FTN Associates Ltd.
water resources / environmental consultants

# TMDLS FOR TEMPERATURE AND TURBIDITY IN THE SULPHUR RIVER AND RED RIVER, ARKANSAS

**FINAL**
**SEPTEMBER 27, 2012**

**Revised July 9, 2025**

# TMDLS FOR TEMPERATURE AND TURBIDITY
# IN THE SULPHUR RIVER AND RED RIVER, ARKANSAS

Prepared for

Arkansas Department of Environmental Quality
Water Division
5301 Northshore Drive
North Little Rock, AR 72118

Prepared by

FTN Associates, Ltd.
3 Innwood Circle, Suite 220
Little Rock, AR 72211

FTN No. 3013-380

FINAL
September 27, 2012

Revised by:

Arkansas Department of Energy and Environment
Division of Environmental Quality
Office of Water Quality
Water Quality Planning Branch

July 9, 2025

# EXECUTIVE SUMMARY

Section 303(d) of the Federal Clean Water Act requires states to identify waterbodies that are not meeting water quality standards, and to develop total maximum daily pollutant loads for those waterbodies. A total maximum daily load (TMDL) is the amount of pollutant that a waterbody can assimilate without exceeding the established water quality standard for that pollutant. Through a TMDL, pollutant loads can be allocated to point sources and nonpoint sources discharging to the waterbody. This report presents TMDLs that have been developed for temperature and turbidity for the Sulphur River and Red River in southwestern Arkansas. These TMDLs cover five reaches of the Sulphur River starting at the Texas/Arkansas state line and extending to the mouth where it empties into the Red River. These TMDLs also cover one reach of the Red River, starting at the mouth of the Sulphur River and extending downstream to the Arkansas/Louisiana state line.

Both the Sulphur River and Red River have large upstream drainage areas in Texas (and Oklahoma for the Red River). The study area for the TMDLs in this report was limited to the Sulphur River drainage area downstream of Wright Patman Lake (excluding Days Creek) and the Red River drainage area starting just upstream of the Sulphur River mouth and extending to the Arkansas/Louisiana state line. Forest and grassland/pasture comprise almost two-thirds of the study area.

A search of point source permits within the study area yielded permits for twelve stormwater discharges, one industrial facility (International Paper Texarkana Mill), and one municipal wastewater treatment plant (Queen City, TX). All of the permits are for facilities in Texas except one stormwater permit.

The reaches of the Sulphur River and Red River addressed in this report were listed as impaired on the final version of the 2008 303(d) list for Arkansas. The pollutants causing the impairments were listed as turbidity/siltation (all reaches) and temperature (Sulphur River only). The 303(d) list specified high priority for the turbidity/siltation impairments in the Sulphur River, and low priority for the other impairments addressed in this report. The *2008 Integrated Water Quality Monitoring and Assessment Report* stated that excessive turbidity in the Sulphur River was “predominately caused by surface erosion” (ADEQ 2008). No specific causes have been documented for the temperature impairments; they appear to be caused simply by atmospheric heating.

The Arkansas Department of Environmental Quality (ADEQ) had collected historical water quality data at one location each on the Sulphur River and Red River within the study area. These data were tabulated and analyzed for basic statistics, seasonal patterns, and relationships between concentration and stream flow. Measurements of turbidity, total suspended solids (TSS), and temperature were higher in the Red River than the Sulphur River. In the seasonal analysis, TSS measurements from the Sulphur River showed slightly higher concentrations in the late summer and fall. Plots of Sulphur River turbidity and TSS versus stream flow indicated that the highest concentrations tended to occur during lower flows. Plots of Red River turbidity and TSS versus stream flow indicated that the highest concentrations tended to occur when flows were between 20,000 cubic feet per second (cfs) and 60,000 cfs.

## ES.1 Turbidity TMDLs

The load duration curve method was used to develop the turbidity TMDLs in this report, with TSS used as a surrogate for turbidity. This method illustrates allowable loading at a wide range of stream flow conditions. The steps for applying this methodology for the TMDLs in this report were (1) developing flow duration curves; (2) converting the flow duration curves to load duration curves; (3) plotting observed loads with load duration curves; (4) calculating the TMDL and establishing the margin of safety (MOS); (5) calculating existing and allowable loads from diffuse sources; (6) calculating allowable loads for non-stormwater point sources; and (7) calculating loads reserved for future growth.

The load duration curves were plotted with units of tons/day on the vertical axis and percent exceedance (unit-less) on the horizontal axis. Each load duration curve was divided into five hydrologic ranges: high flows (0%-10% exceedance), moist conditions (10%-40% exceedance), mid-range flows (40%-60% exceedance), dry conditions (60%-90% exceedance), and low flows (90%-100% exceedance). The TMDLs were set equal to the allowable loads for the minimum stream flow within each hydrologic range. An implicit MOS was established because the TMDLs were set at the minimum flow within each hydrologic range rather than at the median flow for each range.

Existing loads from diffuse sources were calculated based on ADEQ water quality data at the uppermost monitoring station in each reach. The diffuse loads consist of (1) industrial or municipal stormwater that is regulated by a National Pollutant Discharge Elimination System (NPDES) permit, and (2) nonpoint source inflows from all other areas that are not regulated by an NPDES permit. The total diffuse loading was divided between regulated stormwater and unregulated nonpoint source inflows based on drainage area. The loads from regulated stormwater were assigned to a wasteload allocation (WLA) and the remaining diffuse loading was assigned to the load allocation (LA).

Neither of the two non-stormwater point source discharges was included in the turbidity TMDLs because the TSS in their discharges was assumed to consist primarily of organic suspended solids rather than inorganic suspended solids which were assumed to be the primary cause of the turbidity impairment. Therefore, the WLA for non-stormwater point sources was set to not applicable (NA) ~~zero~~.

## ES.2 Temperature TMDLs

The temperature TMDLs were developed using a water quality model (QUAL2K) that simulates water temperature on a diurnally varying basis using meteorologic data and stream channel characteristics. During August and September 2010, FTN conducted field studies in the Sulphur River and Red River to collect data for water temperatures, stream flow rates, and cross-section measurements. These field data were used to set up and calibrate the model. The model was calibrated to three different time periods during August and September 2010. The atmospheric heat load was calculated for each of the three simulation periods as short-wave radiation plus long-wave radiation. The water temperatures predicted by the model were directly related to the atmospheric heat load. Linear interpolation between results from individual simulation periods yielded atmospheric loads that correspond with temperature criteria from the water quality standards. The TMDLs were set equal to these heat loads that correspond to the criteria.

The WLAs were set to zero because no point sources are currently discharging directly to these stream reaches during critical conditions for temperature. The International Paper Texarkana Mill has a large discharge directly into the Sulphur River just upstream of the Texas/Arkansas state line, but their current permit does not allow them to discharge during July and August (the two hottest months when temperature criteria in the stream are most likely to be exceeded).

The MOS for each temperature TMDL was set to 5% of the TMDL. The LA for nonpoint sources was then set to 95% of each TMDL (i.e., the TMDL minus the MOS and WLA).

The results of the TMDL calculations for turbidity and temperature are summarized in Tables ES.1 and ES.2.

Table ES.1. Summary of turbidity TMDLs for the Sulphur River and Red River.

| Stream Reach | Hydrologic Range | Allowable Loads of TSS (tons/day) LA for Non-Regulated Diffuse Sources | WLA for NPDES Regulated Stormwater | WLA for Non-Stormwater Point Sources | MOS | Future Growth | TMDL |
|---|---|---|---|---|---|---|---|
| Sulphur River 11140302-008 | Low flows | 0.69 | 0.01 | ~~0*~~ NA | implicit | 0 | 0.70 |
| | Dry cond. | 11.26 | 0.01 | ~~0*~~ NA | implicit | 0 | 11.27 |
| | Mid-range | 44.75 | 0.01 | ~~0*~~ NA | implicit | 0 | 44.76 |
| | Moist cond. | 201.46 | 0.03 | ~~0*~~ NA | implicit | 52.24 | 253.73 |
| | High flows | 326.85 | 0.04 | ~~0*~~ NA | implicit | 683.49 | 1010.38 |
| Sulphur River 11140302-006 | Low flows | 0.74 | 0.01 | ~~0*~~ NA | implicit | 0 | 0.75 |
| | Dry cond. | 11.33 | 0.01 | ~~0*~~ NA | implicit | 0 | 11.34 |
| | Mid-range | 48.03 | 0.01 | ~~0*~~ NA | implicit | 0 | 48.04 |
| | Moist cond. | 205.27 | 0.03 | ~~0*~~ NA | implicit | 53.23 | 258.53 |
| | High flows | 329.81 | 0.04 | ~~0*~~ NA | implicit | 689.69 | 1019.54 |
| Sulphur River 11140302-004 | Low flows | 0.75 | 0* | ~~0*~~ NA | implicit | 0 | 0.75 |
| | Dry cond. | 11.35 | 0* | ~~0*~~ NA | implicit | 0 | 11.35 |
| | Mid-range | 49.60 | 0* | ~~0*~~ NA | implicit | 0 | 49.60 |
| | Moist cond. | 207.51 | 0* | ~~0*~~ NA | implicit | 53.80 | 261.31 |
| | High flows | 330.96 | 0* | ~~0*~~ NA | implicit | 692.00 | 1022.96 |
| Sulphur River 11140302-002 | Low flows | 2.25 | 0.01 | ~~0*~~ NA | implicit | 0 | 2.26 |
| | Dry cond. | 13.16 | 0.01 | ~~0*~~ NA | implicit | 0 | 13.17 |
| | Mid-range | 58.84 | 0.01 | ~~0*~~ NA | implicit | 0 | 58.85 |
| | Moist cond. | 221.33 | 0.01 | ~~0*~~ NA | implicit | 57.38 | 278.72 |
| | High flows | 340.17 | 0.01 | ~~0*~~ NA | implicit | 711.28 | 1051.46 |
| Sulphur River 11140302-001 | Low flows | 2.26 | 0* | ~~0*~~ NA | implicit | 0 | 2.26 |
| | Dry cond. | 13.18 | 0* | ~~0*~~ NA | implicit | 0 | 13.18 |
| | Mid-range | 59.20 | 0* | ~~0*~~ NA | implicit | 0 | 59.20 |
| | Moist cond. | 221.75 | 0* | ~~0*~~ NA | implicit | 57.49 | 279.24 |
| | High flows | 340.52 | 0* | ~~0*~~ NA | implicit | 712.00 | 1052.52 |
| Red River 11140201-003 | Low flows | 144.5 | 0* | ~~0*~~ NA | implicit | 57.1 | 201.6 |
| | Dry cond. | 300.4 | 0* | ~~0*~~ NA | implicit | 87.9 | 388.3 |
| | Mid-range | 957 | 0* | ~~0*~~ NA | implicit | 3427 | 4384 |
| | Moist cond. | 2747 | 0* | ~~0*~~ NA | implicit | 6362 | 9109 |
| | High flows | 11524 | 0* | ~~0*~~ NA | implicit | 23892 | 35416 |

~~*Note: These WLAs are zero because there are currently no discharges to these reaches for these hydrologic ranges. Future discharges are allowable if they do not violate water quality standards.~~

Table ES.2. Summary of temperature TMDLs for Sulphur River and Red River.

| Stream Reach | Existing Criterion (°C) | LA for Nonpoint Sources ($W/m^2$) | WLA for Point Sources ($W/m^2$) | MOS ($W/m^2$) | TMDL ($W/m^2$) |
|---|---|---|---|---|---|
| Sulphur River 11140302-008 | 30 | 530.8 | 0 | 27.9 | 558.7 |
| Sulphur River 11140302-006 | 30 | 530.8 | 0 | 27.9 | 558.7 |
| Sulphur River 11140302-004 | 30 | 530.8 | 0 | 27.9 | 558.7 |
| Sulphur River 11140302-002 | 30 | 530.8 | 0 | 27.9 | 558.7 |
| Sulphur River 11140302-001 | 30 | 530.8 | 0 | 27.9 | 558.7 |
| Red River 11140201-003 | 32 | 584.2 | 0 | 30.8 | 615.0 |

# TABLE OF CONTENTS

# TABLE OF CONTENTS (CONTINUED)

# LIST OF APPENDICES



# LIST OF TABLES

# LIST OF ABBREVIATIONS

| | |
|---|---|
| ADEQ | Arkansas Department of Environmental Quality |
| APCEC | Arkansas Pollution Control and Ecology Commission |
| BMPs | best management practices |
| CFR | Code of Federal Regulations |
| cfs | cubic feet per second |
| CPP | Continuing Planning Process |
| EPA | United States Environmental Protection Agency |
| FG | future growth |
| FTN | FTN Associates, Ltd. |
| GPS | global positioning system |
| HUC12 | 12-digit hydrologic unit code |
| ICIS | Integrated Compliance Information System |
| LA | load allocation |
| LDEQ | Louisiana Department of Environmental Quality |
| MGD | million gallons per day |
| MOS | margin of safety |
| MRLC | Multi-Resolution Land Characterization |
| MS4 | Municipal Separate Storm Sewer System |
| NLCD | National Land Cover Database |
| NPDES | National Pollutant Discharge Elimination System |
| NTU | nephelometric turbidity units |
| TCEQ | Texas Commission on Environmental Quality |
| TMDL | total maximum daily load |
| UAA | use attainability analysis |
| USACE | United States Army Corps of Engineers |
| USGS | United States Geological Survey |
| WLA | wasteload allocation |
| WQBEL | water quality based effluent limitation |
| WWTP | wastewater treatment plant |

# 1.0 INTRODUCTION

This report presents total maximum daily loads (TMDLs) for the Sulphur River from the Texas/Arkansas state line to its confluence with the Red River (reaches 11140302-001, -002, -004, -006, and -008), and the Red River from the mouth of the Sulphur River to the Arkansas/Louisiana state line (reach 11140201-003). TMDLs were developed for temperature and turbidity for each of these stream reaches. These stream reaches were listed as impaired on the final version of the 2008 303(d) list for Arkansas (United States Environmental Protection Agency [EPA] 2008). Table 1.1 presents information concerning these impairments from the final 2008 303(d) list and the Arkansas Department of Environmental Quality (ADEQ) 2008 Integrated Water Quality Monitoring and Assessment Report (ADEQ 2008). The TMDLs in this report were developed in accordance with Section 303(d) of the Federal Clean Water Act and EPA regulations at Title 40 Code of Federal Regulations (CFR) Part 130.7.

The purpose of a TMDL is to determine the pollutant loading that a waterbody can assimilate without exceeding the water quality standard for that pollutant. The TMDL is the sum of the waste load allocation (WLA), load allocation (LA), and a margin of safety (MOS). The WLA is the load allocated to point sources of the pollutant of concern. The LA is the load allocated to nonpoint sources, including natural background. The MOS is a percentage of the TMDL that takes into account any lack of knowledge concerning the relationship between pollutant loadings and water quality.

Table 1.1. Impairments being addressed by TMDLs in this report.

| Reach Number | Stream Name | Impaired Uses | Pollutants Causing Impairment | Suspected Pollutant Sources | TMDL Priority |
|---|---|---|---|---|---|
| 11140201-003 | Red River [1] | Aquatic Life | Siltation / Turbidity | Surface Erosion [2] | Low |
| 11140302-001 | Sulphur River | Aquatic Life | Temperature | Unknown | Low |
| | | | Siltation / Turbidity | Surface Erosion [2] | High |
| 11140302-002 | Sulphur River | Aquatic Life | Temperature | Unknown | Low |
| | | | Siltation / Turbidity | Surface Erosion [2] | High |
| 11140302-004 | Sulphur River | Aquatic Life | Temperature | Unknown | Low |
| | | | Siltation / Turbidity | Surface Erosion [2] | High |
| 11140302-006 | Sulphur River | Aquatic Life | Temperature | Unknown | Low |
| | | | Siltation / Turbidity | Surface Erosion [2] | High |
| 11140302-008 | Sulphur River | Aquatic Life | Temperature | Unknown | Low |
| | | | Siltation / Turbidity | Surface Erosion [2] | High |

Notes: 1. This reach of the Red River is not impaired for temperature but this reach of the Red River was included in the temperature modeling and TMDL development because this reach is immediately downstream of the temperature impairments in the Sulphur River.

2. "Surface Erosion" includes erosion from agriculture activities, unpaved road surfaces, in stream erosion, mainly from unstable stream banks, and any other land surface disturbing activity (ADEQ 2008).

# 2.0 BACKGROUND INFORMATION

## 2.1 General Information

The study area for this report is the watershed for the Sulphur River downstream of Wright Patman Lake (excluding Days Creek) and the Red River from the Sulphur River to the Arkansas/Louisiana state line (see Figure A.1 in Appendix A). Days Creek is a tributary of the Sulphur River that drains much of the urban area in and around Texarkana. The Days Creek watershed was excluded from the study area because ADEQ monitoring data on Days Creek show that it is not impaired for temperature or turbidity.

The Sulphur River originates in northeast Texas and flows generally eastward before emptying into the Red River just upstream of Highway 160, east of Doddridge, Arkansas. The drainage area of the Sulphur River at its mouth is approximately 3,748 square miles (United States Geological Survey [USGS] 1978). The Red River drains parts of Texas, Oklahoma, and the southwest corner of Arkansas before flowing into Louisiana. The portion of the Red River drainage area in the study area is approximately 12 square miles at the Arkansas/Louisiana state line (USGS 1978). The locations of the impaired stream reaches addressed in this report are shown on Figure A.1 in Appendix A.

The study area is in the Gulf Coastal Plain ecoregion and ADEQ Planning Segment 1B. Most of the study area lies within Miller and Lafayette counties in Arkansas, but it also includes parts of Bowie and Cass counties in Texas. The Sulphur River Wildlife Management Area is included in the study area.

## 2.2 Land Use

Land use within the study area was characterized using National Land Cover Database (NLCD) 2006 data, which were obtained from the Multi-Resolution Land Characterization consortium (MRLC 2011). These data were based on satellite imagery from 2006 and they represent the most recent available data for this area. The spatial distribution of these land uses is shown on Figure A.2 (located in Appendix A) and land use percentages are shown in Table 2.1. The predominant land uses in the study area are forest, grassland/pasture, and wetlands.

Table 2.1. Land use percentages for the study area.

| Land Use Category | Percentage of Study Area |
|---|---|
| Open Water | 5.1% |
| Wetlands | 17.8% |
| Developed Areas | 7.0% |
| Barren Land | 0.5% |
| Grassland/Pasture | 22.3% |
| Forest | 41.6% |
| Cultivated Crops | 5.7% |
| **TOTAL** | 100.0% |

## 2.3 Stream Flow Data

The study area covers the following 12-digit hydrologic units: 111403020706, 111403020701, 111403020704, 111402010405, 111403020708, 111403020702, 111403020709, 111403020703, 111403020707, 111403020705, and the portion of 111402010504 that is located within Arkansas. The TMDLs in this report were developed using flow data from several sources. The US Army Corps of Engineers (USACE) provided flow data for the Red River at Fulton, Arkansas, and release records for Wright Patman Lake, which releases water into the Sulphur River. The USGS gaging station for the Red River at Spring Bank, Arkansas (07344370) was also utilized. Selected information for these data sources is summarized in Table 2.2. The location of the USGS gaging station is shown on Figure A.1 in Appendix A.

Table 2.2. Information for stream flow data that were used for TMDLs.

| Gage Number | Stream Name | Gage Name | Descriptive Location | Period of Record | Drainage Area (square miles) |
|---|---|---|---|---|---|
| 07344370 | Red River | Red River at Spring Bank, AR | Highway 160 (just downstream of Sulphur River) | October 1997 to present | 56,909 |
| NA | Red River | Fulton | Fulton, AR (just downstream of Little River) | Only 2010 data were obtained | 52,412 |
| NA | Sulphur River | Wright Patman Lake (daily releases) | At the dam for Wright Patman Lake | September 1990 to June 2010 | 3,390 |

## 2.4 Water Quality Standards

Water quality standards for Arkansas waterbodies are listed in Regulation No. 2 (Arkansas Pollution Control and Ecology Commission [APCEC] 2011). Designated uses for the Sulphur River and for the Red River downstream of the Sulphur River are primary and secondary contact recreation; domestic, industrial, and agricultural water supply; and perennial Gulf Coastal fishery.

Section 2.502 of Regulation No. 2 provides a temperature change criterion as well as criteria for maximum temperatures. The criterion for temperature change is given as follows: "Heat shall not be added to any waterbody in excess of the amount that will elevate the natural temperature, outside the mixing zone, by more than 5°F (2.8°C) based upon the monthly average of the maximum daily temperatures measured at mid-depth or three feet (whichever is less) in streams, lakes or reservoirs" (APCEC 2011). The Sulphur River in Arkansas does not have a stream-specific criterion for maximum temperature; therefore, the applicable criterion is the Gulf Coastal Plain ecoregion criterion, which is 30°C (86°F). The Red River in Arkansas does have a stream-specific criterion for maximum temperature; it is 32°C (89.6°F). These temperature criteria are intended to protect aquatic life. Thermal impacts that affect aquatic biota may include triggering seasonal variances in spawning based on water temperature as well as exacerbating lower dissolved oxygen in the summer months.

Although the temperature TMDLs in this report were developed based on Arkansas criteria, the temperature criteria from adjacent states are noted here for informational purposes. The Texas criterion that applies to the Sulphur River between Wright Patman Lake and the Texas/Arkansas state line is 32.2°C (90°F) (Texas Commission on Environmental Quality [TCEQ] 2010). The Louisiana criterion that applies to the Red River immediately downstream of the Arkansas/Louisiana state line is 34°C (93.2°F) (Louisiana Department of Environmental Quality [LDEQ] 2011). Each of these criteria is less stringent than the Arkansas criterion for the same stream.

Section 2.503 of Regulation No. 2 provides narrative and numeric criteria for turbidity. The general narrative criterion is given as follows: "There shall be no distinctly visible increase in turbidity of receiving waters attributable to municipal, industrial, agricultural, other waste discharges or instream activities. Specifically, in no case shall any such waste discharge or instream activity cause turbidity values to exceed the base flows values listed below. Additionally, the non-point source runoff shall not result in the exceedance of the in stream all flows values in more than 20% of the ADEQ ambient monitoring network samples taken in not less than 24 monthly samples" (APCEC 2011). Stream-specific numeric criteria for Sulphur River turbidity are 21 Nephelometric turbidity units (NTU) for base flows and 32 NTU for all flows. For the Red River, the numeric turbidity criteria are 50 NTU for base flows, and 150 NTU for all flows. For these TMDLs, base flow was considered to be the lowest 40% of flows (in accordance with previous turbidity TMDLs approved by EPA Region 6).

As specified in EPA's regulations at 40 CFR 130.7(b)(2), applicable water quality standards include antidegradation requirements. Arkansas' antidegradation policy is listed in Sections 2.201 through 2.204 of Regulation No. 2. These sections impose the following requirements:

- Existing instream water uses and the level of water quality necessary to protect the existing uses shall be maintained and protected;
- Water quality that exceeds standards shall be maintained and protected unless allowing lower water quality is necessary to accommodate important economic or social development, although water quality must still be adequate to fully protect existing uses;
- For outstanding state or national resource waters, those uses and water quality for which the outstanding waterbody was designated shall be protected; and
- For potential water quality impairments associated with a thermal discharge, the antidegradation policy and implementing method shall be consistent with Section 316 of the Clean Water Act.

## 2.5 Nonpoint Sources

The Arkansas 2008 integrated assessment (ADEQ 2008) states that excessive turbidity in the Sulphur River is "predominately caused by surface erosion." The sources of temperature issues in the Sulphur River are specified as "unknown."

## 2.6 Point Sources

For development of these TMDLs, "point sources" were defined to include both continuous discharges (e.g., treated municipal or domestic wastewater) and stormwater runoff that is regulated under the National Pollutant Discharge Elimination System (NPDES). Information for point source discharges in the study area was obtained by searching ADEQ's online permits database and EPA's Integrated Compliance Information System (ICIS). This search yielded a total of 14 permits. Locations of the permitted facilities are shown on Figure A.3 and selected information for these facilities is listed in Table A.1 (Appendix A). Table 2.3 summarizes the numbers and types of permits that were identified, according to the first impaired reach downstream of the discharge.

Table 2.3. Numbers and types of NPDES permits in the study area.

| First Impaired Reach Downstream* | Stream Name | MS4 | Other Stormwater | Domestic Wastewater | Industrial |
|---|---|---|---|---|---|
| 11140201-003 | Red River | 0 | 0 | 0 | 0 |
| 11140302-001 | Sulphur River | 0 | 0 | 0 | 0 |
| 11140302-002 | Sulphur River | 0 | 1 (AR) | 0 | 0 |
| 11140302-004 | Sulphur River | 0 | 0 | 0 | 0 |
| 11140302-006 | Sulphur River | 0 | 4 (TX) | 0 | 0 |
| 11140302-008 | Sulphur River | 0 | 7 (TX) | 1(TX) | 1(TX) |
| **TOTALS:** | | 0 | 12 | 1 | 1 |

*Note: Discharges may not directly enter the reach listed here, but this represents the first impaired reach downstream of the discharge.

None of the point sources discharging in the study area have permit limits for temperature or turbidity. However, both of the non-stormwater permits do have limits for total suspended solids (TSS), which is a surrogate used to develop TMDLs for turbidity. The International Paper Company Texarkana Mill has a TSS permit limit of 175 mg/L (single grab sample) and the Queen City, TX wastewater treatment plant (WWTP) has limits ranging from 15 mg/L for the daily average up to 60 mg/L for a single grab sample. As a surrogate for turbidity, TSS was considered to represent inorganic suspended solids (i.e., soil and sediment particles from erosion or sediment resuspension) for the TMDLs in this report. The suspended solids discharged by the two non-stormwater point sources in the study area were assumed to consist primarily of organic solids rather than inorganic solids. Discharges of organic suspended solids from these two point sources are already addressed through the permitting of point sources to maintain water quality standards for dissolved oxygen. Therefore, neither of the two non-stormwater point sources was included in the turbidity TMDLs.

## 2.7 Previous Water Quality Studies

No previous water quality studies addressing temperature or turbidity were identified for the Sulphur River or the Red River in the study area. A "319" project to reduce turbidity was implemented in the watershed of Days Creek, a tributary to the Sulphur River in the study area.

The USACE Vicksburg District has studied streambank erosion along the Sulphur River in Arkansas associated with the Highway 237 and Highway 71 bridges.[1]

[1] http://www.ar.nrcs.usda.gov/technical/coe_vicksburg_report_159th.html

# 3.0 ADEQ WATER QUALITY DATA

## 3.1 General Description of Data

Routine monitoring data for temperature, turbidity, and TSS have been collected by ADEQ at one site on Sulphur River (RED0005), and one site on the Red River downstream (RED0009). Locations of the sampling sites are shown on Figure A.1 in Appendix A. The data are summarized in Table 3.1, including comparisons with the current criteria in the water quality standards. Data for TSS are included in Table 3.1 because TSS was used as a surrogate parameter for the turbidity TMDLs, as discussed in Section 3.5 below. Appendix B includes tabular listings of the individual data (Tables B.1 and B.2) and time-series plots of the data (Figures B.1, B2, and B.7 through B.10).

