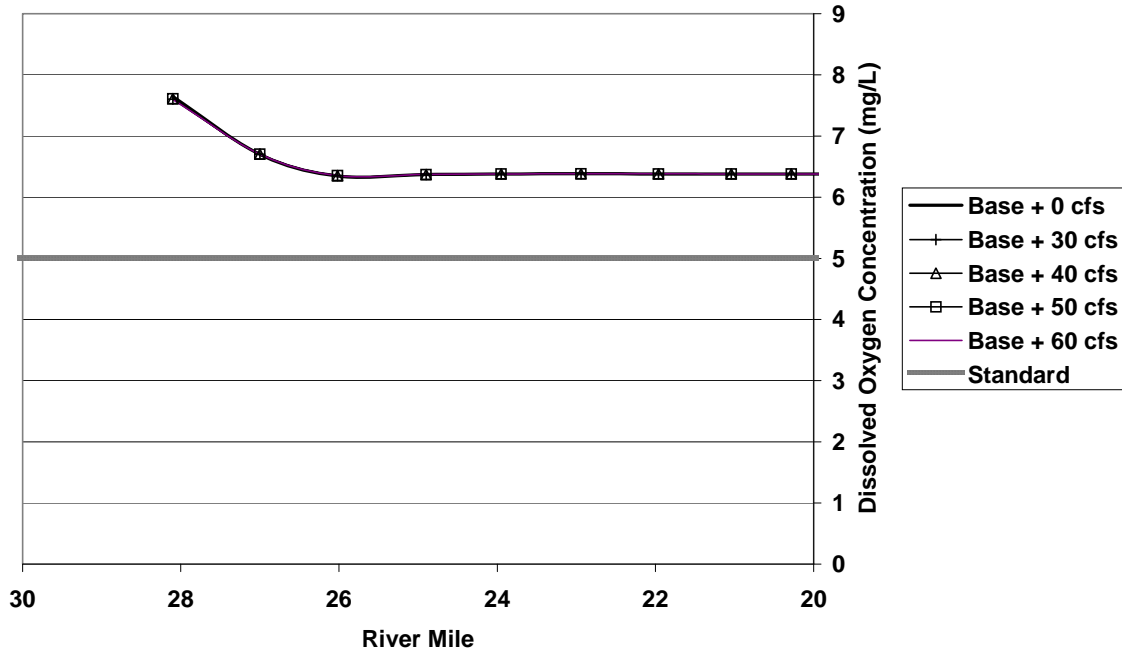
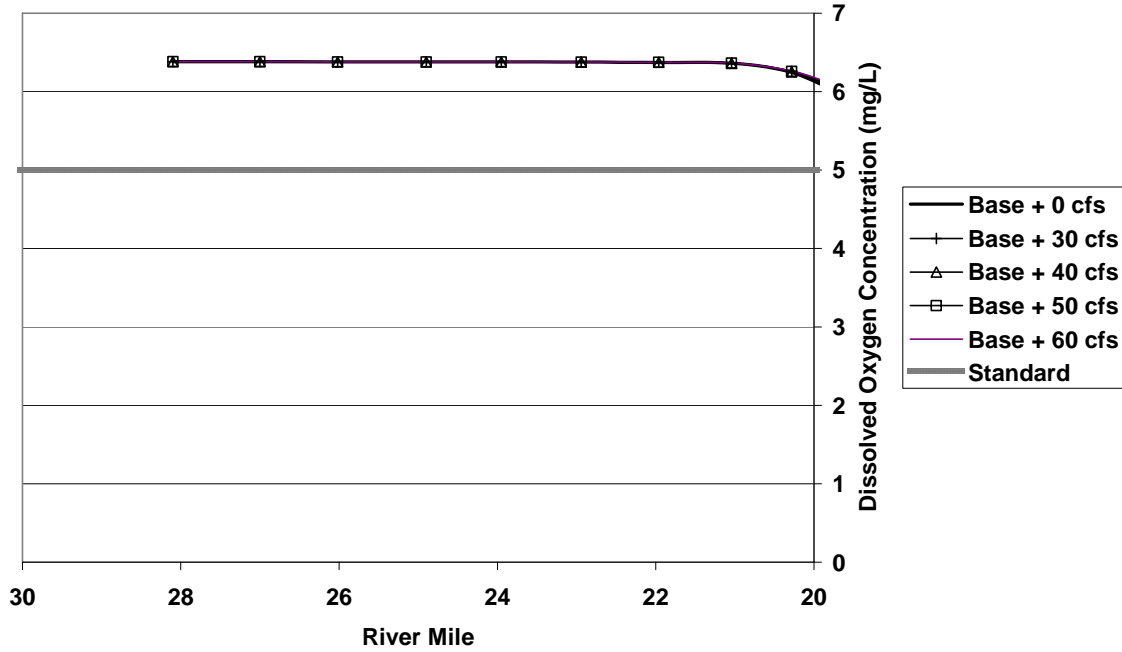


Chart 8. Section 3 of the Big Sunflower River, the Little Sunflower River, for existing, critical condition simulations.

### Section 3: Little Sunflower River



**Chart 9. Section 3 of the Big Sunflower River, the Little Sunflower River, for critical condition simulations following load reductions to Section 2.**