The water quality standards for turbidity, as listed in Section 2.4, are divided into categories of “base flows” and “all flows.” In order to compare the observed data to the criteria, it was necessary to similarly characterize individual observed values. For these turbidity TMDLs, base flow was considered to be the lowest 40% of flows. This assumption was consistent with previous turbidity TMDLs approved by EPA Region 6.

## 3.2 Summary Statistics and Comparisons

Table 3.1 summarizes data for the entire period of record; however, the period of record normally used as an assessment period by ADEQ consists of the previous 5 years of data, usually starting April 1 and ending March 30 of the fifth year.

The temperature statistics were similar between the Sulphur River (RED0005) and Red River (RED0009) sites. Turbidity and TSS values were higher at the Red River site than at the Sulphur River site, but there were more exceedances at the Sulphur River site because the turbidity criteria are more stringent for the Sulphur River.

Table 3.1. Summary of ADEQ data for temperature, turbidity, and TSS.

| | **RED0005** | **RED0009** |
|---|---|---|
| Site description | Sulphur River south of Texarkana, AR | Red River near Doddridge, AR |
| Reach number | 11140302-006 | 11140201-003 |
| Period of record | 9/4/1990 – 2/9/2010 | 9/4/1990 – 2/9/2010 |
| **Temperature (criterion)** | **(30°C)** | **(32°C)** |
| Number of values | 242 | 243 |
| Minimum (°C) | 5.5 | 5.7 |
| Maximum (°C) | 36 | 38 |
| Median (°C) | 21 | 21 |
| Number of values above criterion | 25 | 23 |
| Percent of values above criterion | 10% | 9% |
| **Turbidity (base-flow / all-flow criteria)** | **(21 NTU / 32 NTU)** | **(50 NTU / 150 NTU)** |
| Number of values | 229 | 231 |
| Minimum (NTU) | 3.1 | 4.3 |
| Maximum (NTU) | 135 | 460 |
| Median (NTU) | 30 | 47.5 |
| Number of values above base-flow criterion | 78 | 33 |
| Percent of values above base-flow criterion | 81% | 33.7% |
| Number of values above all-flow criterion | 103 | 15 |
| Percent of values above all-flow criterion | 45% | 6.5% |
| **TSS** | | |
| Number of values | 222 | 224 |
| Minimum (mg/L) | 0.5 | 2 |
| Maximum (mg/L) | 107 | 490 |
| Median (mg/L) | 39.1 | 51 |

## 3.3 Seasonal Patterns

Seasonal plots of temperature, turbidity, and TSS measurements in Sulphur River and Red River are shown on Figures B.3, B.4, and B.11 through B.14 in Appendix B. The temperature plots showed characteristic seasonal temperature variation (Figures B.3 and B.4). The seasonal TSS plot of the Sulphur River measurements showed generally higher concentrations and greater numbers of criterion exceedances in the late summer and fall (Figure B.12). Turbidity measurements in the Sulphur River did not appear to exhibit seasonal variation (Figure B.11). Neither TSS nor turbidity measurements in the Red River appeared to exhibit seasonal variation (Figures B.13 and B.14).

### 3.4 Relationships between Concentration and Flow

Measurements of turbidity and TSS concentrations were plotted against stream flow to examine any visual correlation between these measurements and flow (Figures B.15 through B.18, Appendix B). In the Sulphur River, the highest values tended to occur during lower flows (Figures B.15 and B.16). In the Red River, the highest values tended to occur at flows between 20,000 cfs and 60,000 cfs (Figures B.17 and B.18).

### 3.5 Relationships between Turbidity and TSS

Plots of TSS versus turbidity for each station (Figures B.19 through B.22, Appendix B) showed a noticeable correlation, with higher turbidity values tending to correspond with higher TSS concentrations. For each water quality station, a linear regression was performed first on the logarithms of turbidity and TSS values and then on the raw (untransformed) values. Regressions using untransformed data gave the best results and are summarized in Table 3.2. Separate regressions were developed for base-flow conditions and for all-flow conditions.

Table 3.2. Summary of results of turbidity and TSS regressions.

| Sampling Station | Flow | Regression Equation | Number of Data Points | Coefficient of Determination ($R^2$) | Significance Level (P value) |
|---|---|---|---|---|---|
| RED0005 | Base | Turbidity = 0.92*TSS-1.19 | 86 | 0.47 | < 0.01 |
| RED0005 | All | Turbidity = 0.66*TSS+9.56 | 218 | 0.51 | < 0.01 |
| RED0009 | Base | Turbidity = 0.84*TSS+4.79 | 57 | 0.40 | < 0.01 |
| RED0009 | All | Turbidity = 0.52*TSS+19.45 | 220 | 0.69 | < 0.01 |

The strength of the linear relationship is measured by the coefficient of determination ($R^2$) calculated during the regression analysis (Zar 1996). The $R^2$ value is the percentage of the total variation in the logarithm of turbidity that is explained or accounted for by the fitted regression (logarithm TSS). For example, 69% of the variation in all-flow turbidity at station RED0009 is accounted for by TSS, and the remaining 31% of variation in turbidity is unexplained. The unexplained portion is attributed to factors other than TSS.

The perfect explanation of the relationship between the measurement of turbidity and the measurement of TSS would require collecting and analyzing a large amount of research data. A number of the items affecting this perfect explanation of the relationship would need to be known. A partial list of the items affecting the relationship follows:

- Velocity of the water at the time of sampling;
- Algal and bacteria masses in the water column;
- Measured color of the water;
- Mass of the organic component of the TSS;
- Mass of the material passing through the filter during the TSS analysis;
- Grain size distribution of the inorganic portion of the TSS;
- Specific gravity of the different sizes of inorganic solids particles;
- Hydrographic conditions at the time of sampling;
- Number, magnitude, and lags of rainfall events represented by the sampling.

Collecting a large volume of research data would not change the fact that inorganic particles represented in the TSS measurements are the major contributors to the turbidity readings and are the major constituents reduced when sediment best management practices (BMPs) are applied to nonpoint sources. The BMPs used on nonpoint sources for sediment also reduce the load of many of the unexplained contributors in the regression. The effort to have a perfect explanation of turbidity may not result in a better selection of BMPs. The regressions presented above between TSS and turbidity are adequate for the preparation of these TMDLs. Stakeholder groups of knowledgeable persons from the watersheds may need additional information to set a plan of action for these TMDLs.

The statistical significance for each regression was evaluated by computing the “P-value” for the slope for each regression. The P-value is essentially the probability that the slope of the regression line is really zero. A low P-value indicates that a non-zero slope calculated from the regression analysis is statistically significant. The P-values for these regressions were all less than 0.01, which is considered good.

# 4.0 FTN FIELD DATA

FTN collected field data for the temperature TMDLs in the Sulphur River and Red River during August and September 2010. The purpose of the field data collection was to obtain data for setting up and calibrating a water temperature model for the Sulphur River and Red River.

Water temperature loggers were deployed at four locations in the Sulphur River, one location in Days Creek, and two locations in the Red River from early August through late September. Each logger was set to measure and record water temperatures at 1-hour intervals. Table 4.1 lists the sites where the temperature loggers were deployed. A map showing the locations of the field sites is provided as Figure C.1 (Appendix C).

Table 4.1. Temperature logger locations and deployment periods.

| Site ID | Stream | Deployment Date | Retrieval Date |
|---|---|---|---|
| RR-0.0 | Red River | 8/4/2010 | Logger was lost |
| RR-7.3 | Red River | 8/4/2010 | 9/21/2010 |
| SR-4.5 | Sulphur River | 8/4/2010 | 9/22/2010 |
| SR-11.5 | Sulphur River | 8/3/2010 | 9/22/2010 |
| DAYS CR | Days Creek | 8/5/2010 | 9/22/2010 |
| SR-19.0 | Sulphur River | 8/5/2010 | 9/23/2010 |
| SR-28.0 | Sulphur River | 8/5/2010 | 9/23/2010 |

Data from only five temperature loggers were used in the temperature TMDLs because the logger at RR-0.0 was not recovered and the data from the logger at SR-4.5 were found to be erroneous and were discarded. At several locations, the water level had dropped below the logger when the logger was retrieved. As a result, the temperature data recorded by each logger were plotted on top of air temperature data from the Texarkana airport to identify time periods when the water level dropped below that logger. Logger data were discarded for periods when the water level was below the logger. Plots of the temperature logger data are shown in Appendix C (Figures C.2 through C.6). The plots for RR-7.3, SR-19.0, and SR-28.0 show that daily maximum water temperatures exceeded 32.0°C from the beginning of the deployment period through August 24. The daily maximum temperatures at SR-19.0 and SR-28.0 did not drop below 30.0°C (the current criterion in the water quality standards that applies to the Sulphur River) until August 29.

Table 4.2 lists the locations where cross sections, stream flows, and vertical profiles of water temperatures were measured during September 21 through 23, when the loggers were retrieved. Appendix C includes summaries of the cross-section data (Table C.1), stream flow measurements (Table C.2), and temperature profiles (Table C.3).

Table 4.2. Summary of field data collected at each site in September 2010.

| Stream | Site ID | Cross Section | Stream Flow | Temperature Profile |
|---|---|---|---|---|
| Red River | RR-0.0 | X | | X |
| Red River | RR-1.0 | X | | X |
| Red River | RR-2.0 | X | | X |
| Red River | RR-3.0 | X | | X |
| Red River | RR-4.0 | X | | X |
| Red River | RR-5.0 | X | | X |
| Red River | RR-6.0 | X | | X |
| Red River | RR-7.3 | | | X |
| Sulphur River | SR-0.5 | X | | X |
| Sulphur River | SR-1.5 | X | | X |
| Sulphur River | SR-4.5 | X | | X |
| Sulphur River | SR-5.5 | X | | X |
| Sulphur River | SR-6.5 | X | | X |
| Sulphur River | SR-7.5 | X | | X |
| Sulphur River | SR-8.5 | X | | X |
| Sulphur River | SR-9.5 | X | | X |
| Sulphur River | SR-10.5 | X | | X |
| Sulphur River | SR-11.5 | X | | X |
| Days Creek | DAYS CR | | X | X |
| Sulphur River | SR-19.0 | X | X | X |
| Sulphur River | SR-20.0 | X | | X |
| Sulphur River | SR-21.0 | X | | X |
| Sulphur River | SR-22.0 | X | | X |
| Sulphur River | SR-24.0 | X | | X |
| Sulphur River | SR-25.0 | X | | X |
| Sulphur River | SR-26.0 | X | | X |
| Sulphur River | SR-27.0 | X | | X |
| Sulphur River | SR-28.0 | X | X | X |

Except for several shallow sites, the cross sections were measured using a sonar transducer that was equipped with a global positioning system (GPS) to record simultaneous readings of water depth and GPS coordinates as the boat moved across the stream. At several sites that were too shallow for the sonar transducer, the cross sections were measured with a surveying rod (depth) and tape measure (horizontal distance). The cross-section data show average depths ranging from 2.1 to 13.0 ft in the Sulphur River and 4.0 to 15.6 ft in the Red River. Measured widths ranged from 46.9 to 238.0 ft in the Sulphur River and 232.8 to 732.5 ft in the Red River (Table C.1).

Stream flows were measured using a Marsh-McBirney velocity meter following standard USGS procedures. The stream flow measurements in the Sulphur River indicated slightly more flow at SR-19.0 than at SR-28.0 (Table C.2). This suggests there was a small amount of inflow along the length of the Sulphur River, presumably due to seepage from shallow groundwater and possibly some minor tributary inflows.

The vertical profiles of water temperature were measured using a Hydrolab sonde. The temperature profiles showed less than 1.0°C vertical variation in water temperatures at most of the sites (Table C.3).

# 5.0 TEMPERATURE TMDL DEVELOPMENT

## 5.1 Setup and Configuration of Temperature Model

The model used for this temperature TMDL was QUAL2K, which is a steady-state, one-dimensional water quality model that has the capability to simulate water temperature on a diurnal time scale.

The model starts in the Sulphur River at the Texas/Arkansas state line and continues downstream into the Red River to the Arkansas/Louisiana state line. The model is divided into 70 reaches and each reach is approximately 0.5 mile in length. The model further subdivides each reach into two elements. Consequently, each element is 0.25 mile in length. There are two tributaries in the model: Days Creek and the Red River upstream of the confluence of the Sulphur River. Each tributary was modeled as a single reach.

The three time periods that were selected for model calibration are displayed in Table 5.1. These are the time periods during which the temperature loggers were deployed and submerged, and there were not drastic changes in stream flow rates (QUAL2K simulates only steady flows).

Table 5.1. Calibration time periods for temperature model.

| Calibration Time Period | Start Date | End Date |
|---|---|---|
| 1 | 8/10/2010 | 8/14/2010 |
| 2 | 8/18/2010 | 8/21/2010 |
| 3 | 9/19/2010 | 9/21/2010 |

## 5.2 Flow Rates and Stream Hydraulics

For the model channel dimensions input parameter, the rating curves option was chosen. The exponents for depth, widths, and velocities were derived from the field data. Width and velocity coefficient were then calculated based on the exponents and the field cross-section data. For the depth coefficient, three-period moving averages of the field cross-section data and the exponents were used in the calculation. The model required several flow inputs, including the mainstem headwater (at the Texas/Arkansas state line), the ungauged flow, and the headwater for the tributaries.

The flow of the Sulphur River at the Texas/Arkansas state line was calculated by summing the USACE release flows from Wright Patman Lake, the flows from the International Paper mill taken from the discharge monitoring reports, and the ungauged flow. The ungauged flow was calculated by multiplying the ungauged flow per unit area by the drainage area that is between the Wright Patman Dam and the Texas/Arkansas state line. The drainage area is comprised of two HUC12s, 111403020701 and 111403020703, which cover a total of 88.7 square miles. The ungauged flow per unit area was assumed to be 0.15 cfs per square mile, as described below for calculations between the Texas/Arkansas state line and Days Creek.

The drainage area for the Sulphur River between the Texas/Arkansas state line and the mouth of Days Creek was determined by summing drainage areas from Mercer Bayou, Turkey Creek, and the adjacent HUC12s. The combined drainage area of Mercer Bayou and Turkey Creek is 18 square miles (USGS 1978). The drainage area was determined to be 62 square miles and is comprised of HUC12 111403020702 and part of HUC12 111403020709 that is upstream of Days Creek. Thus, the drainage area for the Sulphur River between the Texas/Arkansas state line and the mouth of Days Creek was calculated to be 80 square miles.

The ungauged flow per unit area between the Texas/Arkansas state line and the mouth of Days Creek was determined by dividing the ungauged flow into Sulphur River between the Texas/Arkansas state line and mouth of Days Creek by the drainage area. As stated above, the drainage area was found to be 80 square miles. The ungauged flow was calculated by subtracting the flow measured at station SR-28 from the flow measured at station SR-19. The resultant ungauged flow was calculated to be 12 cfs. Thus, the ungauged flow per unit area between the Texas/Arkansas state line and the mouth of Days Creek was calculated to be 0.15 cfs per square mile.

The drainage area for the Sulphur River between the mouth of Days Creek and the confluence with the Red River was determined by subtracting the drainage of the Sulphur River at its mouth from the drainage area of the Sulphur River downstream of the mouth of Days Creek. *Drainage Areas of Streams in Arkansas* (USGS 1978) lists the drainage area of the Sulphur River at its mouth as 3,748 square miles and lists the drainage area of the Sulphur River downstream of the mouth of Days Creek as 3,706 square miles. Therefore, drainage area for the

Sulphur River between the mouth of Days Creek and the confluence with the Red River was calculated to be 42 square miles.

The ungauged flow into the Sulphur River between the mouth of Days Creek and the confluence with the Red River was determined by multiplying the ungauged flow per unit area by the drainage area. As mentioned above, the drainage area for the Sulphur River between the mouth of Days Creek and the confluence with the Red River was calculated to be 42 square miles and the ungauged flow per unit area was assumed to be the same value, 0.15 cfs per square mile, as used between the Texas/Arkansas state line and the mouth of Days Creek. Therefore, the ungauged flow into the Sulphur River between the mouth of Days Creek and the confluence with the Red River was calculated to be 6.3 cfs.

The flow of Days Creek was measured by FTN to be 15 cfs on September 23, 2010. The flow of the Sulphur River at the mouth was determined by summing the flows from Days Creek, the ungauged flow into the Sulphur River between the mouth of Days Creek and the confluence with the Red River, the ungauged flow between the Texas/Arkansas state line and the mouth of Days Creek, and the flow of the Sulphur River at the Texas/Arkansas state line. The flow of the Red River upstream of the confluence with the Sulphur River was calculated by subtracting the flow calculated for the mouth of the Sulphur River from the flow at the Spring Bank, AR, USGS gauge.

## 5.3 Water Temperature Inputs

For the initial headwater temperatures, the QUAL2K model requires one day of hourly temperatures. The headwater temperatures specified in the QUAL2K model were calculated by averaging the hourly field logger temperatures for a given calibration time period. The initial headwater temperatures for the mainstem in the calibration model came from station SR 28.0. The headwater temperatures for the Days Creek tributary in the calibration model came from the Days Creek station. The headwater temperatures for the Red River tributary in the calibration model came from station RR 7.3. Temperatures from stations SR 19.0 and SR 11.5 were used as calibration points. Since the temperature logger at station RR 0.0 was lost, the data from the temperature logger at station RR 7.3 were used as calibration targets at station RR 0.0.

Only one temperature is required for the diffuse inflow. The initial diffuse inflow temperature, 28.5°C, used in the model was calculated from the field data temperature profiles by averaging temperatures at 3 meters or more in depth with the exclusion of station RR 0.0.

## 5.4 Meteorological Inputs

The QUAL2K model requires one day of hourly meteorological data for air temperatures, dew point temperatures, wind speed, and cloud cover. The meteorological data specified in the QUAL2K model are from the Texarkana Regional Airport-Webb Field weather station (WBAN# 13977). All meteorological data specified in the model were calculated by averaging the hourly data for a given calibration time period. A 50% factor was applied to the wind speeds to account for wind sheltering by trees along the edges of the rivers.

## 5.5 Light and Heat Settings

Several parameters in the QUAL2K model's "Light and Heat" tab were modified. These modifications included setting the atmospheric attenuation model to the Bras method and having the atmospheric turbidity coefficient set to a value of 4. The Brutsaert model was selected for the atmospheric longwave emissivity model and the "Adams 2" model was chosen for the wind speed function for evaporation and air convection/conduction. Each of these options was chosen because it provided the best calibration results.

## 5.6 Tributary and Point Source Inflow Rates

A review of discharge monitoring reports for the International Paper Texarkana Mill for August and September 2010 revealed a zero discharge for both months. Therefore, the discharge from the Texarkana Mill was set to zero in the calibration simulations.

Texarkana's South Regional WWTP discharges into Days Creek, which is a tributary to the Sulphur River in the calibration model. As discussed in Section 5.2, the flow rate for Days Creek in the calibration runs was from the flow measurement in the field survey. Because this flow was measured downstream of the South Regional WWTP's discharge, the South Regional WWTP's discharge was not included as a separate inflow in the calibration model.

## 5.7 Model Calibration Results

As previously stated, three time periods were selected for calibration and are shown in Table 5.1. Plots of predicted and observed values of temperature from the calibration model are shown in Appendix D.

For the first calibration time period, the simulated temperatures were close to the observed data for stations SR 19.0 and RR 0.0, but the temperatures were over-predicted at station SR 11.5. For the second calibration time period, the simulated temperatures were similar to the observed data at station RR 0.0 but the predicted diel fluctuation was greater than the observed range for station SR 19.0. For the third calibration time period, the simulated maximum temperatures were similar to the observed data at all three stations but the simulated mean and minimum temperatures were under-predicted at stations SR 19.0 and SR 11.5.

As with any simulation model, there is uncertainty associated with the model results because 1) the processes in the model are incomplete and/or simplified representations of the real system, and 2) the input data do not exactly describe the real system due to factors such as measurement error, aggregation and/or averaging, interpolation, and missing data. For example, the nearest meteorological station with the necessary data for QUAL2K was the Texarkana airport, which was more than 12 miles from the nearest part of the simulated streams. Another example is the input data for depth, which were obtained from cross sections taken at intervals of 1 mile or more; any abnormal variations in depth that may exist between cross section locations would not have been detected in the field data and are not represented in the model.

These inherent uncertainties in the model predictions are considered acceptable if reasonable model inputs are used and the calibration results show a good match between predicted and observed values. For this project, the goal for model calibration accuracy was a median relative error of 5% or less. Relative error is calculated by taking the absolute value of the difference between a pair of predicted and observed values, and dividing it by the observed value. As shown in Table 5.2, the median relative error for the three calibration simulations was determined to be 0.81%.

Table 5.2. Median relative error for model calibration.

| Calibration Time Period | Station | Observed Daily Average Temperature (°C) | Simulated Daily Average Temperature (°C) | Relative Error | Median Relative Error |
|---|---|---|---|---|---|
| 1 | SR 19.0 | 33.74 | 33.87 | 0.39% | 0.81% |
| | SR 11.5 | 33.22 | 34.01 | 2.38% | |
| | RR 0.0 | 33.01 | 33.16 | 0.45% | |
| 2 | SR 19.0 | 32.80 | 32.42 | 1.16% | |
| | RR 0.0 | 31.72 | 31.82 | 0.32% | |
| 3 | SR 19.0 | 29.15 | 28.64 | 1.77% | |
| | SR 11.5 | 29.24 | 28.51 | 2.51% | |
| | RR 0.0 | 29.18 | 29.11 | 0.24% | |

## 5.8 Allowable Heat Loads

EPA regulations at 40 CFR 130.2 state the following: “TMDLs can be expressed in terms of either mass per time, toxicity, or other appropriate measure.” The thermal energy that causes high water temperatures cannot be expressed as mass per time. Therefore, the temperature TMDLs in this report were expressed as maximum allowable atmospheric heat loads per unit area. Although atmospheric heat loads are essentially uncontrollable by human efforts, this approach was considered acceptable. For these rivers, the atmospheric heat load is by far the dominant source of heat because there are no point sources that are adding heat, and the thermal energy from upstream inflows is small due to low stream flow rates during critical conditions for temperature.

The atmospheric heat loads were calculated as the short-wave radiation plus the long-wave radiation. Short-wave radiation is commonly referred to as solar radiation and occurs only during the daytime as a result of sunshine. The QUAL2K model calculates short-wave radiation based primarily on variables that include latitude, day of the year, cloud cover, and atmospheric attenuation. The QUAL2K output includes calculated values of short-wave radiation over a full 24-hour diurnal cycle. Long-wave radiation occurs both day and night; it is the thermal energy that is being radiated by the atmosphere as a result of the air temperature. The QUAL2K model calculates long-wave radiation internally, but those values are not included in the model output. For the TMDL calculations, long-wave radiation was calculated in a spreadsheet using the equations that are printed in the QUAL2K manual. Appendix D includes printouts of the spreadsheet with these calculations for daily averages of short-wave radiation, long-wave radiation, and total atmospheric radiation (short-wave + long-wave). These calculations were performed for each of the three simulation periods. Also included in Appendix D are excerpts from the QUAL2K User Manual showing the theory and equations for calculating short-wave and long-wave radiation, including literature references.

For each of the three simulation periods, the atmospheric heat load and the highest value of the predicted daily average temperature were compiled in a table (see Appendix D). As expected, these values show a direct relationship between atmospheric heat load and water temperature. The atmospheric heat load (i.e., total atmospheric radiation) that corresponds to the Sulphur River criterion (30°C) was calculated using linear interpolation between the values for simulation periods 2 and 3 (because 30°C fell in between the predictions for those simulation periods). In similar fashion, the atmospheric heat load that corresponds to the Red River criterion (32°C) was calculated using linear interpolation between the values for simulation periods 1 and 2. The TMDLs for the two rivers were set equal to the atmospheric heat loads that correspond to the temperature criteria (615.0 $W/m^2$ for the Red River and 558.7 $W/m^2$ for the Sulphur River).

## 5.9 Temperature TMDLs

The WLAs were set to zero because no point sources are currently discharging directly to these stream reaches during critical conditions for temperature. Twelve of the fourteen point source discharges in the study area are stormwater permits (Table 2.5); none of these point sources would discharge during low-flow conditions that are most critical for water temperature. One of the two non-stormwater point sources is the Queen City WWTP, which likely discharges on a continuous basis even during critical conditions for water temperature, but it is unlikely to affect temperatures in the Sulphur River because its effluent travels about 14 miles before reaching the Sulphur River and it has a small flow rate. The other non-stormwater point source discharge is the International Paper Texarkana Mill, which has a large discharge into the Sulphur River just upstream of the Arkansas/Texas state line. However, the Texarkana Mill’s permit does not allow them to discharge during July or August (the two hottest months when water temperature exceedances are most likely to occur). The WLA values of zero do not prohibit the Texarkana Mill or other point sources from discharging during non-critical conditions for temperature, nor do they prohibit point sources from discharging during critical conditions in such a way that they do not cause exceedances of water temperatures in the Sulphur River or Red River (e.g., Queen City WWTP). Current point source permits should not need any changes to be consistent with the requirements in these temperature TMDLs.

The MOS for each TMDL was set to 5% of the TMDL. The LA for nonpoint sources was then set to 95% of each TMDL (i.e., the TMDL minus the MOS and WLA). Because the TMDLs are expressed as a rate of energy per unit area ($W/m^2$), the values are independent of the length of each reach. The TMDLs are summarized in Table 5.3.

The temperature TMDLs have been calculated for critical conditions as required by EPA regulations at 40 CFR 130.7. These streams have additional assimilative capacity for point source or nonpoint source thermal inputs during non-critical conditions (i.e., when stream flows are higher or when atmospheric heat loads are less).

Table 5.3. Summary of temperature TMDLs for Sulphur River and Red River.

| Stream Reach | Existing Criterion (°C) | LA for Nonpoint Sources ($W/m^2$) | WLA for Point Sources ($W/m^2$) | MOS ($W/m^2$) | TMDL ($W/m^2$) |
|---|---|---|---|---|---|
| Sulphur River 11140302-008 | 30 | 530.8 | 0 | 27.9 | 558.7 |
| Sulphur River 11140302-006 | 30 | 530.8 | 0 | 27.9 | 558.7 |
| Sulphur River 11140302-004 | 30 | 530.8 | 0 | 27.9 | 558.7 |
| Sulphur River 11140302-002 | 30 | 530.8 | 0 | 27.9 | 558.7 |
| Sulphur River 11140302-001 | 30 | 530.8 | 0 | 27.9 | 558.7 |
| Red River 11140201-003 | 32 | 584.2 | 0 | 30.8 | 615.0 |

# 6.0 TURBIDITY TMDL DEVELOPMENT

## 6.1 Seasonality and Critical Conditions

EPA regulations at 40 CFR 130.7 require the determination of TMDLs to take into account critical conditions for stream flow, loading, and water quality parameters. Also, both Section 303(d) of the Clean Water Act and regulations at 40 CFR 130.7 require TMDLs to consider seasonal variations for meeting water quality standards. Therefore, the historical data and analyses discussed in Section 3.0 were used to evaluate whether there were certain flow conditions or certain periods of the year that could be used to characterize critical conditions.

The turbidity TMDLs in this report were not developed for individual seasons because (1) the water quality data do not show strong, consistent seasonal patterns; (2) none of the point source discharges have seasonal permit limits for turbidity or TSS; and (3) the assimilative capacity for turbidity or TSS does not vary with seasonal temperature changes (unlike parameters such as dissolved oxygen). Critical flow conditions were addressed by using the load duration curve methodology to develop these TMDLs. This methodology results in allowable loads calculated for a wide range of flows.

## 6.2 Water Quality Targets

The water quality targets for TMDLs are generally the criteria that have been approved by EPA as discussed in Section 2.4. Turbidity is an expression of the optical properties in a water sample that cause light to be scattered or absorbed, and may be caused by suspended matter such as clay, silt, finely divided organic and inorganic matter, soluble colored organic compounds, and plankton and other microscopic organisms (Standard Methods 1999). Turbidity cannot be expressed as a load as preferred for TMDLs. To achieve a load-based value, turbidity is often correlated with a surrogate parameter such as TSS that may be expressed as a load. In general, activities that generate varying amounts of suspended sediment will proportionally change or affect turbidity (EPA 1991). Research by Relyea et al. (2000) states that “increased turbidity by sediments can reduce stream primary production by reducing photosynthesis, physically abrading algae and other plants, and preventing attachment of autotrophs to substrate surfaces.”

The relationships between turbidity and TSS presented in Table 3.4 were used to develop target TSS concentrations (i.e., numeric endpoints for the TMDLs). The target TSS concentrations developed for these TMDLs are shown in Table 6.1.

Table 6.1. Summary of target TSS concentrations.

| Stream Name | Sampling Station | Flow Category | Turbidity Criterion (NTU) | Target TSS (mg/L) |
|---|---|---|---|---|
| Sulphur River | RED0005 | Base flow | 21 | 24 |
| | | All flow | 32 | 34 |
| Red River | RED0009 | Base flow | 50 | 53 |
| | | All flow | 150 | 252 |

## 6.3 Methodology for TMDL Calculations

The methodology used for the turbidity TMDLs in the report is the load duration curve. Because loading capacity varies as a function of the flow present in the stream, these TMDLs represent a continuum of allowable loads (both point source and nonpoint source) over all flow conditions, rather than fixed at a single value. This methodology is described in an EPA guidance document titled "An Approach for Using Load Duration Curves in the Development of TMDLs" (EPA 2007). The steps for application of this methodology for the TMDLs in this report can be summarized as follows:

1. Develop flow duration curves (Section 6.4),
2. Convert the flow duration curve to load duration curve (Section 6.5),
3. Plot observed loads with the load duration curves (Section 6.6),
4. Calculate the TMDL and establish the MOS (Section 6.7),
5. Calculate existing and allowable loads from diffuse sources (Section 6.7.3),
6. Calculate allowable loads for non-stormwater point sources (Section 6.7.4), and
7. Calculate the loads reserved for future growth (Section 6.7.5).

## 6.4 Flow Duration Curves

For the Sulphur River, daily stream flows were estimated for each reach by adding ambient flows (Lake Wright Patman releases plus ambient flows originating downstream of Lake Wright Patman), allowable effluent flows from the International Paper Texarkana Mill, and estimated flows from upstream WWTPs in the Days Creek watershed. Selected percentiles of the daily flow data were calculated for each reach.

For the Red River, daily stream flows at the downstream end of reach 11140201-003 were estimated by taking published flows from the USGS gage at Spring Bank (07344370; just downstream of the mouth of the Sulphur River) and adding local ambient inflow that was estimated based on the Red River drainage area between the USGS gage and the Arkansas/Louisiana state line. Selected percentiles of the daily flow data were calculated.

Each flow duration curve was then formulated as daily flow (cfs) versus percent exceedance (100% minus percentile ranking). Each flow duration curve was divided into five hydrologic ranges: high flows (0%-10% exceedance), moist conditions (10%-40% exceedance), mid-range flows (40%-60% exceedance), dry conditions (60%-90% exceedance), and low flows (90%-100% exceedance). These ranges were defined the same as in EPA's guidance document for load duration curves (EPA 2007). The flow duration curve for the farthest downstream Sulphur River reach (11140302-001) is shown on Figure E.1 (Appendix E). The flow duration curve for Red River reach 11140201-003 is shown on Figure F.1 in Appendix F.

## 6.5 Load Duration Curves

For each TMDL, the flow values from the flow duration curves were multiplied by the appropriate target concentration of TSS (from Section 6.2) to make a duration curve of allowable loads. Each load duration curve is a plot of tons per day of TSS versus the percent exceedances from the flow duration curve. The load duration curves for the Sulphur River are shown on Figures E.2 through E.6 (Appendix E), and the load duration curve for the Red River is shown in Figure F.2 (Appendix F). The calculations for these load duration curves are shown in Tables E.1 through E.5 (Appendix E) for the Sulphur River reaches, and Table F.1 (Appendix F) for the Red River.

The load duration curve shows the calculation of the TMDL at a wide range of flows rather than at a single critical flow. The official TMDL number is reported as one or more discrete numbers, but the curve is provided to demonstrate the value of the acceptable load at other flows. This will allow analysis of load cases in the future for different flow regimes.

## 6.6 Observed Loads

The plots of the load duration curves for Sulphur River reach 11140302-006 and Red River reach 11140201-003 also show observed loads on sampling days because those are the two stream reaches for which observed TSS data were available. The observed loads were calculated by multiplying observed TSS concentrations from the ADEQ stations in the reaches by the estimated flow at the downstream end of the reach on the sampling day. These observed loads were then plotted versus the percent exceedances of the flow on the sampling day and placed on the plot with the corresponding load duration curve. These plots with the load duration curves and observed loads are shown in Appendices E and F of this report as listed in Section 6.5.

These plots provide visual comparisons between observed and allowable loads under different flow conditions. Observed loads that are plotted above the load duration curve (identified as "TMDL" curve in the legend) represent conditions where observed loads exceed the loads corresponding to the numeric criterion from the calculated target concentration. Observed loads below the load duration curve represent conditions where observed loads were less than loads corresponding to the numeric criterion or target concentration (i.e., not violating water quality standards).

The load duration curve is beneficial when analyzing monitoring data with its corresponding flow information plotted as a load. This allows the monitoring data to be plotted in relation to its place in the flow continuum.

## 6.7 TMDL Calculations

The turbidity TMDLs are summarized in Table 6.2. The methods used to calculate each element of the TMDLs are described below.

Table 6.2. Summary of turbidity TMDLs for the Sulphur River and Red River.

| Stream Reach | Hydrologic Range | Allowable Loads of TSS (tons/day) | | | | | |
|---|---|---|---|---|---|---|---|
| | | LA for Non-Regulated Diffuse Sources | WLA for NPDES Regulated Stormwater | WLA for Non-Stormwater Point Sources | MOS | Future Growth | TMDL |
| Sulphur River 11140302-008 | Low flows | 0.69 | 0.01 | ~~0*~~ NA | implicit | 0 | 0.70 |
| | Dry cond. | 11.26 | 0.01 | ~~0*~~ NA | implicit | 0 | 11.27 |
| | Mid-range | 44.75 | 0.01 | ~~0*~~ NA | implicit | 0 | 44.76 |
| | Moist cond. | 201.46 | 0.03 | ~~0*~~ NA | implicit | 52.24 | 253.73 |
| | High flows | 326.85 | 0.04 | ~~0*~~ NA | implicit | 683.49 | 1010.38 |
| Sulphur River 11140302-006 | Low flows | 0.74 | 0.01 | ~~0*~~ NA | implicit | 0 | 0.75 |
| | Dry cond. | 11.33 | 0.01 | ~~0*~~ NA | implicit | 0 | 11.34 |
| | Mid-range | 48.03 | 0.01 | ~~0*~~ NA | implicit | 0 | 48.04 |
| | Moist cond. | 205.27 | 0.03 | ~~0*~~ NA | implicit | 53.23 | 258.53 |
| | High flows | 329.81 | 0.04 | ~~0*~~ NA | implicit | 689.69 | 1019.54 |
| Sulphur River 11140302-004 | Low flows | 0.75 | 0* | ~~0*~~ NA | implicit | 0 | 0.75 |
| | Dry cond. | 11.35 | 0* | ~~0*~~ NA | implicit | 0 | 11.35 |
| | Mid-range | 49.60 | 0* | ~~0*~~ NA | implicit | 0 | 49.60 |
| | Moist cond. | 207.51 | 0* | ~~0*~~ NA | implicit | 53.80 | 261.31 |
| | High flows | 330.96 | 0* | ~~0*~~ NA | implicit | 692.00 | 1022.96 |
| Sulphur River 11140302-002 | Low flows | 2.25 | 0.01 | ~~0*~~ NA | implicit | 0 | 2.26 |
| | Dry cond. | 13.16 | 0.01 | ~~0*~~ NA | implicit | 0 | 13.17 |
| | Mid-range | 58.84 | 0.01 | ~~0*~~ NA | implicit | 0 | 58.85 |
| | Moist cond. | 221.33 | 0.01 | ~~0*~~ NA | implicit | 57.38 | 278.72 |
| | High flows | 340.17 | 0.01 | ~~0*~~ NA | implicit | 711.28 | 1051.46 |
| Sulphur River 11140302-001 | Low flows | 2.26 | 0* | ~~0*~~ NA | implicit | 0 | 2.26 |
| | Dry cond. | 13.18 | 0* | ~~0*~~ NA | implicit | 0 | 13.18 |
| | Mid-range | 59.20 | 0* | ~~0*~~ NA | implicit | 0 | 59.20 |
| | Moist cond. | 221.75 | 0* | ~~0*~~ NA | implicit | 57.49 | 279.24 |
| | High flows | 340.52 | 0* | ~~0*~~ NA | implicit | 712.00 | 1052.52 |
| Red River 11140201-003 | Low flows | 144.5 | 0* | ~~0*~~ NA | implicit | 57.1 | 201.6 |
| | Dry cond. | 300.4 | 0* | ~~0*~~ NA | implicit | 87.9 | 388.3 |
| | Mid-range | 957 | 0* | ~~0*~~ NA | implicit | 3427 | 4384 |
| | Moist cond. | 2747 | 0* | ~~0*~~ NA | implicit | 6362 | 9109 |
| | High flows | 11524 | 0* | ~~0*~~ NA | implicit | 23892 | 35416 |

~~*Note: These WLAs are zero because there are currently no discharges to these reaches for these hydrologic ranges. Future discharges are allowable if they do not violate water quality standards.~~

### 6.7.1 TMDLs

The TMDLs were set equal to the allowable loads for the minimum flow within each hydrologic range. In other words, TMDLs were set to the allowable loads with an exceedance of 10% for high flows, 40% for moist conditions, 60% for mid-range flows, and 90% for dry conditions. For low-flow conditions, the Red River allowable loads were computed for stream flows at the 7Q10 flow, which was estimated to be approximately 1,400 cfs based on the published 7Q10 flow for the Red River at Index, AR (1,240 cfs; USGS 2008) plus additional inflows from the Little River and Sulphur River. For the Sulphur River reaches, the allowable loads for low-flow conditions were computed for the 99.9 percent exceedance level because those flows were consistent with published ranges of 7Q10 flows for the Sulphur River (USGS 1983). These calculations for TMDLs for each hydrologic range are shown for the Sulphur River in Tables E.7 through E.11 (Appendix E) and for the Red River in Table F.3 (Appendix F).

### 6.7.2 MOS

Both Section 303(d) of the Clean Water Act and regulations at 40 CFR 130.7 require TMDLs to include an MOS to account for any lack of knowledge concerning the relationship between pollutant loading and water quality. The MOS may be expressed explicitly as unallocated assimilative capacity or implicitly through conservative assumptions used in establishing the TMDL. For the TMDLs in this report, an implicit MOS was established by setting each TMDL equal to the allowable load for the minimum flow within each hydrologic range rather than at the median flow for the range. This procedure is conservative because the allowable load is lowest at the minimum flow.

### 6.7.3 Loads from Diffuse Sources

Loads from diffuse sources consist of (1) industrial or municipal stormwater that is regulated by an NPDES permit, and (2) nonpoint source runoff or baseflow from all other areas that are not regulated by an NPDES permit. The total existing loads from diffuse sources were calculated for each hydrologic range using the same percent exceedance flows as for calculating the TMDLs. The ambient stream flows were multiplied by existing average concentrations from diffuse sources. The existing average concentrations for the different hydrologic ranges were estimated from historical water quality data for the ADEQ monitoring sites within the study area. For each monitoring site, the water quality data were averaged within each of the hydrologic ranges, based on the stream flow rate on the sampling date. These calculations are shown in Tables E.6 and F.2. The average concentrations are shown in Table 6.3. The calculated loads from diffuse sources are shown on the rows labeled "Existing load from diffuse sources" in Tables E.7 through E.11 and F.3.

Table 6.3. Average existing TSS concentrations from diffuse sources.

| Stream | Average Existing Concentration (mg/L) from Diffuse Sources for Each Hydrologic Range | | | | | Reductions of Diffuse Sources Needed? |
|---|---|---|---|---|---|---|
| | High Flows | Moist Cond. | Mid-Range Flows | Dry Cond. | Low Flows | |
| Sulphur River (RED0005) | 11 | 27 | 43 | 54 | 51 | Yes, for flows at mid-range and lower |
| Red River (RED0009) | 82 | 76 | 55 | 41 | 38 | No |

The allowable diffuse loads were calculated in the same manner as the existing diffuse loads except that the concentration used in the calculation was not allowed to exceed the applicable TSS target concentration. In other words, the ambient flow rate for each hydrologic range was multiplied by either the target concentration or the average existing concentration in Table 6.3, whichever was lower. The results of these calculations are shown in Tables E.7 through E.11 and F.3 (rows labeled "Allowable load from diffuse sources").

The allowable diffuse loads were then divided into WLAs for stormwater regulated by an NPDES permit and LAs for all other diffuse loading. Dividing the diffuse loading was necessary because EPA requires loads from stormwater regulated by an NPDES permit to be classified as a WLA rather than an LA (EPA 2002). The total diffuse loading was divided based on drainage area. Because information concerning drainage area was not available for individual stormwater facilities, each facility was assumed to cover 40 acres. The WLA for regulated stormwater was then calculated as the total diffuse loading multiplied by the percentage of the total drainage area that was comprised of facilities with regulated stormwater discharges. The remainder of the total diffuse loading was assigned to the LA.

The WLAs for regulated stormwater were not specified for individual facilities because there was not sufficient information available. EPA's latest guidance for stormwater WLAs recommends that "WLAs for NPDES-regulated stormwater discharges be disaggregated ... to the extent feasible based on available data and/or modeling projections" and that "these disaggregated WLAs should be defined as narrowly as available information allows ..." (EPA 2010). For this report, though, the WLAs for regulated stormwater were not disaggregated because there is no readily available information concerning either the quantity or quality of regulated stormwater discharges in the study area.

### 6.7.4 Non-Stormwater Point Source Discharges

The WLAs for non-stormwater point source loads were set to ~~zero~~ NA because the surrogate being used for turbidity (TSS) is considered to represent inorganic suspended solids (i.e., soil and sediment particles from erosion or sediment resuspension). The suspended solids discharged by the two non-stormwater point sources discharging to these streams are assumed to consist primarily of organic solids rather than inorganic solids (see Section 2.6). Discharges of organic suspended solids from point sources are already addressed through the permitting of point sources to maintain water quality standards for dissolved oxygen.

### 6.7.5 Loads Reserved for Future Growth

For certain flow conditions, the total allowable loading to meet the criterion (i.e., the TMDL) exceeded the sum of the loading that was allocated to non-regulated diffuse sources, NPDES-regulated stormwater, and continuous point source discharges. The portion of the allowable loading that exceeded the sum of the allocations was reserved for future growth of either nonpoint or point sources. The loads reserved for future growth are calculated in Tables E.7 through E.11 and F.3. These calculations show that future growth is permissible for certain reaches during certain hydrologic conditions.

## 6.8 Implementation in NPDES Permits

This TMDL report provides allowable loadings but does not specify numeric permit limits because the permitting authorities (ADEQ and TCEQ) will calculate limits where applicable when permits are issued, modified, or renewed. The permitting authorities can take into account detailed information such as specific discharge regimes of individual facilities to ensure that the discharges do not cause or contribute to a violation of water quality standards. EPA regulations at 40 CFR 122.44(d)(1)(iii) require an NPDES permit to have numeric limits when the discharge has reasonable potential to cause or contribute to a violation of water quality standards. However, there are no state or federal regulations that require numeric limits if the discharge does not have reasonable potential to cause or contribute to a violation of water quality standards. Reasonable potential can be determined much more effectively during the permitting process rather than during development of the TMDL.

EPA regulations at 40 CFR 122.44(d)(1)(vii)(B) require that permit limits be “consistent with the assumptions and requirements” of WLAs in approved TMDLs. If a discharge does not have reasonable potential to exceed the allowable load determined from a TMDL, numeric limits are not required in the NPDES permit for that discharge because the expected load would be less than (i.e., consistent with) the allowable load in the TMDL.

The NPDES permits that regulate stormwater in the study area do not currently contain numeric limits for turbidity or TSS. EPA’s 2002 guidance concerning stormwater WLAs and permits stated that “most WQBELs [water quality-based effluent limitations] for NPDES-regulated municipal and small construction storm water discharges will be in the form of BMPs, and that numeric limits will be used only in rare instances” (EPA 2002). Since that time, EPA has issued revised guidance, stating the following:

> "EPA recommends that NPDES permitting authorities use numeric effluent limitations where feasible.... The permitting authority's decision as to how to express the WQBEL(s), either as numeric effluent limitations or BMPs, including BMPs accompanied by numeric benchmarks, should be based on an analysis of the specific facts and circumstances surrounding the permit, and/or the underlying WLA, including the nature of the stormwater discharge, available data, modeling results or other relevant information" (EPA 2010).

The use of BMPs to control the discharge of pollutants from stormwater is consistent with EPA regulations at 40 CFR 122.44(k). In the Sulphur River, erosion has been identified as a source of the turbidity/siltation impairment.

Future growth for point sources (i.e., growth of existing facilities or establishment of new point sources) is allowed by these TMDLs as long as the discharge does not cause or contribute to a downstream violation of water quality standards for turbidity or sediment (including narrative criteria prohibiting excessive silt deposits).

# 7.0 OTHER RELEVANT INFORMATION

## 7.1 Ambient Monitoring

In accordance with Section 106 of the Federal Clean Water Act and under its own authority, ADEQ has established a comprehensive program for monitoring the quality of the state's surface waters. ADEQ collects surface water samples at various locations, utilizing appropriate sampling methods and procedures for ensuring the quality of the data collected. The objectives of the surface water monitoring program are to determine the quality of the state's surface waters, to develop a long-term data base for long-term trend analysis, and to monitor the effectiveness of pollution controls. The data obtained through the surface water monitoring program is used to develop the state's biennial 305(b) report (*Water Quality Inventory*) and the 303(d) list of impaired waters, which are issued as a single document titled *Arkansas Integrated Water Quality Monitoring and Assessment Report*.

## 7.2 Reasonable Assurances

This section of the TMDL report focuses on implementation activities that have reasonable potential to achieve the WLAs and LAs presented in this report. The focus of this section is to identify the most appropriate structural and non-structural best management practices (BMPs) and control technologies to reduce temperature as well as turbidity/TSS loads from sources throughout the watershed.

Many BMPs intended to reduce TSS may have a beneficial impact on in-stream temperatures. Increased TSS leads to pools being filled in with sediment, leaving shallower streams, which are more likely to have higher temperatures. Wide streams may also be more susceptible to higher water temperatures as there is less stream area protected by shade provided by riparian buffers. Erosive land use practices may lead to increased TSS, which leads to more turbid waters, which in turn causes increased temperature as suspended sediments darken water and absorb more heat from sunlight, thus increasing the temperature of the water.

Implementation, including the BMPs listed in the table below, can reduce turbidity and TSS loads. The implementation of BMPs to reduce the turbidity and TSS within the Red and

Sulphur Rivers will reasonably assure that reductions in the turbidity, TSS loads and temperature will occur, allowing the rivers to meet allocations.

Table 7.1. Pollutants and sources addressed by various BMPs.

| | Pollutant | Point Sources | | | | | Nonpoint Sources | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Implementation Activities** | **Sediment** | **WWTPs and Industrial Facilities** | **CSOs** | **Regulated Stormwater Sources** | **CAFOs** | **Illicitly Connected “ Straight Pipe” Systems** | **Cropland** | **Pastures and Livestock Operations** | **CFOs and AFOs** | **Streambank Erosion** | **Onsite Wastewater Treatment Systems** | **Wildlife/Domestic Pets** |
| Inspection and maintenance | X | X | X | X | X | | | | | | X | |
| Outreach and education and training | X | X | X | X | X | X | X | X | X | X | X | X |
| Conservation tillage/residue management | X | | | | | | X | | | | | |
| Cover crops | X | | | | | | X | | | X | | |
| Filter strips | X | | | X | X | | X | X | X | X | | |
| Grassed waterways | X | | | | X | | X | | X | X | | |
| Riparian buffers | X | | | | X | | X | X | X | X | | X |
| Stream fencing (animal exclusion) | X | | | | | | | X | | | | |
| Grazing land management | X | | | | | | | X | | X | | |
| Conservation easements | X | | | | | | | | | | | |
| Levee or dike modification or removal | X | | | | | | | | | | | |
| Constructed wetland | X | X | | | | X | X | | | | | X |
| Critical area planting | X | | | | | | | X | | X | | |
| Terrace | X | | | | | | X | | | | | |

# 8.0 PUBLIC PARTICIPATION

Federal regulations at 40 CFR 130.7(c)(1)(ii) specify that TMDLs shall be subject to public review as defined in the state's Continuing Planning Process (CPP). In accordance with this requirement, ADEQ conducted a public review period to seek comments and relevant information from the public concerning the TMDLs in this report. The public review period was initiated on August 3, 2012 and concluded on September 4, 2012. This report was available on ADEQ's web site throughout the public review period. ADEQ did not receive any public comments concerning these TMDLs during the public review period.

# 9.0 REFERENCES

ADEQ. 2008. *2008 Integrated Water Quality Monitoring and Assessment Report*. Prepared pursuant to Section 305(b) and 303(d) of the Federal Water Pollution Control Act. Published by Arkansas Department of Environmental Quality. Downloaded from ADEQ web site (www.adeq.state.ar.us/water/branch_planning/pdfs/WQ08-04-01.pdf).

APCEC. 2011. *Regulation No. 2, As Amended. Regulation Establishing Water Quality Standards for Surface Waters of the State of Arkansas.* Adopted by the Arkansas Pollution Control and Ecology Commission on August 26, 2011. Effective September 26, 2011. Downloaded from ADEQ web site (www.adeq.state.ar.us/regs/files/reg02_final_110926.pdf).

EPA. 1991. *Monitoring Guidelines to Evaluate Effects of Forestry Activities on Streams in Pacific Northwest* [EPA 910/9-91/001]. United States Environmental Protection Agency, Region 10. Seattle, WA.

EPA. 2002. "Establishing Total Maximum Daily Load (TMDL) Wasteload Allocations (WLAs) for Storm Water Sources and NPDES Permit Requirements Based on Those WLAs". Memorandum from Robert Wayland and James Hanlon to Regional Water Division Directors. Dated November 22, 2002. Downloaded from EPA web site (http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/upload/final-wwtmdl.pdf).

EPA. 2007. *An Approach for Using Load Duration Curves in the Development of TMDLs* [EPA 841-B-07-006]. US Environmental Protection Agency, Office of Wetlands, Oceans and Watersheds. Downloaded from EPA web site (http://water.epa.gov/lawsregs/ lawsguidance/cwa/tmdl/upload/2007_08_23_tmdl_duration_curve_guide_aug2007.pdf)

EPA. 2008. *Approved Arkansas 2008 Section 303(d) List*. Downloaded from EPA web site (www.epa.gov/Region6/water/npdes/tmdl/303d/ar/2008-epa-final-approved-list.pdf).

EPA. 2010. "Revisions to the November 22, 2002 Memorandum 'Establishing Total Maximum Daily Load (TMDL) Wasteload Allocations (WLAs) for Storm Water Sources and NPDES Permit Requirements Based on Those WLAs.'" Memorandum from James Hanlon and Denise Keehner to Regional Water Management Division Directors. Dated November 12, 2010. Downloaded from EPA web site (www.epa.gov/npdes/pubs/establishingtmdlwla_revision.pdf)

LDEQ. 2011. Surface Water Quality Standards. Title 33 Environmental Regulatory Code, Part IX Water Quality, Chapter 11. With amendments through October 2011. Downloaded from Louisiana Department of Environmental Quality web site (www.deq.louisiana.gov/portal/Portals/0/planning/regs/title33/33v09-201110.pdf)

MRLC. 2011. *National Land Cover Database 2006*. Data generated by the Multi-Resolution Land Characterization consortium. Downloaded from the MRLC web site (http://www.mrlc.gov/nlcd2006.php).

Relyea, C.D., C.W. Marshall, and R.J. Danehy. 2000. *Stream insects as indicators of fine sediment*. Stream Ecology Center, Idaho State University, Pocatello, ID. Presented at WEF 2000 Watershed Management Conference.

TCEQ. 2010. Texas Surface Water Quality Standards. Texas Administrative Code, Title 30, Part 1, Chapter 307, Rule §307.10, Appendix A (Site-specific Uses and Criteria for Classified Segments). Available online at http://info.sos.state.tx.us/fids/201003720-6.pdf

USGS. 1978. *Drainage Areas of Streams in Arkansas, Red River Basin*. Open-File Report. By M.S. Hines and J.J. Yanchosek. United States Geological Survey, Little Rock, AR.

USGS. 1983. Identification and Classification of Perennial Streams of Arkansas. Water Resources Investigations Report 83-4063. By R. A. Hunrichs, U.S. Geological Survey, Little Rock, Arkansas.

USGS. 2003. *Low-flow Characteristics of Louisiana Streams*. Water Resources Technical Report No. 70. By P.A. Ensminger, and L.S. Wright, US Geological Survey, Baton Rouge, LA.

USGS. 2008. *Low-flow characteristics and regionalization of low-flow characteristics for selected streams in Arkansas*. Scientific Investigations Report 2008-5065. By J.E. Funkhouser, K. Eng, and M.W. Moix, U.S. Geological Survey, Little Rock, AR.

USGS. 2011. *Water Data Report 2010 – 07344370 Red River at Spring Bank, AR*. US Geological Survey. October 2011. Downloaded from USGS web site (http://wdr.water.usgs.gov/wy2010/pdfs/07344370.2010.pdf).

Zar, J.H. 1996. *Biostatistical Analysis, 3rd edition*. Prentice Hall. New Jersey.

# APPENDIX A

**Maps of Watershed, Land Use and Point Sources**

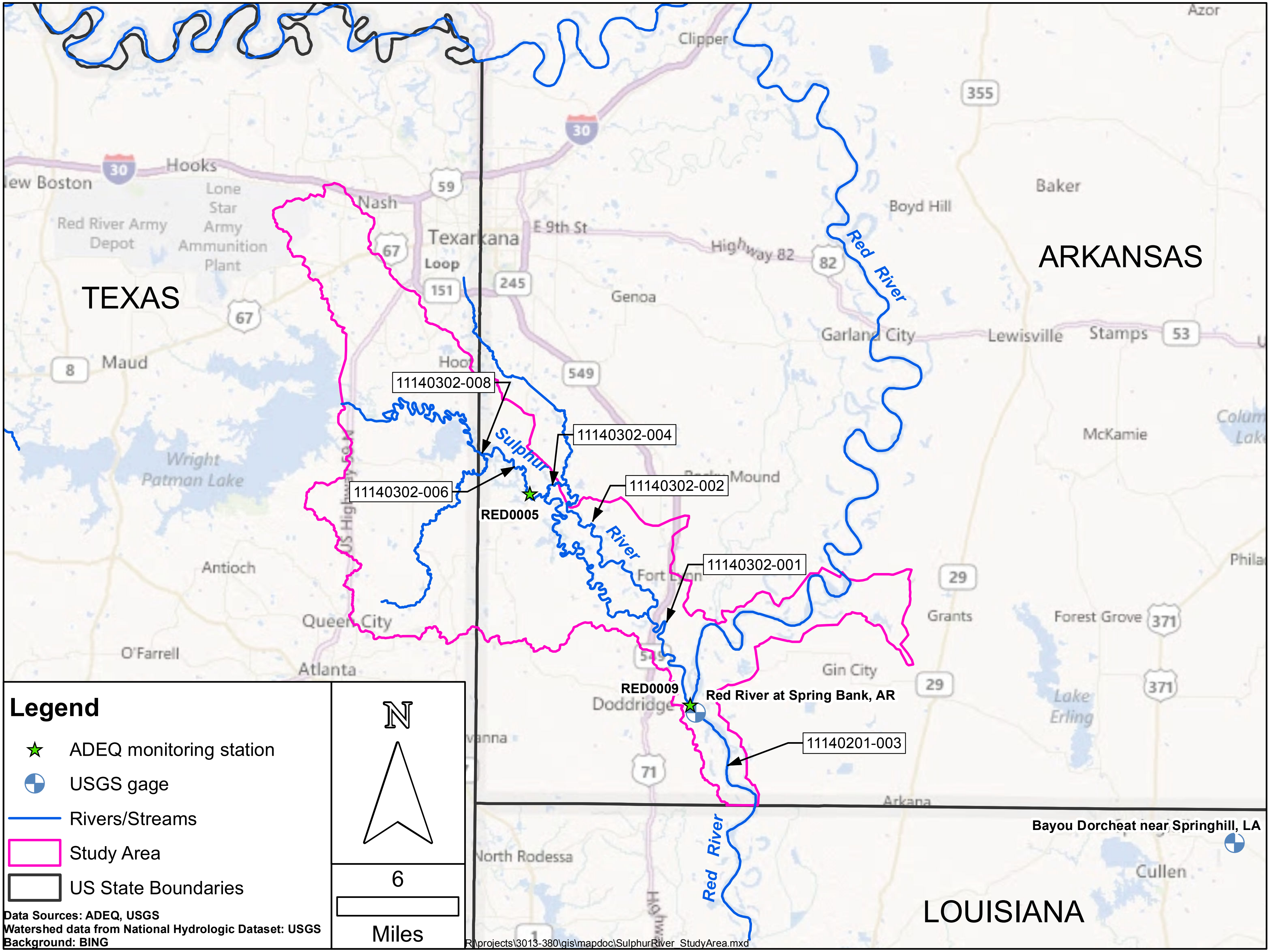



Figure A.1. Study Area Map

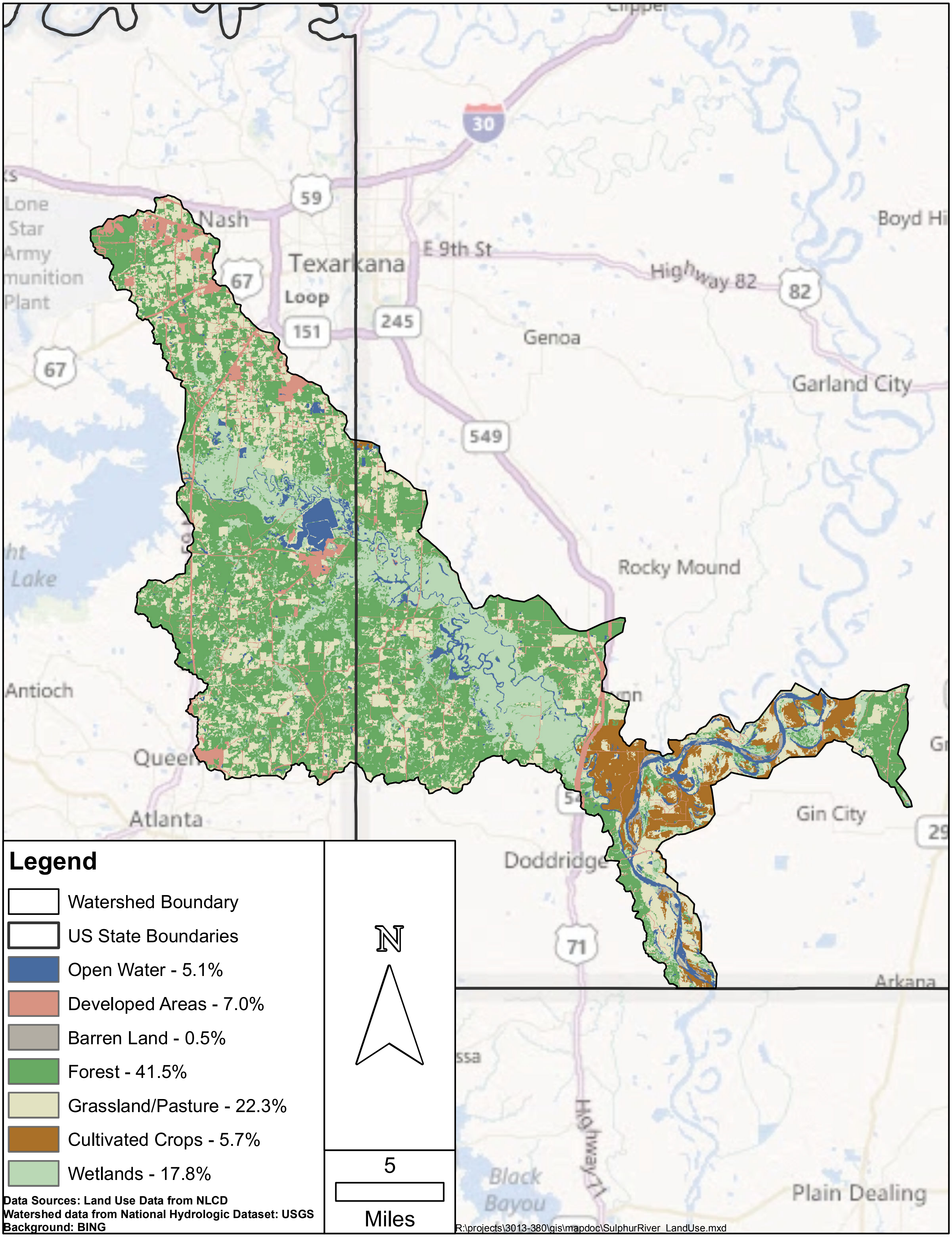



Figure A.2. Land use map

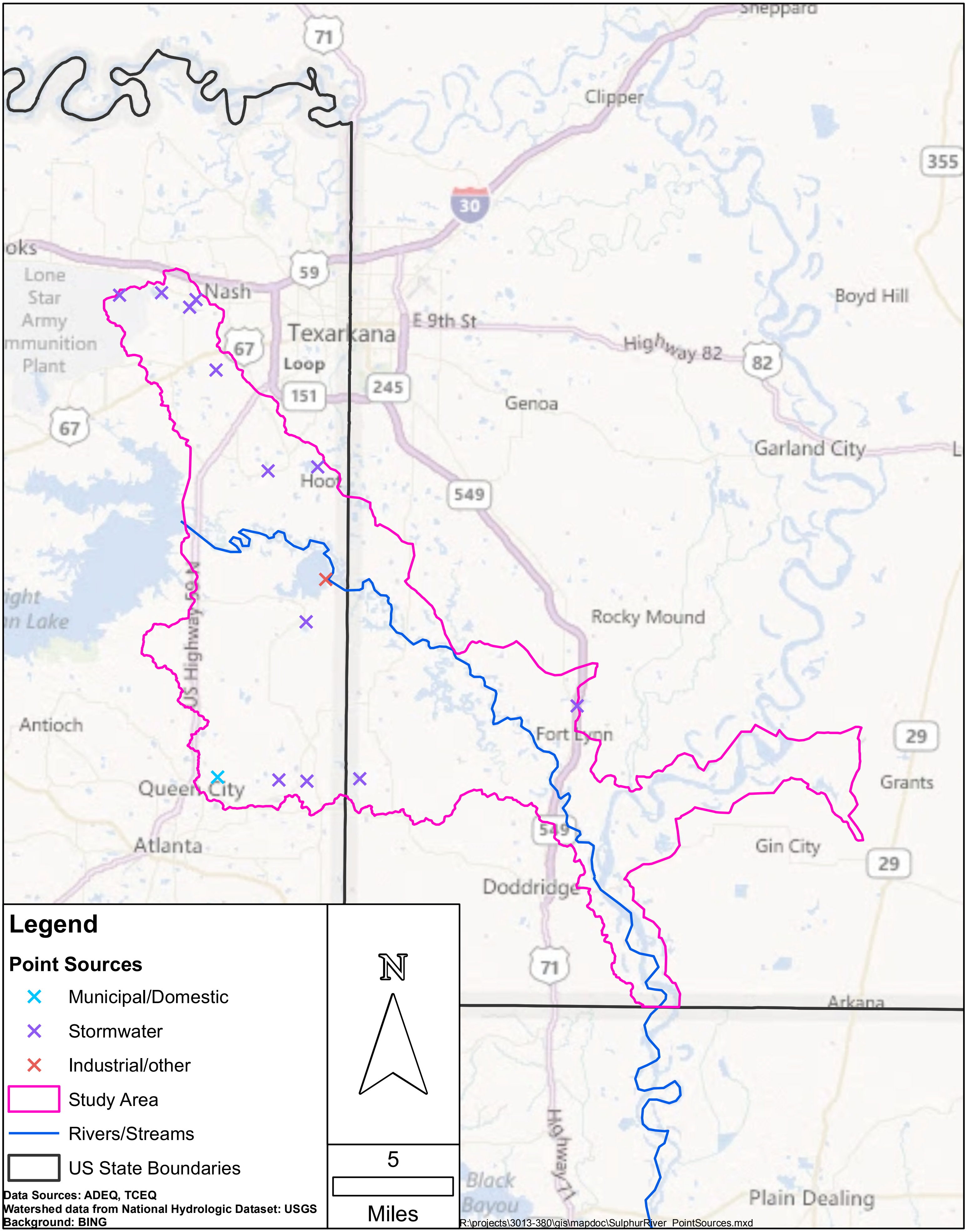



Figure A.3. Point Source Map

Table A.1. Inventory of Permitted Discharges in the Study Area
for
Temperature and Turbidity TMDLs for the Sulphur River and Red River, Arkansas

Sorted by “First impaired reach downstream”, and then by “Permit number”

| Permit number | Facility name | Type of discharge | Flow rate (MGD) | Receiving waterbody | First impaired reach down-stream | Permit expiration date |
|---|---|---|---|---|---|---|
| ARR10C801 | Ark Hwy Dept / Fouke-South | Storm Runoff | n.a. | Unnamed Tributary, Sulphur River | 11140302-002 | 12/31/2011 |
| TXR05Z598 | International Paper Co. Texarkana Mill | Storm Runoff | n.a. | Unnamed Tributary, Sulphur River | 11140302-006 | 8/14/2016 |
| TXR15PR02 | TX Dept of Transportation -Atl-Csj3195-01-010 | Storm Runoff | n.a. | Sulphur River | 11140302-006 | 3/5/2013 |
| TXR15SP26 | TX Dept of Transportation -Atl-Csj 0218-03-076 Etc | Storm Runoff | n.a. | Sulphur River Basin | 11140302-006 | 3/5/2013 |
| TXR15SR96 | International Paper Waste Water Lagoon Improvements | Storm Runoff | n.a. | Area Creeks Thence To Sulphur River | 11140302-006 | 3/5/2013 |
| TX0000167 | International Paper Co. Texarkana Mill | Industrial Wastewater | 646.3* | Baker Slough, Sulphur River | 11140302-008 | 1/1/2012 |
| TX0034797 | City Of Queen City WWTP | Municipal Wastewater | 0.25 | Cypress Creek, Cypress Slough, Sulphur River | 11140302-008 | 1/1/2013 |
| TXR05AE46 | Specified C&D Recycling Yard | Storm Runoff | n.a. | Sulpher River via drainage | 11140302-008 | 8/14/2016 |
| TXR05L095 | Lone Star Army Ammunition Plant | Storm Runoff | n.a. | Red River; Sulphur River; and Wright Patman Lake | 11140302-008 | 8/14/2016 |

| Permit number | Facility name | Type of discharge | Flow rate (MGD) | Receiving waterbody | First impaired reach down-stream | Permit expiration date |
|---|---|---|---|---|---|---|
| TXR05N304 | JCM Industries | Storm Runoff | n.a. | Unnamed Tributary, Aiken Creek | 11140302-008 | 8/14/2016 |
| TXR05O455 | Texana Tank Car | Storm Runoff | n.a. | Aiken Creek | 11140302-008 | 8/14/2016 |
| TXR05Q775 | Martin Nash Facility | Storm Runoff | n.a. | Aiken Creek | 11140302-008 | 8/14/2016 |
| TXR15MX58 | New House Construction | Storm Runoff | n.a. | | 11140302-008 | 3/5/2013 |
| TXR15PC54 | Buchanan Road Pit | Storm Runoff | n.a. | Crutchers Creek | 11140302-008 | 3/5/2013 |

*Daily average effluent flow is limited by the flow in the Sulphur River at Wright Patman Dam. The allowable effluent flow as a percentage of Sulphur River flow varies from 0% in May, July, and August to 100% in January (Outfall 001B). The maximum daily flow can never exceed 646.3 MGD.

# APPENDIX B

**Tabular Listings and Plots of Historic Water Quality Data**

Table B.1  Historical Water Quality Data for Sulphur River south of Texarkana, AR

| Site ID | Date Collected | Temperature (°C) | Turbidity (NTU) | Base-flow Turbidity (NTU) | TSS (mg/L) | Base-flow TSS (mg/L) |
|---|---|---|---|---|---|---|
| RED0005 | 9/4/1990 | 30 | 8.1 | | 18 | |
| RED0005 | 10/2/1990 | 25 | 30 | | 54 | |
| RED0005 | 10/30/1990 | 17 | 8.0 | | 28 | |
| RED0005 | 11/27/1990 | 18 | 9.4 | | 36 | |
| RED0005 | 1/22/1991 | 6 | 38 | | 23 | |
| RED0005 | 2/19/1991 | 12 | 44 | | 42 | |
| RED0005 | 3/26/1991 | 20 | 38 | | 39 | |
| RED0005 | 4/16/1991 | 21 | 28 | | | |
| RED0005 | 5/21/1991 | 25 | 18 | | 12 | |
| RED0005 | 6/18/1991 | 29 | 29 | | 43 | |
| RED0005 | 7/16/1991 | 28 | 28 | | 38 | |
| RED0005 | 8/20/1991 | 28 | 40 | 40 | 27.5 | 27.5 |
| RED0005 | 9/17/1991 | 28 | 9 | | 43 | |
| RED0005 | 10/15/1991 | 20 | 24 | | 36 | |
| RED0005 | 11/12/1991 | 13 | 22 | | 72 | |
| RED0005 | 12/10/1991 | | 18 | | 15 | |
| RED0005 | 1/21/1992 | 7 | 27 | | 22 | |
| RED0005 | 2/25/1992 | 13 | 29 | | 24 | |
| RED0005 | 3/17/1992 | 15 | 27 | | 16 | |
| RED0005 | 4/21/1992 | 20 | 28 | | 37 | |
| RED0005 | 5/19/1992 | 26 | 21 | 21 | 36 | 36 |
| RED0005 | 6/16/1992 | 26 | 11 | | 4 | |
| RED0005 | 7/21/1992 | 28 | 9 | | 14 | |
| RED0005 | 8/18/1992 | 25 | 10 | | 16 | |
| RED0005 | 9/15/1992 | 27 | 41 | | 28 | |
| RED0005 | 10/13/1992 | 21 | 16 | | 34 | |
| RED0005 | 11/9/1992 | 14 | 14 | 14 | 26 | 26 |
| RED0005 | 12/8/1992 | 7 | 21 | | 22 | |
| RED0005 | 1/26/1993 | 8 | 24 | | 16 | |
| RED0005 | 2/23/1993 | 10 | 22 | | 32 | |
| RED0005 | 3/23/1993 | 14 | 28 | | 26 | |
| RED0005 | 5/4/1993 | 18 | 19 | | 28 | |
| RED0005 | 5/17/1993 | 23 | 13 | | 25 | |
| RED0005 | 6/29/1993 | 29 | 21 | | 40.0 | |
| RED0005 | 7/13/1993 | 31 | 33 | 33 | 37 | 37 |
| RED0005 | 8/10/1993 | 28 | 45 | 45 | 76 | 76 |
| RED0005 | 9/7/1993 | 29 | 28 | 28 | 46 | 46 |
| RED0005 | 10/12/1993 | 23 | 35 | 35 | 46 | 46 |
| RED0005 | 11/9/1993 | 13 | 16 | | 6 | |
| RED0005 | 12/21/1993 | 11.0 | 34 | | 10.5 | |
| RED0005 | 1/25/1994 | 13.0 | 19 | | 19.5 | |
| RED0005 | 2/14/1994 | 9 | 12 | | 32.5 | |

| Site ID | Date Collected | Temperature (°C) | Turbidity (NTU) | Base-flow Turbidity (NTU) | TSS (mg/L) | Base-flow TSS (mg/L) |
|---|---|---|---|---|---|---|
| RED0005 | 3/14/1994 | 15 | 26 | | 12.0 | |
| RED0005 | 4/18/1994 | 21 | 29 | | 32.5 | |
| RED0005 | 5/23/1994 | 25 | 11 | | 27.0 | |
| RED0005 | 6/27/1994 | 30 | 50 | 50 | 87.0 | 87.0 |
| RED0005 | 7/18/1994 | 29 | 16 | | 56.5 | |
| RED0005 | 8/15/1994 | 26 | 37 | | 67.5 | |
| RED0005 | 9/26/1994 | 23 | 24 | 24 | 53.5 | 53.5 |
| RED0005 | 10/24/1994 | 21 | 15 | | 29.5 | |
| RED0005 | 11/29/1994 | 15 | 22 | | 23.0 | |
| RED0005 | 12/20/1994 | 10.5 | 11 | | 9.5 | |
| RED0005 | 1/9/1995 | | 19 | | | |
| RED0005 | 2/13/1995 | 7 | 26 | | 9 | |
| RED0005 | 3/27/1995 | | 15 | | 32* | |
| RED0005 | 4/24/1995 | | 16 | | 15.5 | |
| RED0005 | 5/22/1995 | 23 | 18 | | 10.5 | |
| RED0005 | 6/19/1995 | 26 | 23 | | 48.5 | |
| RED0005 | 7/18/1995 | | 27 | 27 | 55.0 | 55.0 |
| RED0005 | 8/7/1995 | 29 | 32 | 32 | 62.0 | 62.0 |
| RED0005 | 9/18/1995 | 25 | 41 | 41 | 56.5 | 56.5 |
| RED0005 | 10/16/1995 | 21 | 30 | | 78.0 | |
| RED0005 | 11/14/1995 | 13 | 15 | | 21.5 | |
| RED0005 | 11/28/1995 | 12 | 12 | | 17.5 | |
| RED0005 | 1/2/1996 | 8 | 15 | 15 | 21.5 | 21.5 |
| RED0005 | 2/13/1996 | 9 | 3 | 3 | 37.5 | 37.5 |
| RED0005 | 3/5/1996 | 15 | 3 | 3 | 41.0 | 41.0 |
| RED0005 | 4/2/1996 | 15 | 40 | 40 | 60.0 | 60.0 |
| RED0005 | 5/14/1996 | 23 | 48 | 48 | 61.0 | 61.0 |
| RED0005 | 6/11/1996 | 24 | 35 | | 53.0 | |
| RED0005 | 7/16/1996 | 31 | 37 | 37 | 44.0 | 44.0 |
| RED0005 | 8/20/1996 | 29 | 19 | | 39.0 | |
| RED0005 | 9/24/1996 | 24 | 35 | 35 | 55.0 | 55.0 |
| RED0005 | 10/22/1996 | 18 | 35 | | 48.0 | |
| RED0005 | 11/19/1996 | 14 | 18 | | 14.5 | |
| RED0005 | 12/17/1996 | 9 | 32 | | 6.5 | |
| RED0005 | 1/28/1997 | 8 | 35 | | 36.5 | |
| RED0005 | 2/25/1997 | 11 | 52 | | 18.5 | |
| RED0005 | 3/25/1997 | 18 | 40 | | 14.5* | |
| RED0005 | 4/14/1997 | 18 | 20 | | 4.5 | |
| RED0005 | 5/12/1997 | 20.4 | 13 | | 15.0 | |
| RED0005 | 6/16/1997 | 25.5 | 19 | | 27.0 | |
| RED0005 | 7/14/1997 | 33.2 | 39 | | 64.0 | |
| RED0005 | 8/25/1997 | 29 | 24 | 24 | 59.5 | 59.5 |
| RED0005 | 9/15/1997 | 28.8 | 37 | 37 | 50.0 | 50.0 |
| RED0005 | 10/21/1997 | 22 | 23 | | 49.0 | |

| Site ID | Date Collected | Temperature (°C) | Turbidity (NTU) | Base-flow Turbidity (NTU) | TSS (mg/L) | Base-flow TSS (mg/L) |
|---|---|---|---|---|---|---|
| RED0005 | 11/18/1997 | 11 | 13 | | 18.0* | |
| RED0005 | 12/16/1997 | 9.5 | 16 | | 20.0 | |
| RED0005 | 1/27/1998 | 11 | 30 | | 6.0 | |
| RED0005 | 2/17/1998 | 10 | 23 | | | |
| RED0005 | 3/3/1998 | 13 | 22 | | 9.0 | |
| RED0005 | 4/7/1998 | 21 | 29 | | 22.5 | |
| RED0005 | 5/5/1998 | 25 | 43 | 43 | 68.0 | 68.0 |
| RED0005 | 6/2/1998 | 28 | 27 | | 26.0 | |
| RED0005 | 7/21/1998 | 36 | 43 | 43 | 49.5 | 49.5 |
| RED0005 | 8/11/1998 | 30 | 60 | 60 | 57.5 | 57.5 |
| RED0005 | 9/22/1998 | 32 | 30 | 30 | 43.0 | 43.0 |
| RED0005 | 10/27/1998 | 20 | 16 | | 30.0 | |
| RED0005 | 11/17/1998 | 16 | 16 | | 28.0 | |
| RED0005 | 12/21/1998 | 13 | 29 | | 11.5 | |
| RED0005 | 1/26/1999 | 15 | 18 | | 9.5 | |
| RED0005 | 2/16/1999 | 14 | 21* | | 17.5 | |
| RED0005 | 3/23/1999 | 16 | 19 | | 24.0 | |
| RED0005 | 4/27/1999 | 23 | 44 | | 70.0* | |
| RED0005 | 5/18/1999 | 24 | 28 | 28 | 40.5 | 40.5 |
| RED0005 | 6/29/1999 | 30 | 39.5 | 39.5 | 62.0* | |
| RED0005 | 7/27/1999 | 34 | 78 | 78 | 72.0 | 72.0 |
| RED0005 | 8/31/1999 | | 26 | 26 | 39.0 | 39.0 |
| RED0005 | 9/28/1999 | 28 | 35 | 35 | 51.5 | 51.5 |
| RED0005 | 10/12/1999 | 26 | 43 | 43 | 64.0 | 64.0 |
| RED0005 | 11/16/1999 | 21 | 28 | 28 | 45.5 | 45.5 |
| RED0005 | 12/14/1999 | 12 | | | 48 | 48 |
| RED0005 | 1/18/2000 | 16 | 34 | 34 | 52.0 | 52.0 |
| RED0005 | 2/15/2000 | 14 | 26 | 26 | 42 | 42 |
| RED0005 | 3/21/2000 | 17 | 18 | | 31 | |
| RED0005 | 4/18/2000 | 21 | 23 | | 33 | |
| RED0005 | 5/23/2000 | 27 | 21 | | 38.5 | |
| RED0005 | 6/20/2000 | 29 | 20 | | | |
| RED0005 | 7/25/2000 | 31 | 57 | | 106.5 | |
| RED0005 | 8/29/2000 | 30 | | | 55.0 | 55.0 |
| RED0005 | 9/26/2000 | 23 | 40 | 40 | 60.0 | 60.0 |
| RED0005 | 10/24/2000 | 23 | 32 | 32 | 49.5 | 49.5 |
| RED0005 | 11/14/2000 | 13 | 12 | | 16.5 | |
| RED0005 | 12/18/2000 | 9 | 22 | | 5.5 | |
| RED0005 | 1/29/2001 | 11 | 29 | | 16.0 | |
| RED0005 | 2/26/2001 | 15 | 13 | | 6.0 | |
| RED0005 | 3/27/2001 | 13 | 18 | | 2.2 | |
| RED0005 | 4/16/2001 | 19 | 14 | | 7.0 | |
| RED0005 | 5/22/2001 | 22.5 | 6.8 | | 5.25* | |
| RED0005 | 6/19/2001 | 27 | 5.7 | | 6.8 | |

| Site ID | Date Collected | Temperature (°C) | Turbidity (NTU) | Base-flow Turbidity (NTU) | TSS (mg/L) | Base-flow TSS (mg/L) |
|---|---|---|---|---|---|---|
| RED0005 | 7/17/2001 | 30 | 45 | | 68.5 | |
| RED0005 | 8/21/2001 | 31 | 32 | 32 | 49.5 | 49.5 |
| RED0005 | 9/18/2001 | 26 | 29 | | 51.5 | |
| RED0005 | 10/23/2001 | 23 | 14 | | 21.8 | |
| RED0005 | 11/19/2001 | 17 | 47 | 47 | 60.0 | 60.0 |
| RED0005 | 12/11/2001 | 12 | 23 | | 19.5 | |
| RED0005 | 1/2/2002 | 6 | 45 | | 13.0 | |
| RED0005 | 2/19/2002 | 11 | 30 | | 4.5 | |
| RED0005 | 3/19/2002 | 14 | 27 | | 14.5 | |
| RED0005 | 4/16/2002 | 21 | 21 | | 13.5 | |
| RED0005 | 5/21/2002 | 22 | 40 | | 57.5 | |
| RED0005 | 6/4/2002 | 29 | 35 | | 51.5 | |
| RED0005 | 7/1/2002 | 28 | 38 | 38 | 53.3 | 53.3 |
| RED0005 | 8/6/2002 | 32 | 38 | 38 | 60.0 | 60.0 |
| RED0005 | 9/3/2002 | 31 | 30.8 | 30.8 | 46.3 | 46.3 |
| RED0005 | 10/1/2002 | 27.0 | 55 | 55 | 67.5 | 67.5 |
| RED0005 | 11/5/2002 | 15.0 | 42.8 | | 27.5 | |
| RED0005 | 12/3/2002 | 11.0 | 24.2 | 24.2 | 18.2 | 18.2 |
| RED0005 | 1/7/2003 | 12.0 | 22.0 | | 17.8 | |
| RED0005 | 2/4/2003 | 12.0 | 54.4 | | 44.8 | |
| RED0005 | 3/3/2003 | 10.0 | 28.4 | | 13.5 | |
| RED0005 | 4/8/2003 | 18.0 | 54.7 | | 46.0 | |
| RED0005 | 5/6/2003 | 25.0 | 135.0 | 135.0 | 52.3 | 52.3 |
| RED0005 | 6/10/2003 | 31.0 | 75.5 | 75.5 | 57.7 | 57.7 |
| RED0005 | 7/15/2003 | 32.0 | 57.8 | 57.8 | 64.0 | 64.0 |
| RED0005 | 8/12/2003 | 30.0 | 50.7 | 50.7 | 49.3 | 49.3 |
| RED0005 | 9/23/2003 | 25.0 | 44.0 | 44.0 | 45.0 | 45.0 |
| RED0005 | 10/21/2003 | 23.0 | 39.5 | | 37.5 | |
| RED0005 | 11/18/2003 | 20.0 | 78.3 | 78.3 | 86.7 | 86.7 |
| RED0005 | 12/16/2003 | 9.00 | 32.7 | 32.7 | 33.0 | 33.0 |
| RED0005 | 1/27/2004 | 10.0 | 69.0 | 69.0 | 51.8 | 51.8 |
| RED0005 | 2/24/2004 | 12.0 | 28.7 | | 19.0 | |
| RED0005 | 3/30/2004 | 21.0 | 67.5 | 67.5 | 61.9 | 61.9 |
| RED0005 | 4/27/2004 | 24.0 | 53.0 | 53.0 | 53.5 | 53.5 |
| RED0005 | 5/25/2004 | 27.0 | 79.2 | 79.2 | 87.9 | 87.9 |
| RED0005 | 6/29/2004 | 27.0 | 27.3 | | 33.8 | |
| RED0005 | 7/27/2004 | 29.0 | 108 | 108 | 91.5 | 91.5 |
| RED0005 | 8/17/2004 | 28.0 | 83.8 | 83.8 | 69.6 | 69.6 |
| RED0005 | 9/21/2004 | 27.0 | 86.8 | 86.8 | 95.6 | 95.6 |
| RED0005 | 10/26/2004 | 25.0 | 36.1 | | 43.7 | |
| RED0005 | 11/16/2004 | 18.0 | 69.9 | 69.9 | 80.0 | 80.0 |
| RED0005 | 12/7/2004 | 17.0 | 40.1 | | 22.2 | |
| RED0005 | 1/25/2005 | 14.0 | 93.8 | | 102 | |
| RED0005 | 2/22/2005 | 18.0 | 44.5 | | 31.3 | |

| Site ID | Date Collected | Temperature (°C) | Turbidity (NTU) | Base-flow Turbidity (NTU) | TSS (mg/L) | Base-flow TSS (mg/L) |
|---|---|---|---|---|---|---|
| RED0005 | 3/29/2005 | 18.0 | 43.9 | | 39.2 | |
| RED0005 | 4/26/2005 | 23.0 | 46.2 | | 41.2 | |
| RED0005 | 5/17/2005 | 28.0 | 60.1 | 60.1 | 48.8 | 48.8 |
| RED0005 | 6/28/2005 | 32.0 | 89.7 | 89.7 | 72.0 | 72.0 |
| RED0005 | 7/26/2005 | 33.0 | 94.8 | 94.8 | 75.5 | 75.5 |
| RED0005 | 8/30/2005 | 34.0 | 96.7 | 96.7 | 75.0 | 75.0 |
| RED0005 | 9/27/2005 | 30.0 | 62.3 | 62.3 | 46.2 | 46.2 |
| RED0005 | 10/18/2005 | 24.0 | 43.9 | 43.9 | 33.8 | 33.8 |
| RED0005 | 11/15/2005 | 21.0 | 61.2 | 61.2 | 51.2 | 51.2 |
| RED0005 | 12/13/2005 | 10.0 | 23.8 | 23.8 | 17.8 | 17.8 |
| RED0005 | 1/10/2006 | 12.0 | 57.3 | 57.3 | 51.0 | 51.0 |
| RED0005 | 1/31/2006 | 13.0 | 30.3 | | 28.0 | |
| RED0005 | 3/14/2006 | 19.0 | 65.4 | 65.4 | 61.2 | 61.2 |
| RED0005 | 4/11/2006 | 21.0 | 47.6 | | 41.2 | |
| RED0005 | 5/16/2006 | 24.0 | 49.2 | 49.2 | 51.5 | 51.5 |
| RED0005 | 6/13/2006 | 32.0 | 58.4 | 58.4 | 48.9 | 48.9 |
| RED0005 | 7/11/2006 | 32.0 | 58.8 | 58.8 | 55.8 | 55.8 |
| RED0005 | 8/1/2006 | 33.0 | 74.8 | 74.8 | 66.2 | 66.2 |
| RED0005 | 9/5/2006 | 28.0 | 55.5 | 55.5 | 48.0 | 48.0 |
| RED0005 | 10/3/2006 | 28.0 | 44.6 | 44.6 | 46.2 | 46.2 |
| RED0005 | 10/31/2006 | 19.0 | 51.2 | 51.2 | 47.5 | 47.5 |
| RED0005 | 12/19/2006 | 14.0 | 53.2 | 53.2 | 54.8 | 54.8 |
| RED0005 | 1/23/2007 | 8.00 | 36.7 | | 12.5 | |
| RED0005 | 2/20/2007 | 12.0 | 56.6 | | 39.8 | |
| RED0005 | 3/27/2007 | 20.8 | 73.8 | 73.8 | 74.2 | 74.2 |
| RED0005 | 4/24/2007 | 20.0 | 46.5 | | 48.5 | |
| RED0005 | 5/15/2007 | 28.3 | 25.3 | 25.3 | 15.8 | 15.8 |
| RED0005 | 6/12/2007 | 27.9 | 28.1 | | 37.3 | |
| RED0005 | 7/17/2007 | 29.7 | 4.1 | | < 1.0 | |
| RED0005 | 9/11/2007 | 28.8 | 46.4 | 46.4 | 46.1 | 46.1 |
| RED0005 | 10/15/2007 | 21.0 | 44.1 | 44.1 | 49.2 | 49.2 |
| RED0005 | 11/13/2007 | 19.4 | 41.6 | | 52.2 | |
| RED0005 | 12/4/2007 | 12.6 | 31.6 | 31.6 | 33.0 | 33.0 |
| RED0005 | 1/15/2008 | 10.9 | 26.0 | 26.0 | 40.5 | 40.5 |
| RED0005 | 2/12/2008 | 11.7 | 83.8 | 83.8 | 107 | 107 |
| RED0005 | 3/11/2008 | 12.5 | 28.3 | | 60.0 | |
| RED0005 | 4/1/2008 | 17.3 | 31.1 | | 6.5 | |
| RED0005 | 5/6/2008 | 20.8 | 17.2 | | 7.5 | |
| RED0005 | 6/17/2008 | 28.5 | 60.5 | | 65.0 | |
| RED0005 | 7/15/2008 | 30.7 | 38.9 | | 48.0 | |
| RED0005 | 8/12/2008 | 26.7 | 70.7 | 70.7 | 75.3 | 75.3 |
| RED0005 | 9/1/2008 | 30.1 | 48.7 | 48.7 | 56.8 | 56.8 |
| RED0005 | 9/30/2008 | 24.8 | 35.4 | | 39.0 | |
| RED0005 | 11/4/2008 | 18.2 | 45.4 | 45.4 | 47.0 | 47.0 |

| Site ID | Date Collected | Temperature (°C) | Turbidity (NTU) | Base-flow Turbidity (NTU) | TSS (mg/L) | Base-flow TSS (mg/L) |
|---|---|---|---|---|---|---|
| RED0005 | 12/8/2008 | 10.5 | 32.2 | 32.2 | 32.0 | 32.0 |
| RED0005 | 1/6/2009 | 9.70 | 27.6 | | 33.5 | |
| RED0005 | 2/3/2009 | 10.8 | 26.4 | 26.4 | 28.5 | 28.5 |
| RED0005 | 3/31/2009 | 15.4 | 31.5 | | 45.0 | |
| RED0005 | 4/14/2009 | 16.6 | 46.1 | | 64.0 | |
| RED0005 | 5/26/2009 | 23.0 | 11.0 | | 5.8 | |
| RED0005 | 6/15/2009 | 27.5 | 11.4 | | 9.0 | |
| RED0005 | 7/14/2009 | 32.0 | 71.5 | | 85.3 | |
| RED0005 | 8/4/2009 | 30.2 | 37.7 | | 57.2 | |
| RED0005 | 9/29/2009 | 24.9 | 29.9 | | 45.5 | |
| RED0005 | 10/27/2009 | 16.0 | | | | |
| RED0005 | 11/17/2009 | 14.3 | 16.1 | | 7.5 | |
| RED0005 | 12/8/2009 | 11.3 | 13.3 | | 8.0 | |
| RED0005 | 1/26/2010 | 9.50 | 16.5 | | 3.0 | |
| RED0005 | 2/9/2010 | 7.10 | 18.8 | | 3.0 | |

Notes:

● Base-flow defined as less than the 40th percentile.

● Values below detection limits are treated as being one-half of detection limit.

* Values with asterisk were flagged in original data received from ADEQ as failing ADEQ's QC criteria; therefore this value is not used in statistics or graphs.

Summary:

| | | | | | |
|---|---|---|---|---|---|
| Period of Record | 9/4/90 - 2/9/10 | | | | |
| No. of Values | 227 | 229 | 88 | 222 | 89 |
| Minimum | 6 | 3.1 | 3.1 | 0.5 | 15.8 |
| Maximum | 36 | 135 | 135 | 107 | 107 |
| Median | 21 | 30 | 43.95 | 39.1 | 51.5 |
| Criterion from standards | 30 | 32 | 21 | n/a | n/a |
| No. Values > criterion | 22 | 103 | 83 | | |
| % Values > criterion | 9.7% | 45.0% | 94.3% | | |

FILE: R:\PROJECTS\3013-380\TECH\ADEQ_WQ_DATA\RED RIVER\RED0005 SULPHUR RIVER.XLSX

Table B.2 Historical Water Quality Data for Red River near Doddridge, AR

| Site ID | Date Collected | Temperature (°C) | Turbidity (NTU) | Base-flow Turbidity (NTU) | TSS (mg/L) | Base-flow TSS (mg/L) |
|---|---|---|---|---|---|---|
| RED0009 | 9/4/1990 | 29 | 25 | n/a | 28 | n/a |
| RED0009 | 10/2/1990 | 24 | 74 | n/a | 100 | n/a |
| RED0009 | 10/30/1990 | 18 | 7.6 | n/a | 23 | n/a |
| RED0009 | 11/27/1990 | 19 | 33 | n/a | 33 | n/a |
| RED0009 | 1/22/1991 | 7 | 52 | n/a | 51 | n/a |
| RED0009 | 2/19/1991 | 12 | 130 | n/a | 160 | n/a |
| RED0009 | 3/26/1991 | 21 | 30 | n/a | 2 | n/a |
| RED0009 | 4/16/1991 | 21 | 460 | n/a | | n/a |
| RED0009 | 5/21/1991 | 25 | 74 | n/a | 100 | n/a |
| RED0009 | 6/18/1991 | 28 | 340 | n/a | 310 | n/a |
| RED0009 | 7/16/1991 | 28 | 36 | n/a | 42 | n/a |
| RED0009 | 8/20/1991 | 28 | 49 | n/a | 39.5 | n/a |
| RED0009 | 9/10/1991 | 27 | 4.3 | n/a | 4 | n/a |
| RED0009 | 9/17/1991 | 28 | 55 | n/a | 135 | n/a |
| RED0009 | 10/15/1991 | 20 | 21 | n/a | 26 | n/a |
| RED0009 | 11/12/1991 | 13 | 110 | n/a | 264 | n/a |
| RED0009 | 12/10/1991 | | 80 | n/a | 181 | n/a |
| RED0009 | 1/21/1992 | 6 | 195 | n/a | 307 | n/a |
| RED0009 | 2/25/1992 | 13 | 59 | n/a | 166 | n/a |
| RED0009 | 3/17/1992 | 15 | 78 | n/a | 173 | n/a |
| RED0009 | 4/21/1992 | 20 | 52 | n/a | 86 | n/a |
| RED0009 | 5/19/1992 | 25 | 90 | n/a | 201 | n/a |
| RED0009 | 6/16/1992 | 26 | 190 | n/a | 379 | n/a |
| RED0009 | 7/21/1992 | 28 | 260 | n/a | 69 | n/a |
| RED0009 | 8/18/1992 | 25 | 41 | n/a | 68 | n/a |
| RED0009 | 9/15/1992 | 26 | 73 | n/a | 108 | n/a |
| RED0009 | 10/13/1992 | 20 | 24 | n/a | 41 | n/a |
| RED0009 | 11/9/1992 | 14 | 28 | n/a | 51 | n/a |
| RED0009 | 12/8/1992 | 7 | 52 | n/a | 106 | n/a |
| RED0009 | 1/26/1993 | 7 | 130 | n/a | 236 | n/a |
| RED0009 | 2/23/1993 | 9 | 170 | n/a | 83 | n/a |
| RED0009 | 3/23/1993 | 13 | 105 | n/a | 229 | n/a |
| RED0009 | 5/4/1993 | 19 | 94 | n/a | 191 | n/a |
| RED0009 | 5/17/1993 | 22 | 200 | n/a | 444 | n/a |
| RED0009 | 6/29/1993 | 29 | 92 | n/a | 160 | n/a |
| RED0009 | 7/13/1993 | 31 | 13 | n/a | 20 | n/a |
| RED0009 | 8/10/1993 | 29 | 48 | n/a | 77 | n/a |
| RED0009 | 9/7/1993 | 27 | 19 | n/a | 32 | n/a |
| RED0009 | 10/12/1993 | 23 | 31 | n/a | 32 | n/a |
| RED0009 | 11/9/1993 | 11 | 38 | n/a | 24 | n/a |
| RED0009 | 12/21/1993 | 9.0 | 74 | n/a | 126 | n/a |
| RED0009 | 1/25/1994 | 13.0 | 41 | n/a | 65.5 | n/a |

| Site ID | Date Collected | Temperature (°C) | Turbidity (NTU) | Base-flow Turbidity (NTU) | TSS (mg/L) | Base-flow TSS (mg/L) |
|---|---|---|---|---|---|---|
| RED0009 | 2/14/1994 | 9 | 16 | n/a | 38.0 | n/a |
| RED0009 | 3/14/1994 | 14 | 110 | n/a | 260 | n/a |
| RED0009 | 4/18/1994 | 20 | 32 | n/a | 56.0 | n/a |
| RED0009 | 5/23/1994 | 26 | 75 | n/a | 168 | n/a |
| RED0009 | 6/27/1994 | 29 | 16 | n/a | 26.0 | n/a |
| RED0009 | 7/18/1994 | 28 | 120 | n/a | 272 | n/a |
| RED0009 | 8/15/1994 | 28 | 120 | n/a | 174 | n/a |
| RED0009 | 9/26/1994 | 23 | 17 | n/a | 22.0 | n/a |
| RED0009 | 10/24/1994 | 24 | 43 | n/a | 93.5 | n/a |
| RED0009 | 11/29/1994 | 15 | 200 | n/a | 371 | n/a |
| RED0009 | 12/20/1994 | 11 | 43 | n/a | 95.5 | n/a |
| RED0009 | 1/9/1995 | | 38 | n/a | | n/a |
| RED0009 | 2/13/1995 | 7 | 26 | n/a | 57.5 | n/a |
| RED0009 | 3/27/1995 | | 89 | n/a | 211.5* | n/a |
| RED0009 | 4/24/1995 | | 112 | n/a | 152.5 | n/a |
| RED0009 | 5/22/1995 | 24 | 68 | n/a | 108 | n/a |
| RED0009 | 6/19/1995 | 27 | 210 | n/a | 490.0 | n/a |
| RED0009 | 7/18/1995 | | 110 | n/a | 221.0 | n/a |
| RED0009 | 8/7/1995 | 30 | 28 | n/a | 36.0 | n/a |
| RED0009 | 9/18/1995 | 25 | 29 | n/a | 48.5 | n/a |
| RED0009 | 10/16/1995 | 20 | 29 | n/a | 36.0 | n/a |
| RED0009 | 11/14/1995 | 13 | 20 | n/a | 34.0 | n/a |
| RED0009 | 11/28/1995 | 12 | 17 | n/a | 22.0 | n/a |
| RED0009 | 1/2/1996 | 7 | 22 | n/a | 25.0 | n/a |
| RED0009 | 2/13/1996 | 10 | 46 | n/a | 64.5 | n/a |
| RED0009 | 3/5/1996 | 15 | 26 | n/a | 35.0 | n/a |
| RED0009 | 4/2/1996 | 14 | 210 | n/a | 305.0 | n/a |
| RED0009 | 5/14/1996 | 23 | 160 | n/a | 251.0 | n/a |
| RED0009 | 6/11/1996 | 28 | 109 | n/a | 114.0 | n/a |
| RED0009 | 7/16/1996 | 29 | 73 | n/a | 105.0 | n/a |
| RED0009 | 8/20/1996 | 30 | 84 | n/a | 152.0 | n/a |
| RED0009 | 9/24/1996 | 23 | 190 | n/a | 300.0 | n/a |
| RED0009 | 10/22/1996 | 17 | 190 | n/a | 258.0 | n/a |
| RED0009 | 11/19/1996 | 14 | 99 | n/a | 134.0 | n/a |
| RED0009 | 12/17/1996 | 9 | 66 | n/a | 99.5 | n/a |
| RED0009 | 1/28/1997 | 9 | 73 | n/a | 89.0 | n/a |
| RED0009 | 2/25/1997 | 11 | 300 | n/a | 419.0 | n/a |
| RED0009 | 3/25/1997 | 18 | 112 | n/a | 1139.0* | n/a |
| RED0009 | 4/14/1997 | 18 | 47 | n/a | 99.0 | n/a |
| RED0009 | 5/12/1997 | 20 | 55 | n/a | 88.5 | n/a |
| RED0009 | 6/16/1997 | 27.0 | 90 | n/a | 139.5 | n/a |
| RED0009 | 7/14/1997 | 32.5 | 31 | n/a | 38.0 | n/a |
| RED0009 | 8/25/1997 | 29 | 38 | n/a | 62.5 | n/a |
| RED0009 | 9/15/1997 | 28.5 | 20 | n/a | 31.0 | n/a |

| Site ID | Date Collected | Temperature (°C) | Turbidity (NTU) | Base-flow Turbidity (NTU) | TSS (mg/L) | Base-flow TSS (mg/L) |
|---|---|---|---|---|---|---|
| RED0009 | 10/21/1997 | 22 | 29 | 29 | 47.5 | 47.5 |
| RED0009 | 11/18/1997 | 10.5 | 25 | | 20.5* | |
| RED0009 | 12/16/1997 | 11 | 46 | | 39.5 | |
| RED0009 | 1/27/1998 | 11 | 100 | | 185.5 | |
| RED0009 | 2/17/1998 | 10 | 58 | | | |
| RED0009 | 3/3/1998 | 12 | 8.6 | | 118.0 | |
| RED0009 | 4/7/1998 | 20 | 150 | | 248.0 | |
| RED0009 | 5/5/1998 | 25 | 25 | | 46.0 | |
| RED0009 | 6/2/1998 | 29 | 5.4 | | 2.5 | |
| RED0009 | 7/21/1998 | 34 | 26 | 26 | 44.5 | 44.5 |
| RED0009 | 8/11/1998 | 28 | 16 | 16 | 35.0 | 35.0 |
| RED0009 | 9/22/1998 | 30 | 21 | | 44.0 | |
| RED0009 | 10/27/1998 | 20 | 36 | | 73.0 | |
| RED0009 | 11/17/1998 | 16 | 41 | | 55.5 | |
| RED0009 | 12/21/1998 | 15 | 90 | | 112.5 | |
| RED0009 | 1/26/1999 | 16 | 39 | | 94.0 | |
| RED0009 | 2/16/1999 | 13 | 53* | | 72.5 | |
| RED0009 | 3/23/1999 | 16 | 65 | | 66.0 | |
| RED0009 | 4/27/1999 | 24 | 56 | | 95.5* | |
| RED0009 | 5/18/1999 | 23 | 100 | | 149.0 | |
| RED0009 | 6/29/1999 | 30 | 37 | | 46.0* | |
| RED0009 | 7/27/1999 | 33 | 22 | | 39.0 | |
| RED0009 | 8/31/1999 | | 24 | 24 | 37.0 | 37.0 |
| RED0009 | 9/28/1999 | 27 | 18 | 18 | 26.0 | 26.0 |
| RED0009 | 10/12/1999 | 27 | 36 | 36 | 38.0 | 38.0 |
| RED0009 | 11/16/1999 | 21 | 23 | 23 | 29 | 29 |
| RED0009 | 12/14/1999 | 12 | | | 51 | 51 |
| RED0009 | 1/18/2000 | 16 | 25 | 25 | 46.5 | 46.5 |
| RED0009 | 2/15/2000 | 16 | 25 | 25 | 46 | 46 |
| RED0009 | 3/21/2000 | 17 | 69 | | 124 | |
| RED0009 | 4/18/2000 | 22 | 120 | | 218 | |
| RED0009 | 5/23/2000 | 27 | 73 | | 132.5 | |
| RED0009 | 6/20/2000 | 28 | 39 | | | |
| RED0009 | 7/25/2000 | 31 | 24 | | 37.5 | |
| RED0009 | 8/29/2000 | 31 | | | 71.5 | 71.5 |
| RED0009 | 9/26/2000 | 22 | 23 | 23 | 31.0 | 31.0 |
| RED0009 | 10/24/2000 | 23 | 22 | 22 | 32.0 | 32.0 |
| RED0009 | 11/14/2000 | 12 | 87 | | 156.8 | |
| RED0009 | 12/18/2000 | 8 | 43 | | 38.5 | |
| RED0009 | 1/29/2001 | 11 | 59 | | 64.3 | |
| RED0009 | 2/26/2001 | 15 | 46 | | 61.8 | |
| RED0009 | 3/27/2001 | 15 | 50 | | 77.8 | |
| RED0009 | 4/16/2001 | 19 | 59 | | 101.0 | |
| RED0009 | 5/22/2001 | 21.5 | 27 | | 32.75* | |

| Site ID | Date Collected | Temperature (°C) | Turbidity (NTU) | Base-flow Turbidity (NTU) | TSS (mg/L) | Base-flow TSS (mg/L) |
|---|---|---|---|---|---|---|
| RED0009 | 6/19/2001 | 27 | 28 | | 37.8 | |
| RED0009 | 7/17/2001 | 31 | 16 | | 21.0 | |
| RED0009 | 8/21/2001 | 31 | 18 | 18 | 26.0 | 26.0 |
| RED0009 | 9/18/2001 | 27 | 40 | | 50.5 | |
| RED0009 | 10/23/2001 | 20 | 47 | | 62.7 | |
| RED0009 | 11/19/2001 | 18 | 24 | 24 | 24.5 | 24.5 |
| RED0009 | 12/11/2001 | 12 | 42 | | 45.8 | |
| RED0009 | 1/2/2002 | 6 | 63 | | 37.8 | |
| RED0009 | 2/19/2002 | 10 | 48 | | 37.5 | |
| RED0009 | 3/19/2002 | 15 | 64 | | 48.8 | |
| RED0009 | 4/16/2002 | 21 | 135 | | 152.7 | |
| RED0009 | 5/21/2002 | 21 | 41 | | 56.5 | |
| RED0009 | 6/4/2002 | 30 | 20 | | 33.5 | |
| RED0009 | 7/1/2002 | 28 | 30 | 30 | 61.8 | 61.8 |
| RED0009 | 8/6/2002 | 32 | 21 | | 31.5 | |
| RED0009 | 9/3/2002 | 31 | 20.4 | 20.4 | 42.8 | 42.8 |
| RED0009 | 10/1/2002 | 28.0 | 27 | 27 | 28.2 | 28.2 |
| RED0009 | 11/5/2002 | 15.0 | 117 | | 114 | |
| RED0009 | 12/3/2002 | 12.0 | 25.0 | 25.0 | 21.2 | 21.2 |
| RED0009 | 1/7/2003 | 12.0 | 53.5 | | 44.8 | |
| RED0009 | 2/4/2003 | 13.0 | 6.3 | | 36.0 | |
| RED0009 | 3/3/2003 | 10.0 | 73.2 | | 76.5 | |
| RED0009 | 4/8/2003 | 19.0 | 51.5 | 51.5 | 39.2 | 39.2 |
| RED0009 | 5/6/2003 | 25.0 | 108 | 108 | 33.5 | 33.5 |
| RED0009 | 6/10/2003 | 29.0 | 27.1 | 27.1 | 44.5 | 44.5 |
| RED0009 | 7/15/2003 | 32.0 | 48.3 | 48.3 | 55.2 | 55.2 |
| RED0009 | 8/12/2003 | 29.0 | 67.5 | | 75.6 | |
| RED0009 | 9/23/2003 | 26.0 | 38.0 | 38.0 | 36.0 | 36.0 |
| RED0009 | 10/21/2003 | 25.0 | 68.8 | 68.8 | 54.5 | 54.5 |
| RED0009 | 11/18/2003 | 20.0 | 47.8 | 47.8 | 41.5 | 41.5 |
| RED0009 | 12/16/2003 | 10.0 | 36.5 | 36.5 | 29.0 | 29.0 |
| RED0009 | 1/27/2004 | 10.0 | 134 | | 101 | |
| RED0009 | 2/24/2004 | 12.0 | 70.3 | | 56.5 | |
| RED0009 | 3/30/2004 | 21.0 | 51.8 | 51.8 | 39.4 | 39.4 |
| RED0009 | 4/27/2004 | 23.0 | 50.1 | 50.1 | 59.0 | 59.0 |
| RED0009 | 5/25/2004 | 26.0 | 33.2 | 33.2 | 29.0 | 29.0 |
| RED0009 | 6/29/2004 | 27.0 | 66.6 | | 59.8 | |
| RED0009 | 7/27/2004 | 29.0 | 68.4 | | 66.0 | |
| RED0009 | 8/17/2004 | 29.0 | 89.4 | | 76.2 | |
| RED0009 | 9/21/2004 | 28.0 | 58.3 | 58.3 | 52.1 | 52.1 |
| RED0009 | 10/26/2004 | 25.0 | 80.6 | 80.6 | 73.3 | 73.3 |
| RED0009 | 11/16/2004 | 17.0 | 97.5 | | 84.6 | |
| RED0009 | 12/7/2004 | 14.0 | 169 | | 173 | |
| RED0009 | 1/25/2005 | 14.0 | 32 | | 16.8 | |

| Site ID | Date Collected | Temperature (°C) | Turbidity (NTU) | Base-flow Turbidity (NTU) | TSS (mg/L) | Base-flow TSS (mg/L) |
|---|---|---|---|---|---|---|
| RED0009 | 2/22/2005 | 17.0 | 76 | | 64.3 | |
| RED0009 | 3/29/2005 | 17.0 | 130 | | 138 | |
| RED0009 | 4/26/2005 | 23.0 | 47.5 | 47.5 | 42.2 | 42.2 |
| RED0009 | 5/17/2005 | 26.0 | 5.2 | 5.2 | 3.2 | 3.2 |
| RED0009 | 6/28/2005 | 31.0 | 27.2 | 27.2 | 25.8 | 25.8 |
| RED0009 | 7/26/2005 | 33.0 | 28.6 | 28.6 | 32.8 | 32.8 |
| RED0009 | 8/30/2005 | 38.0 | 28.9 | 28.9 | 25.7 | 25.7 |
| RED0009 | 9/27/2005 | 29.0 | 24.2 | 24.2 | 24.2 | 24.2 |
| RED0009 | 10/18/2005 | 26.0 | 33.7 | 33.7 | 29.5 | 29.5 |
| RED0009 | 11/15/2005 | 21.0 | 36.4 | 36.4 | 31.8 | 31.8 |
| RED0009 | 12/13/2005 | 12.0 | 31.3 | 31.3 | 26.2 | 26.2 |
| RED0009 | 1/10/2006 | 14.0 | 21.2 | 21.2 | 19.5 | 19.5 |
| RED0009 | 1/31/2006 | 13.0 | 81.0 | 81.0 | 82.8 | 82.8 |
| RED0009 | 3/14/2006 | 20.0 | 56.1 | 56.1 | 50.5 | 50.5 |
| RED0009 | 4/11/2006 | 22.0 | 83.5 | | 69.0 | |
| RED0009 | 5/16/2006 | 24.0 | 134 | | 96.0 | |
| RED0009 | 6/13/2006 | 31.0 | 41.9 | 41.9 | 35.0 | 35.0 |
| RED0009 | 7/11/2006 | 32.0 | 28.4 | 28.4 | 27.2 | 27.2 |
| RED0009 | 8/1/2006 | 31.0 | 23.0 | 23.0 | 27.8 | 27.8 |
| RED0009 | 9/5/2006 | 29.0 | 22.7 | 22.7 | 23.5 | 23.5 |
| RED0009 | 10/3/2006 | 29.0 | 24.9 | 24.9 | 26.0 | 26.0 |
| RED0009 | 10/31/2006 | 21.0 | 52.6 | 52.6 | 46.5 | 46.5 |
| RED0009 | 12/19/2006 | 13.0 | 59.9 | | 38.0 | |
| RED0009 | 1/23/2007 | 8.0 | 63.4 | | 57.8 | |
| RED0009 | 2/20/2007 | 10.0 | 55.6 | | 53.2 | |
| RED0009 | 3/27/2007 | 20.4 | 39.5 | 39.5 | 37.0 | 37.0 |
| RED0009 | 4/24/2007 | 22.0 | 69.5 | | 68.5 | |
| RED0009 | 5/15/2007 | 26.3 | 144 | | 109 | |
| RED0009 | 6/12/2007 | 27.8 | 129 | | 167 | |
| RED0009 | 7/17/2007 | 28.1 | 78.6 | | 66.6 | |
| RED0009 | 9/11/2007 | 27.3 | 106 | | 107 | |
| RED0009 | 10/15/2007 | 21.0 | 32.5 | | 44.0 | |
| RED0009 | 11/13/2007 | 20.5 | 29.4 | 29.4 | 30.8 | 30.8 |
| RED0009 | 12/4/2007 | 12.9 | 39.0 | | 37.0 | |
| RED0009 | 1/15/2008 | 11.2 | 35.5 | 35.5 | 37.0 | 37.0 |
| RED0009 | 2/12/2008 | 11.8 | 80.3 | | 59.5 | |
| RED0009 | 3/11/2008 | 12.6 | 54.7 | | 4.0 | |
| RED0009 | 4/1/2008 | 17.7 | 47.0 | | 32.0 | |
| RED0009 | 5/6/2008 | 21.1 | 46.4 | | 47.5 | |
| RED0009 | 6/17/2008 | 29.0 | 34.5 | | 44.5 | |
| RED0009 | 7/15/2008 | 31.2 | 40.0 | 40.0 | 42.5 | 42.5 |
| RED0009 | 8/12/2008 | 26.1 | 26.9 | 26.9 | 31.8 | 31.8 |
| RED0009 | 9/1/2008 | 29.5 | 54.8 | 54.8 | 55.0 | 55.0 |
| RED0009 | 9/30/2008 | 25.1 | 41.9 | 41.9 | 35.5 | 35.5 |

| Site ID | Date Collected | Temperature (°C) | Turbidity (NTU) | Base-flow Turbidity (NTU) | TSS (mg/L) | Base-flow TSS (mg/L) |
|---|---|---|---|---|---|---|
| RED0009 | 11/4/2008 | 18.8 | 38.0 | 38.0 | 37.0 | 37.0 |
| RED0009 | 12/8/2008 | 11.1 | 29.4 | 29.4 | 26.2 | 26.2 |
| RED0009 | 1/6/2009 | 9.8 | 42.2 | | 32.3 | |
| RED0009 | 2/3/2009 | 9.1 | 25.7 | | 24.8 | |
| RED0009 | 3/31/2009 | 16.0 | 59.8 | | 74.0 | |
| RED0009 | 4/14/2009 | 19.0 | 67.0 | | 59.3 | |
| RED0009 | 5/26/2009 | 22.6 | 49.1 | | 42.5 | |
| RED0009 | 6/15/2009 | 27.9 | 58.9 | | 70.3 | |
| RED0009 | 7/14/2009 | 32.8 | 31.7 | 31.7 | 32.0 | 32.0 |
| RED0009 | 8/4/2009 | 30.2 | 53.2 | | 50.0 | |
| RED0009 | 9/29/2009 | 25.5 | 57.6 | | 53.0 | |
| RED0009 | 10/27/2009 | 15.8 | 62.4 | | 37.0 | |
| RED0009 | 11/17/2009 | 14.9 | 51.0 | | 45.0 | |
| RED0009 | 12/8/2009 | 10.5 | 39.6 | | 35.0 | |
| RED0009 | 1/26/2010 | 9.8 | 31.3 | | 19.0 | |
| RED0009 | 2/9/2010 | 7.8 | 35.4 | | 16.0 | |

Notes:

- Base-flow defined as less than the 40th percentile.
- Base-flows not determined prior to Oct 1997 due to lack of available flow data.

* Values with asterisk were flagged in original data received from ADEQ as failing ADEQ's QC criteria; therefore this value is not used in statistics or graphs.

Summary:

| | | | | | |
|---|---|---|---|---|---|
| Period of Record | 9/4/90 - 2/9/10 | | | | |
| No. of Values | 228 | 231 | 58 | 224 | 60 |
| Minimum | 6 | 4.3 | 5.19 | 2 | 3.2 |
| Maximum | 38 | 460 | 108 | 490 | 82.8 |
| Median | 21 | 47.5 | 29.7 | 51 | 35.25 |
| Criterion from standards | 32 | 150 | 50 | n/a | n/a |
| No. Values > criterion | 6 | 15 | 11 | | |
| % Values > criterion | 2.6% | 6.5% | 19.0% | | |

FILE: R:\PROJECTS\3013-380\TECH\ADEQ_WQ_DATA\RED RIVER\RED0009 RED RIVER.XLSX

**Figure B.1  Time Series Plot of Temperature in Sulphur River south of Texarkana, AR (RED0005)**

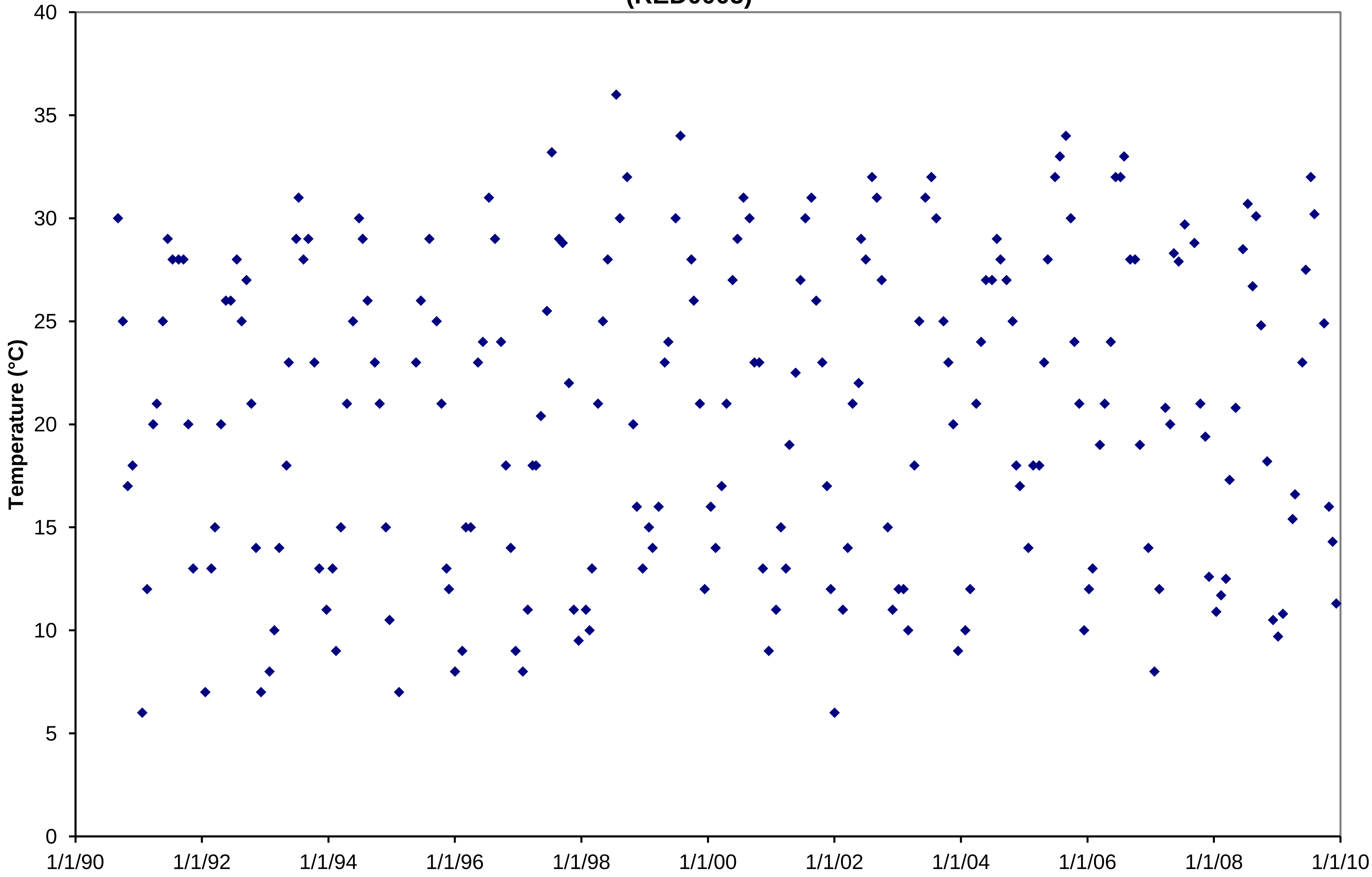


**Figure B.2 Time Series Plot of Temperature in Red River near Doddridge, AR (RED0009)**

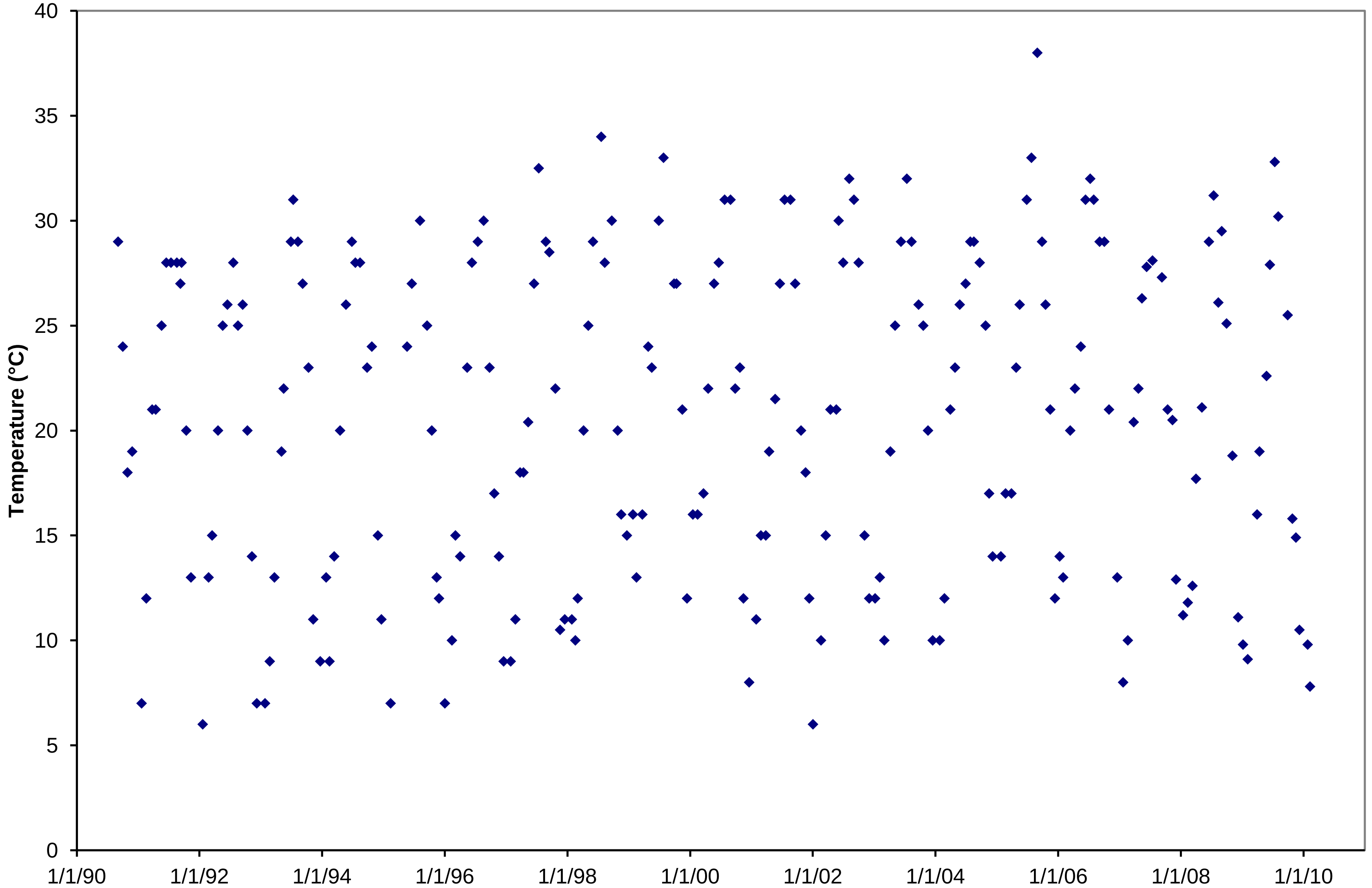


**Figure B.3  Seasonal Plot of Temperature in Sulphur River south of Texarkana, AR (RED0005)**

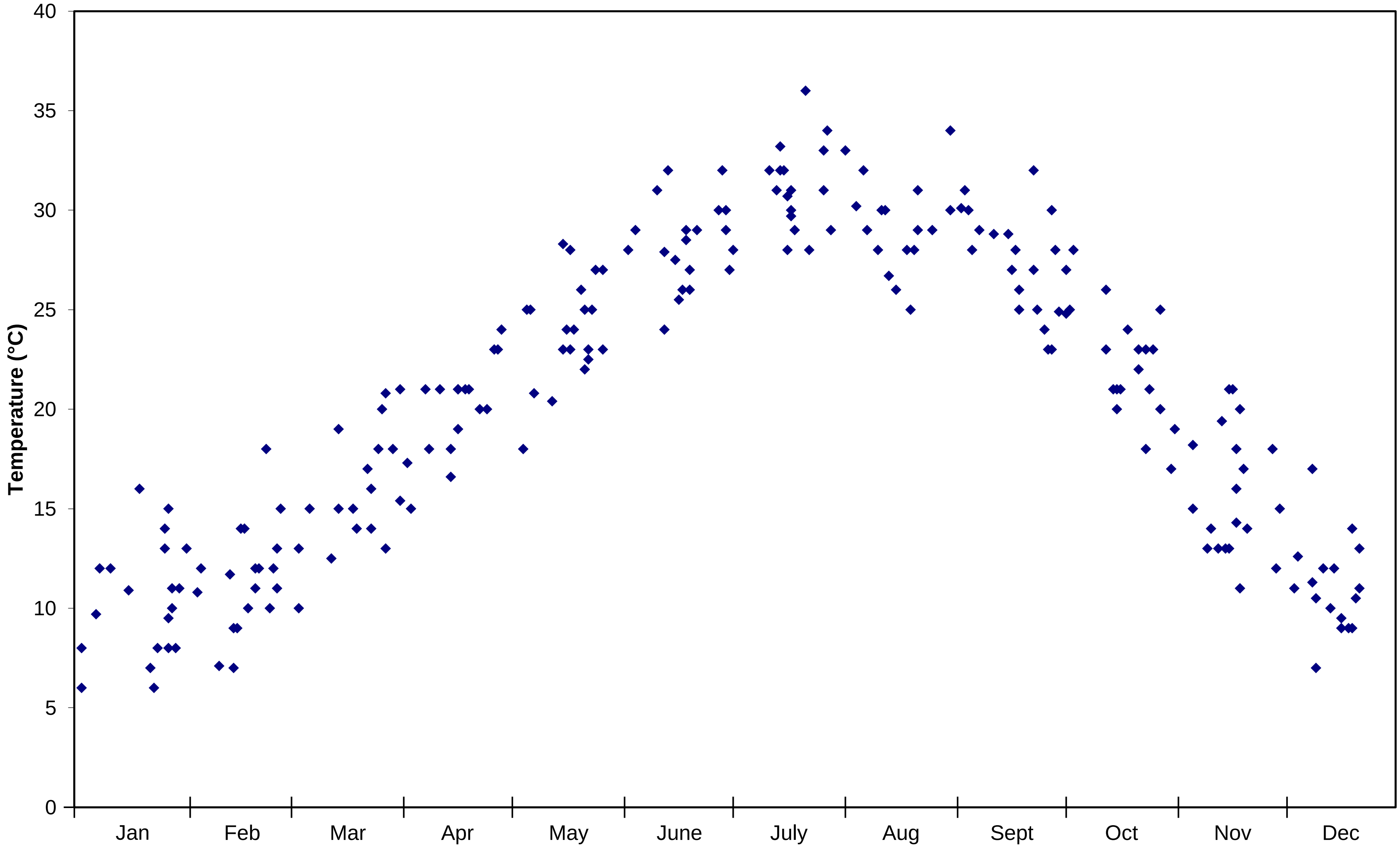
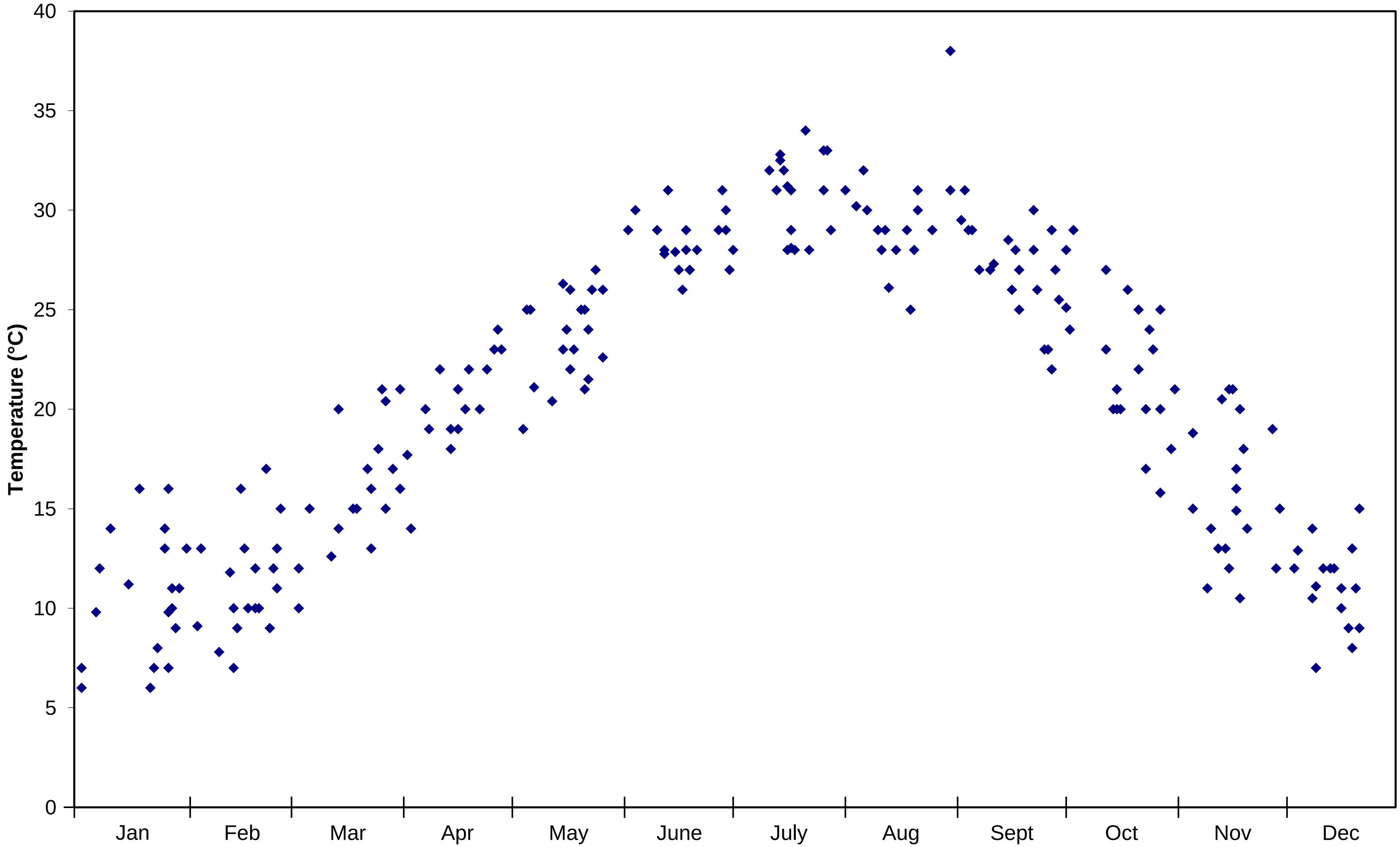
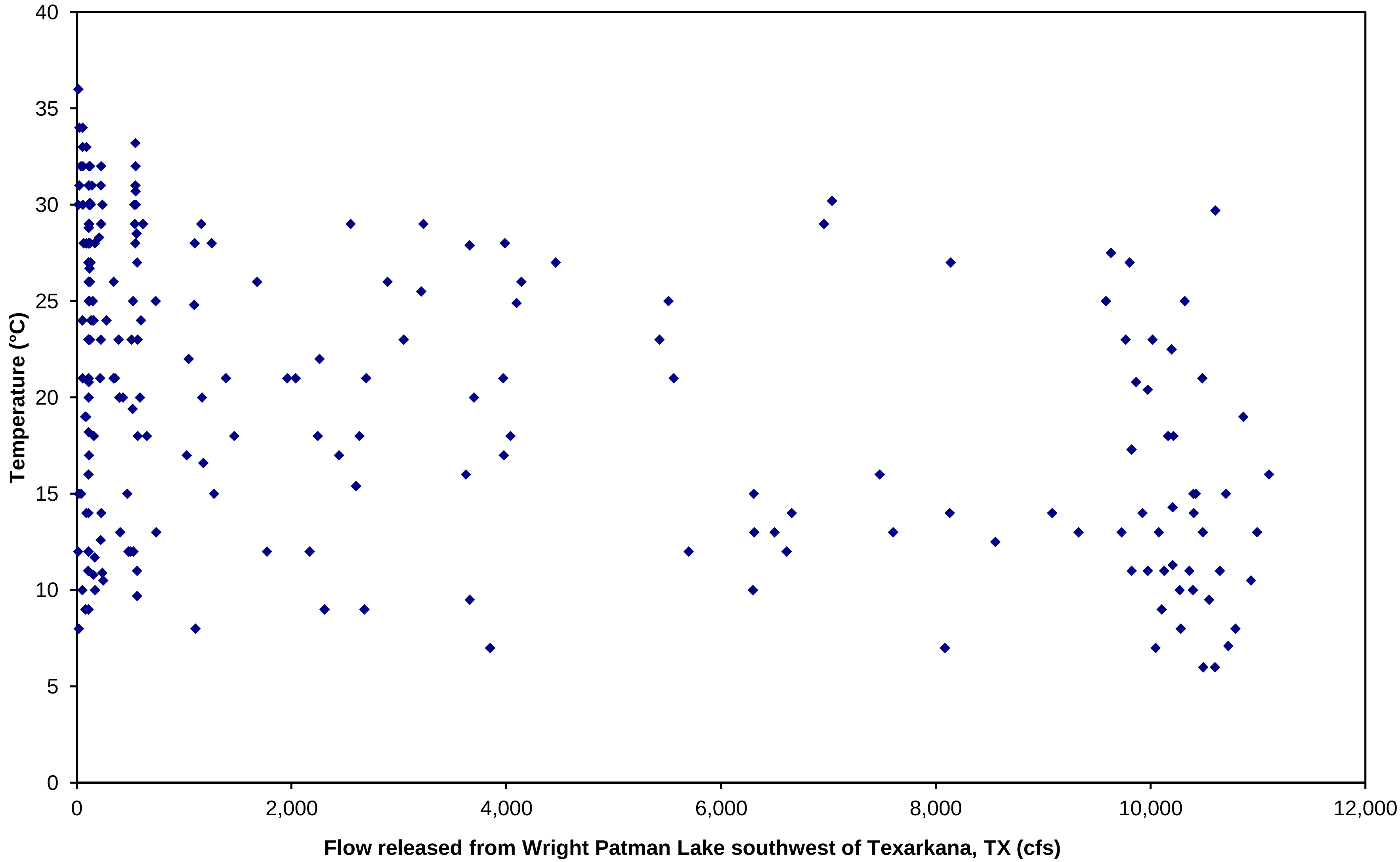


**Figure B.4 Seasonal Plot of Temperature in Red River near Doddridge, AR (RED0009)**

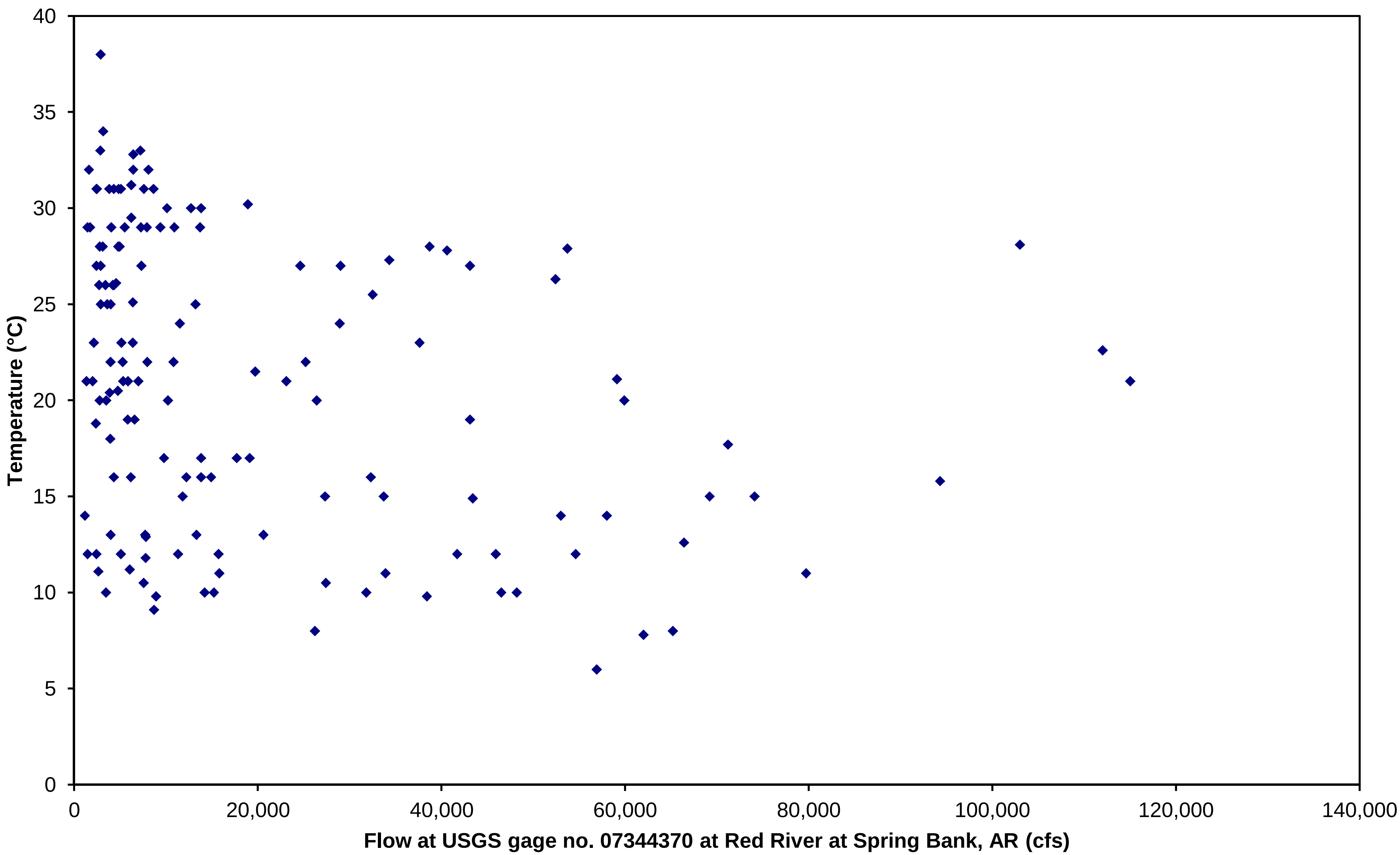


## Figure B.5 Temperature versus Flow in Sulphur River south of Texarkana, AR (RED0005)




Note: Data points shown only for those dates when both temperature and flow are available.

**Figure B.6  Temperature versus Flow in Red River near Doddridge, AR (RED0009)**




Note: Data points shown only for those dates when both temperature and flow are available.

**Figure B.7 Time Series Plot of Turbidity in Sulphur River south of Texarkana, AR (RED0005)**

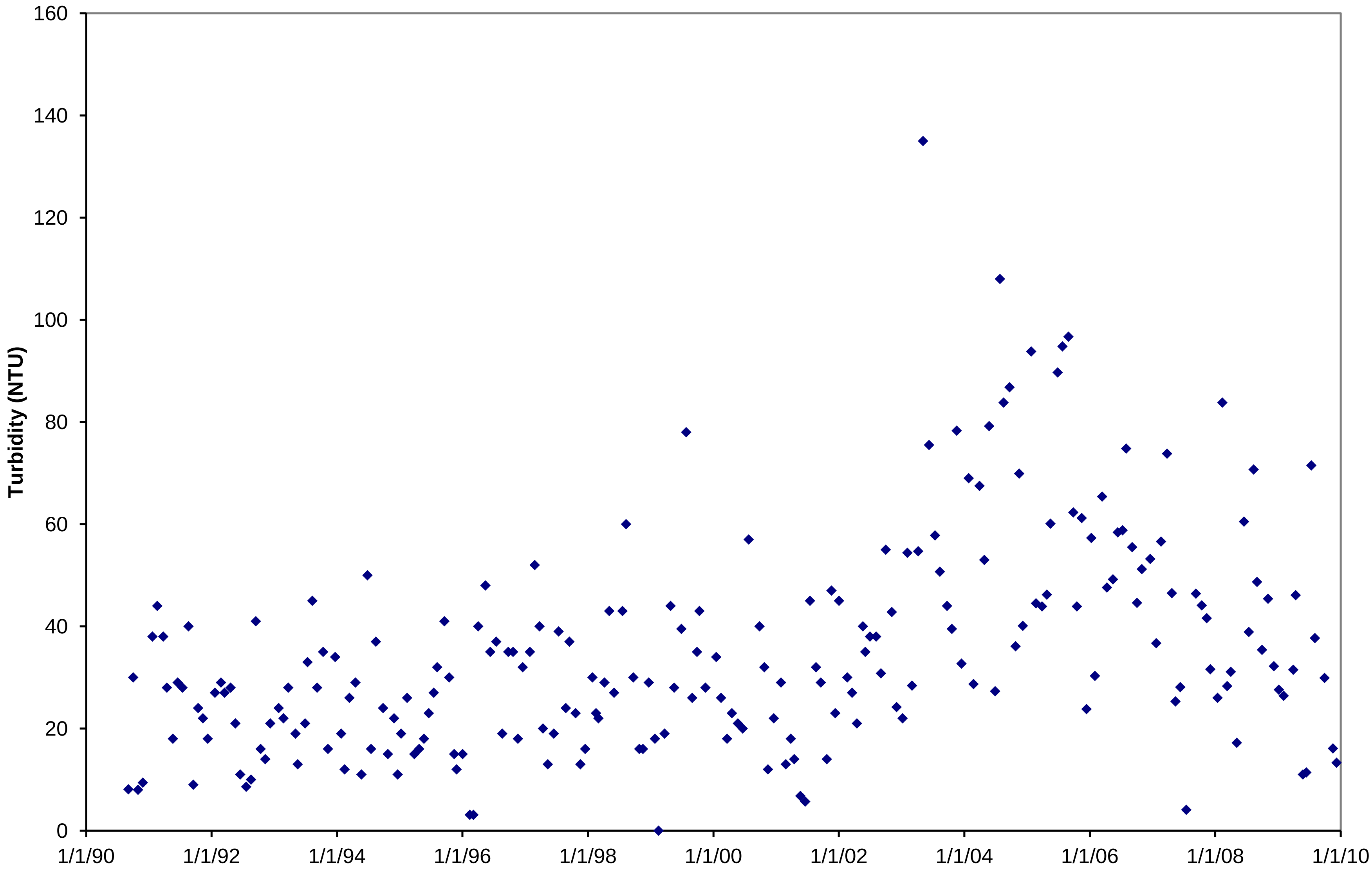


**Figure B.8  Time Series Plot of TSS in Sulphur River south of Texarkana, AR (RED0005)**

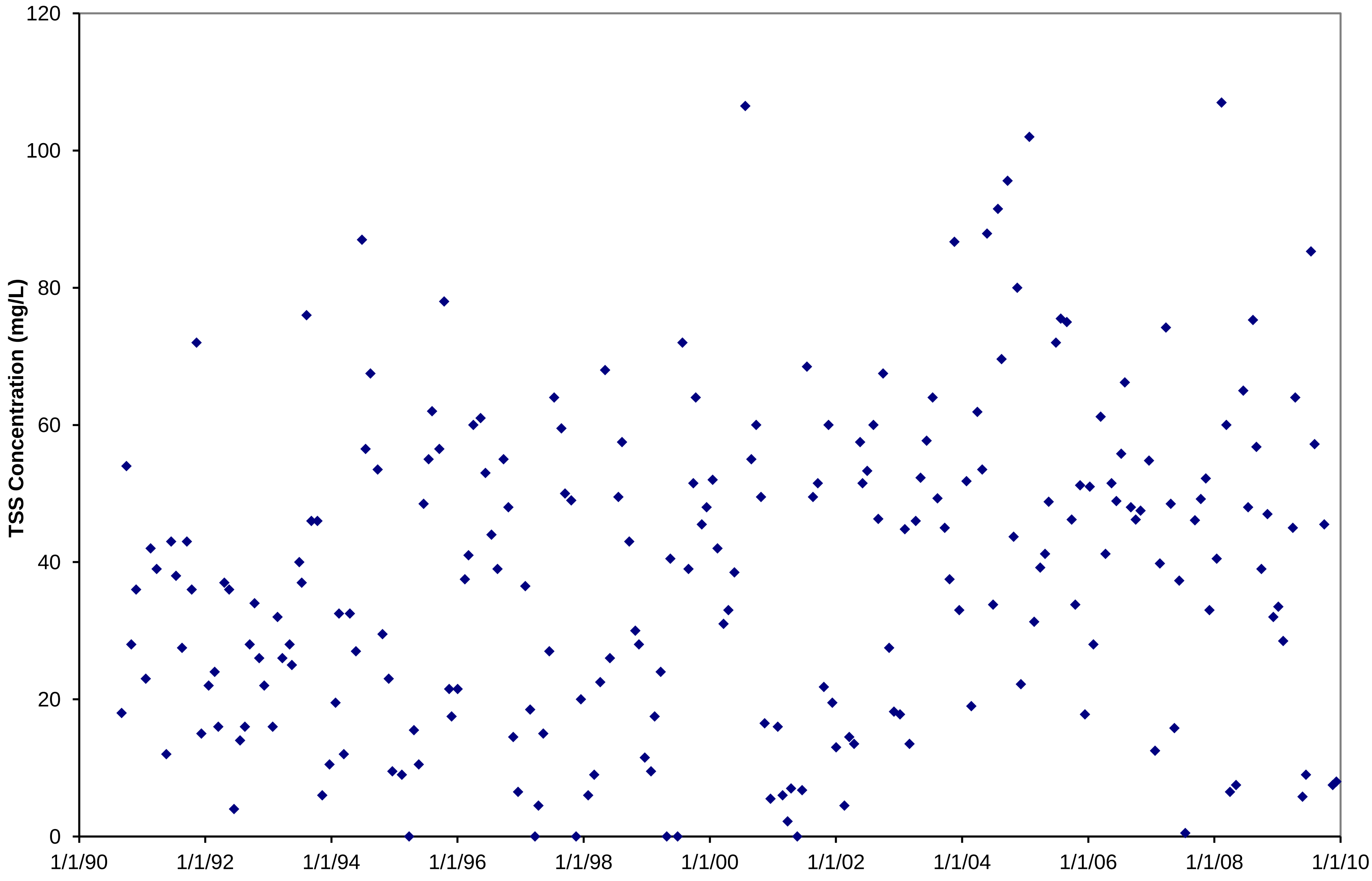


**Figure B.9 Time Series Plot of Turbidity in Red River near Doddridge, AR (RED0009)**

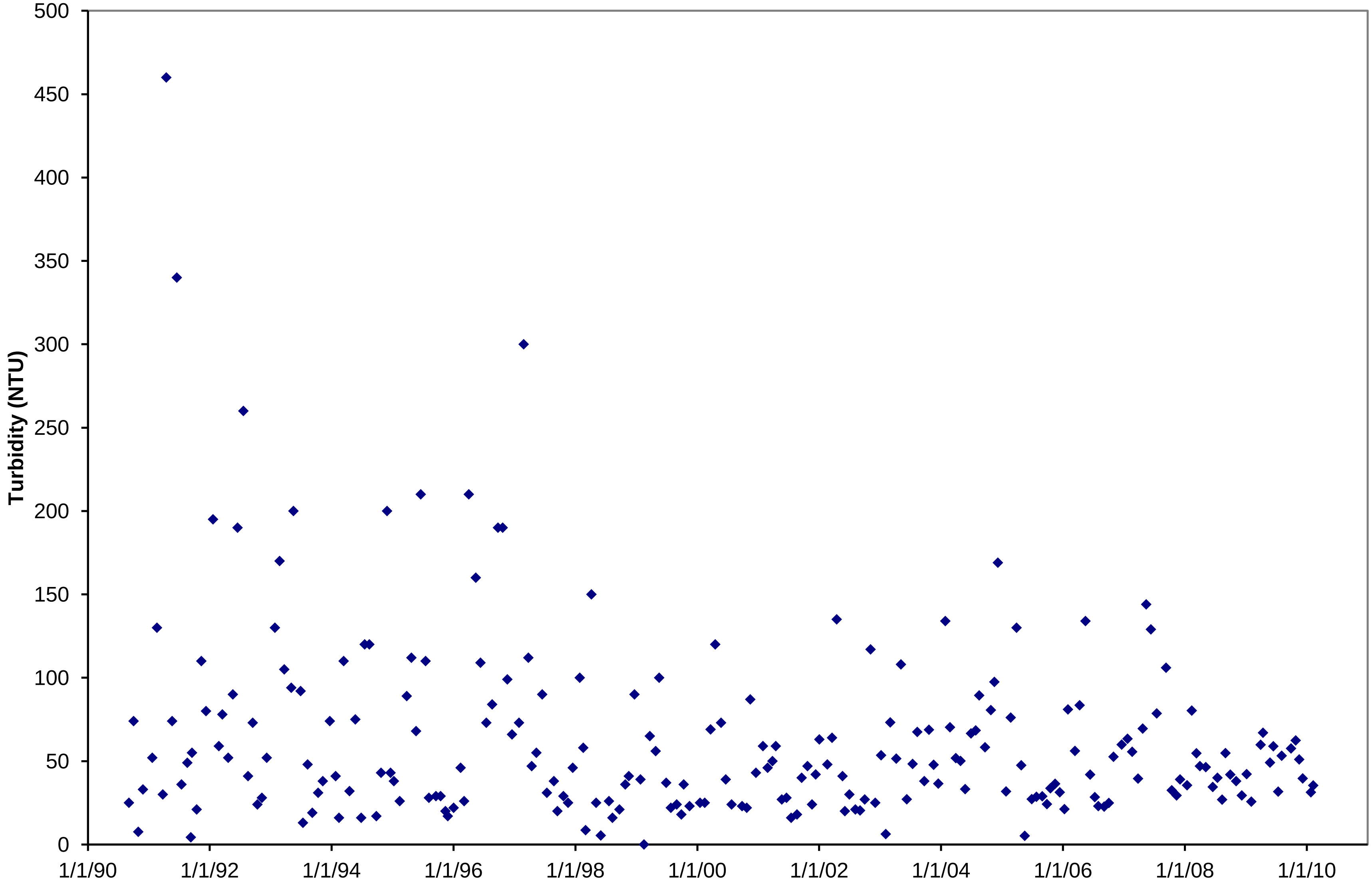


**Figure B.10 Time Series Plot of Total Suspended Solids in Red River near Doddridge, AR (RED0009)**

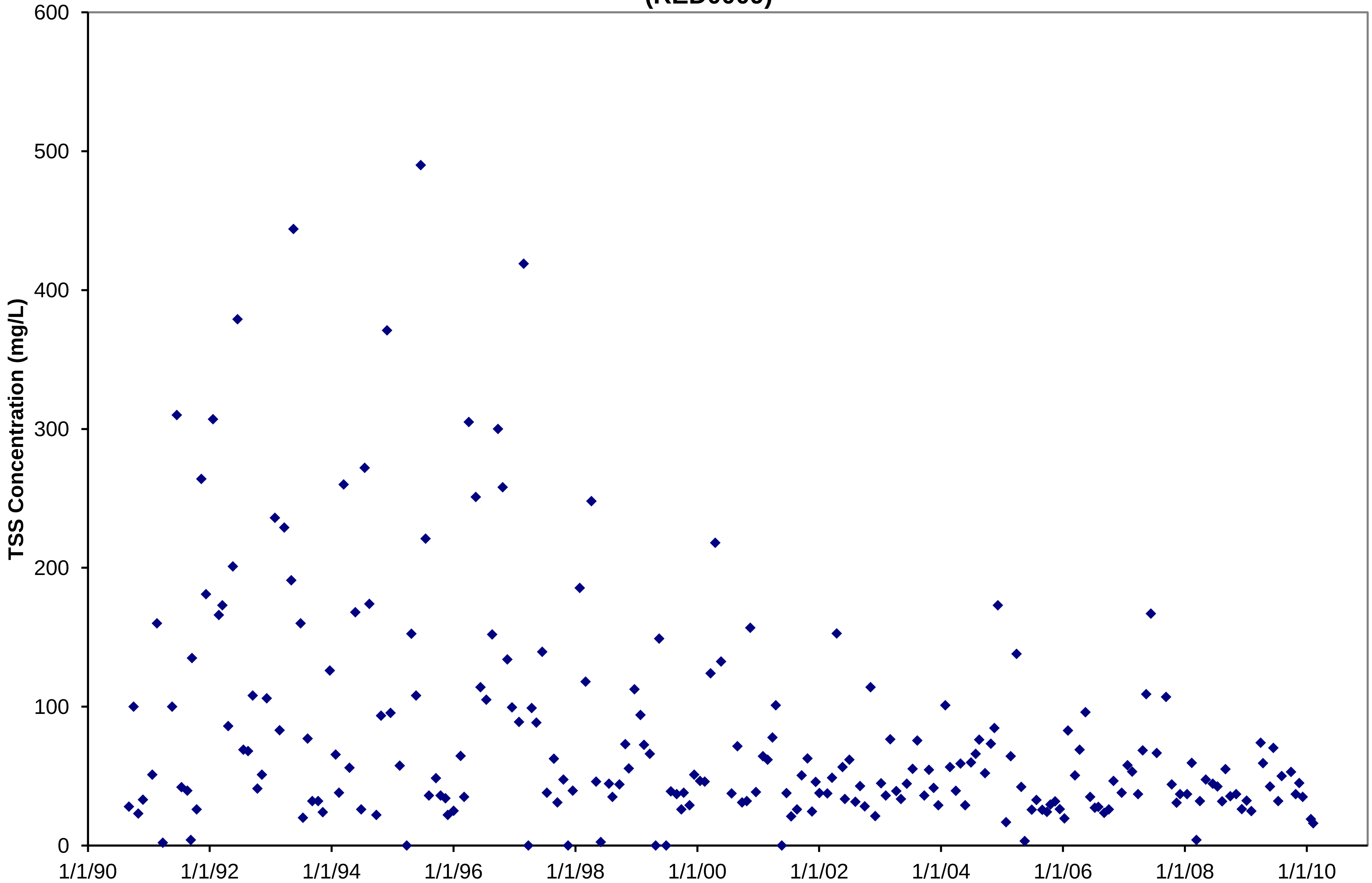


**Figure B.11 Seasonal Plot of Turbidity in Sulphur River south of Texarkana, AR (RED0005)**

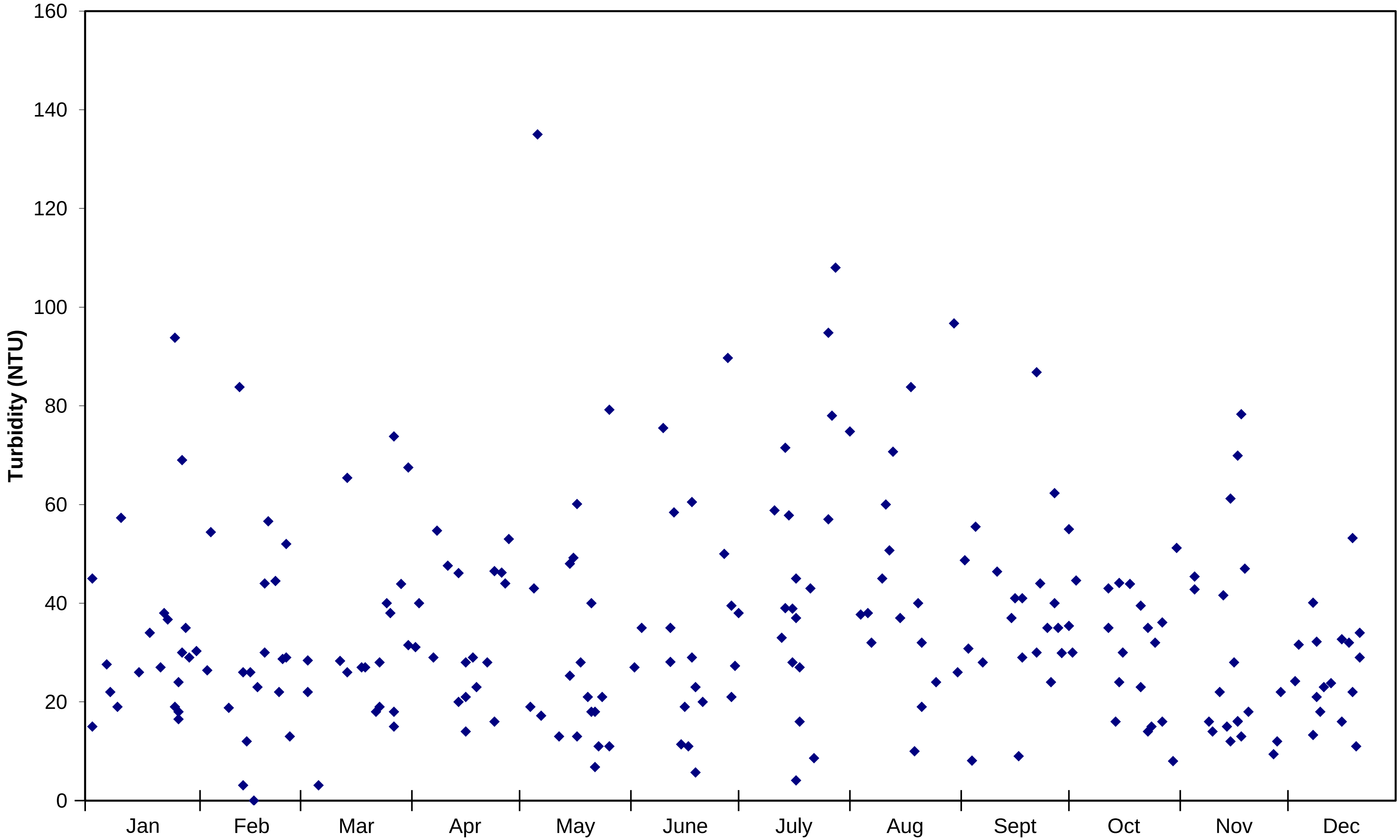
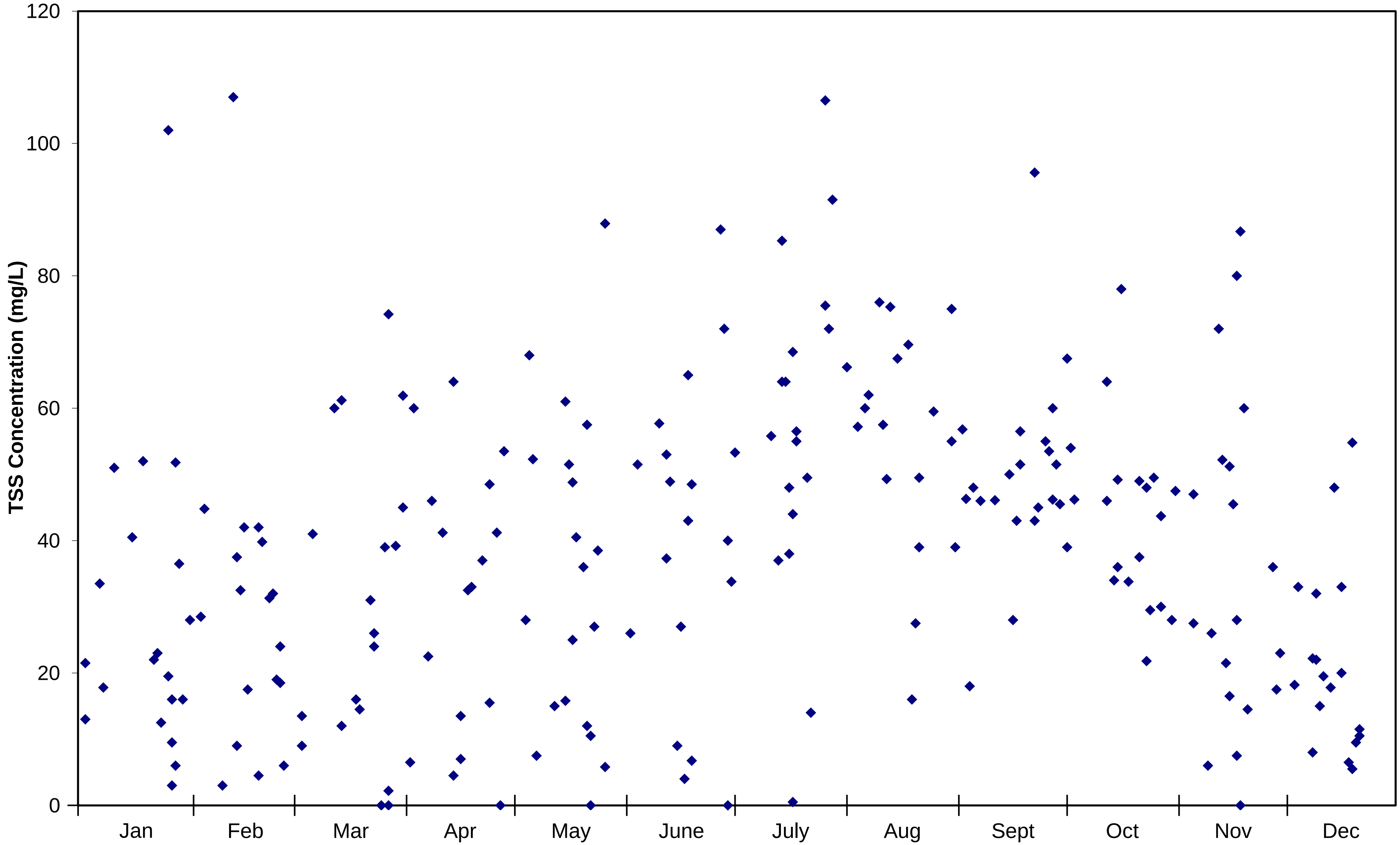
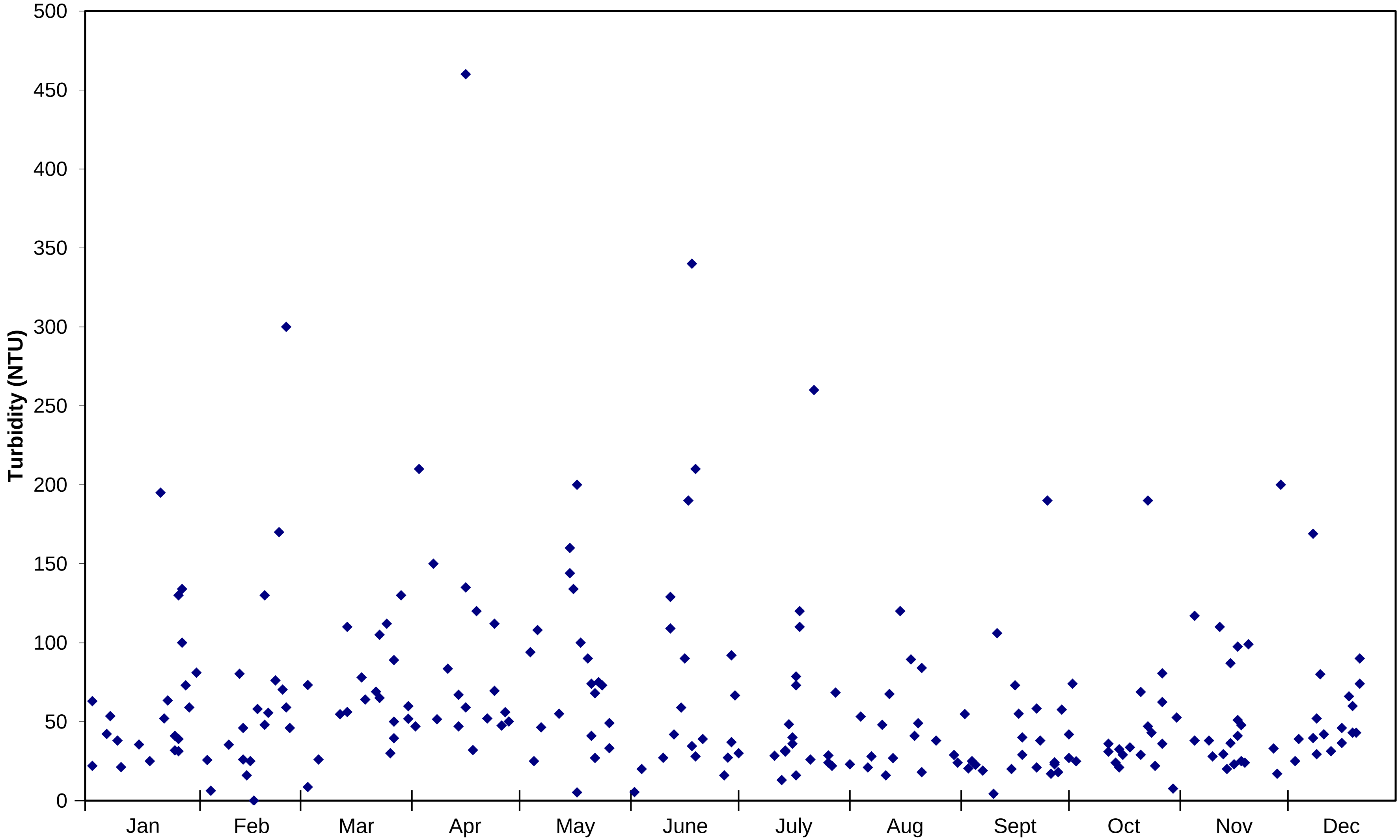


**Figure B.12 Seasonal Plot of TSS in Sulphur River south of Texarkana, AR (RED0005)**



## Figure B.13 Seasonal Plot of Turbidity in Red River near Doddridge, AR (RED0009)



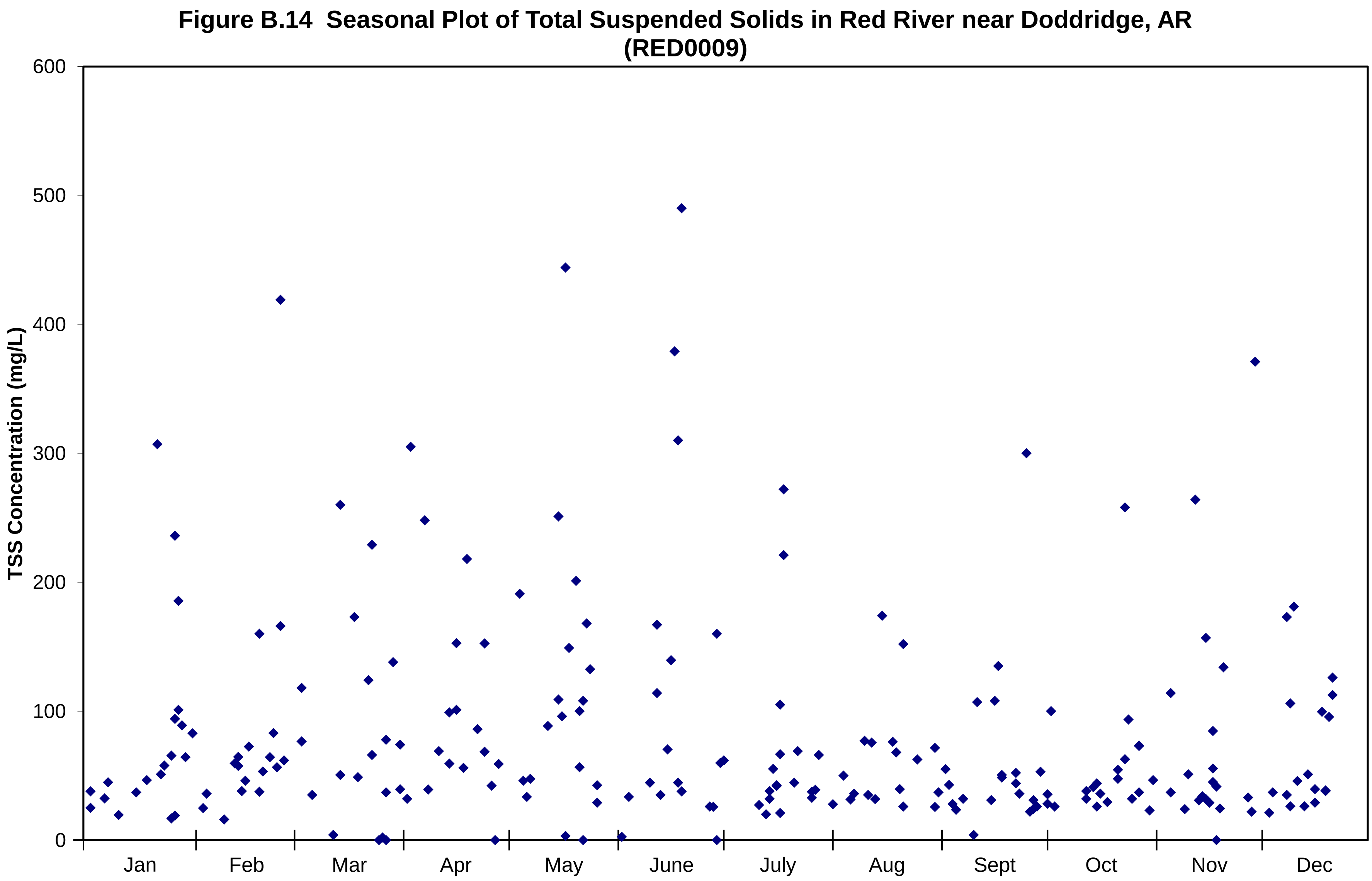
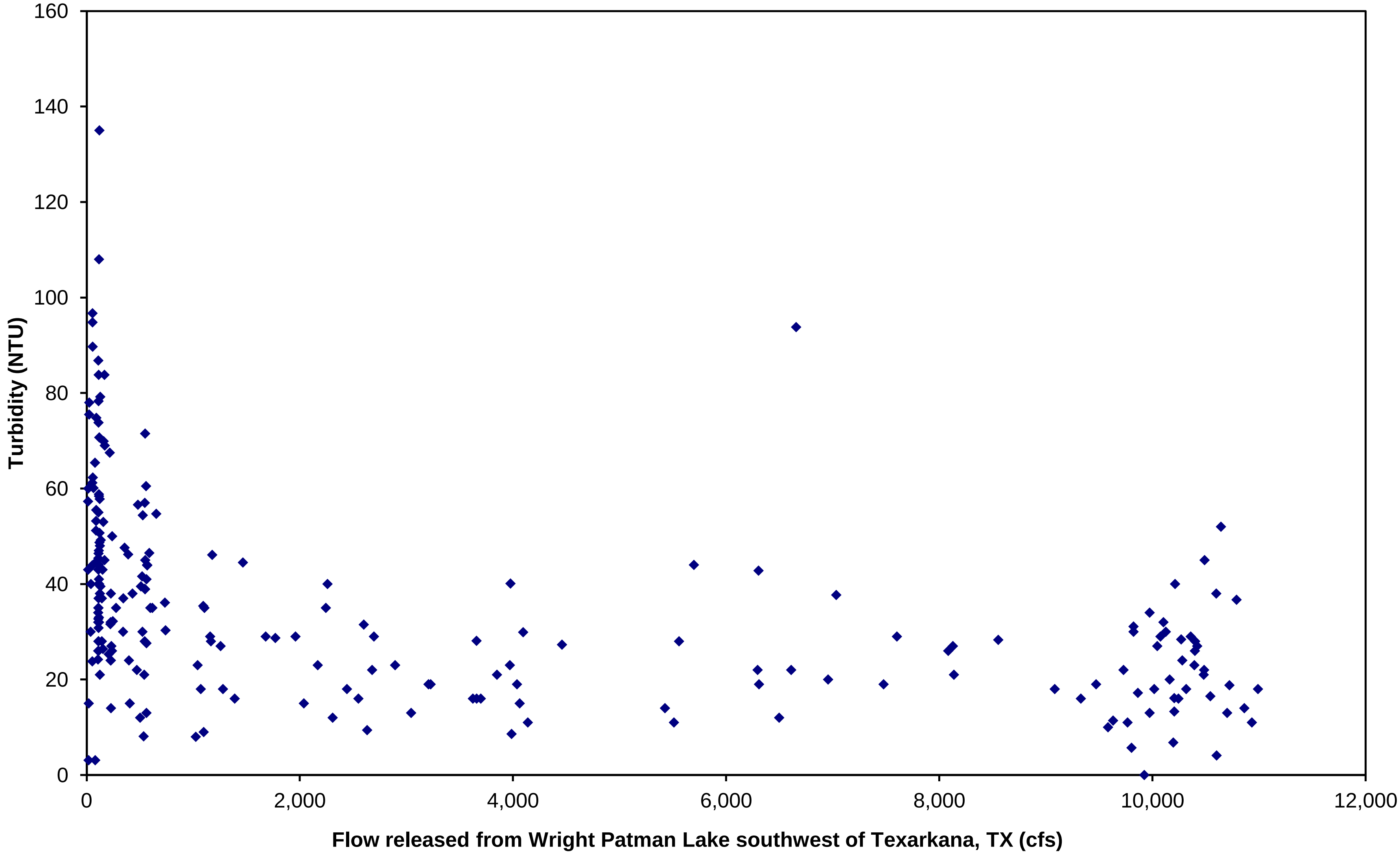


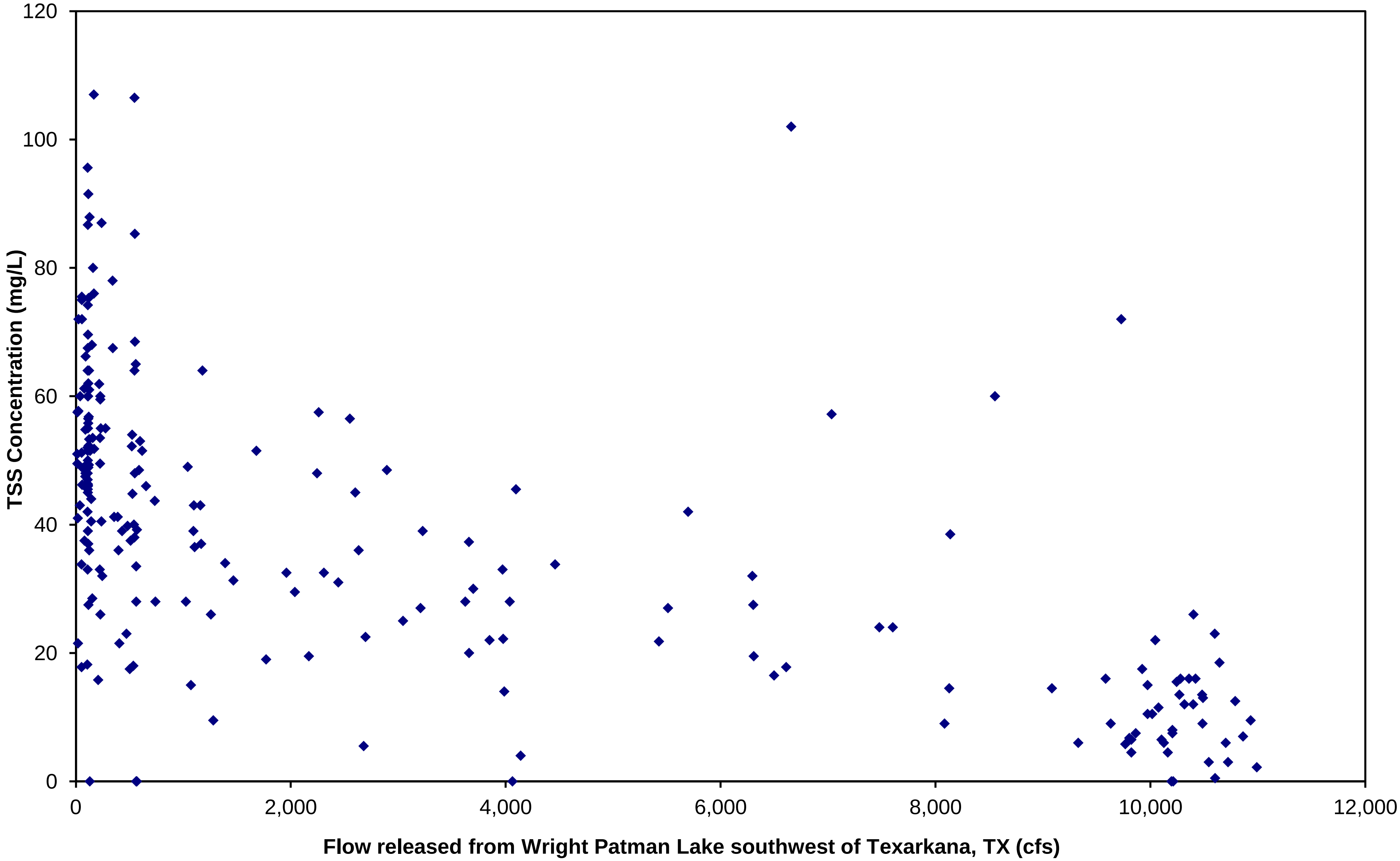
Figure B.14 Seasonal Plot of Total Suspended Solids in Red River near Doddridge, AR
(RED0009)
TSS Concentration (mg/L)
600
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec

Figure B.15  Turbidity versus Flow in Sulphur River south of Texarkana, AR (RED0005)



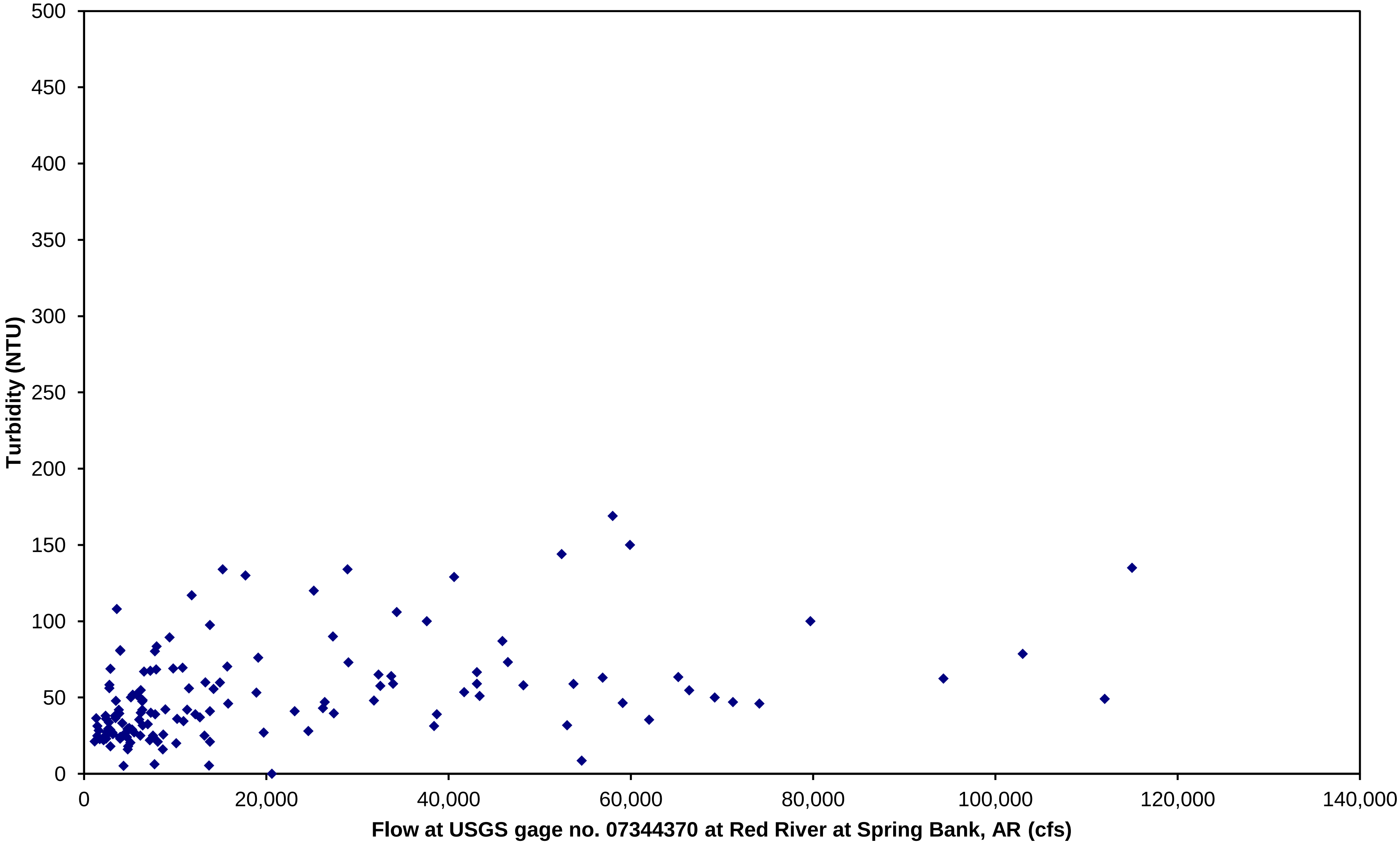

Note: Data points shown only for those dates when both concentration and flow are available.

**Figure B.16 TSS Concentration versus Flow in Sulphur River south of Texarkana, AR (RED0005)**



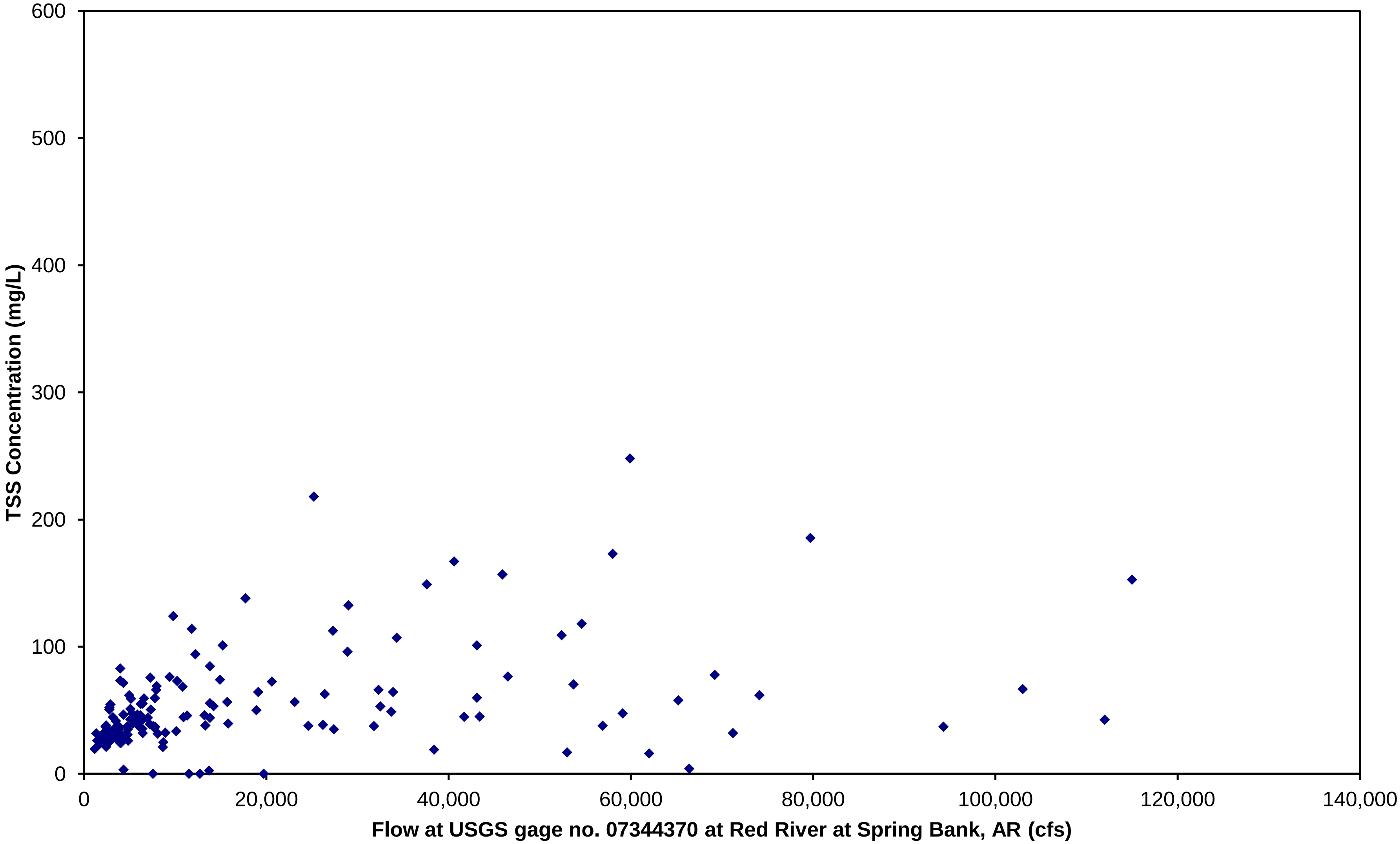

Note: Data points shown only for those dates when both concentration and flow are available.

**Figure B.17 Turbidity versus Flow in Red River near Doddridge, AR (RED0009)**




Note: Data points shown only for those dates when both concentration and flow are available.

**Figure B.18 Total Suspended Solids Concentration versus Flow in Red River near Doddridge, AR (RED0009)**




Note: Data points shown only for those dates when both concentration and flow are available.

**Figure B.19 Turbidity versus TSS for Base Flows in Sulphur River south of Texarkana, AR (RED0005)**

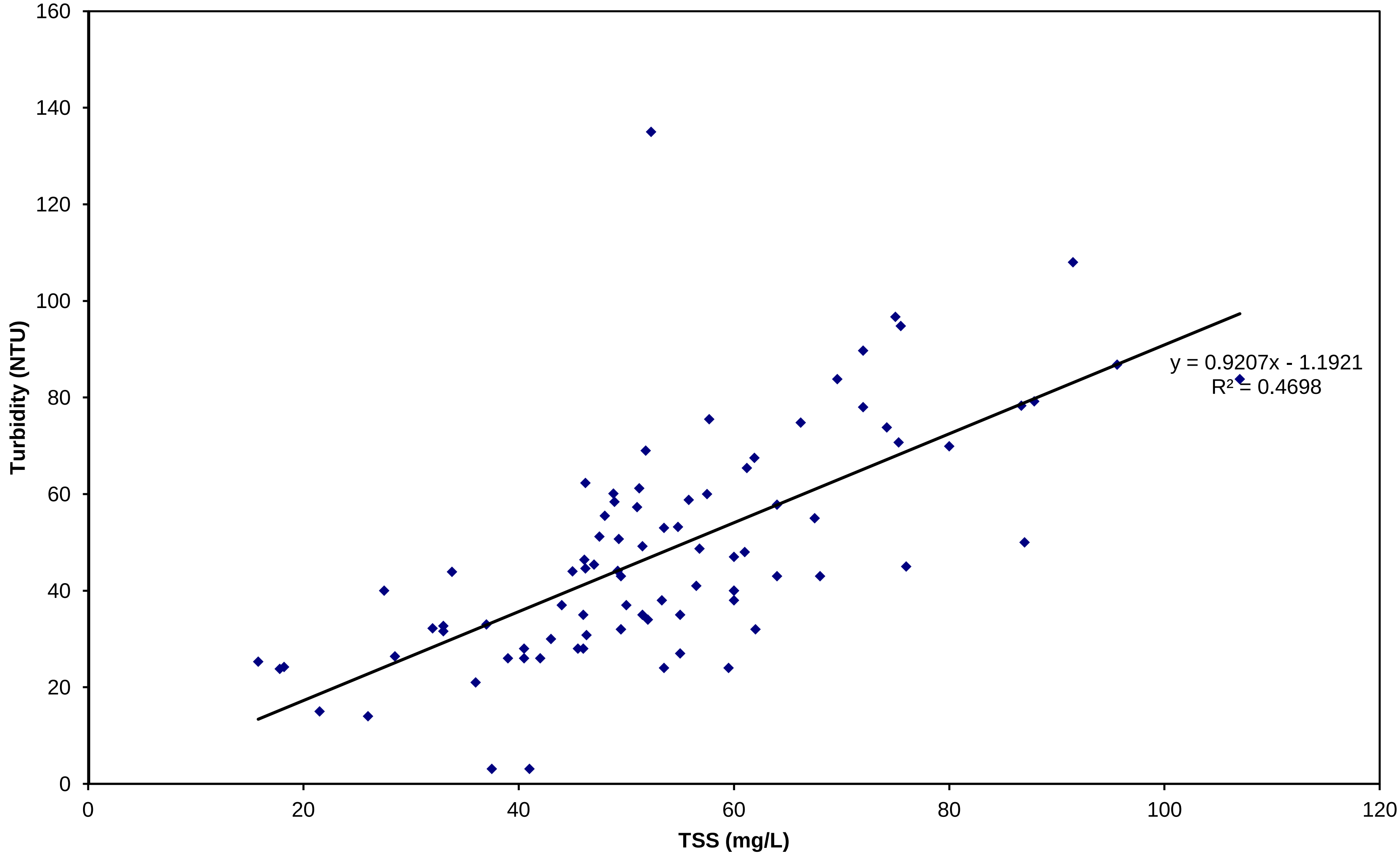


**Figure B.20 Turbidity versus TSS for All Flows in Sulphur River south of Texarkana, AR (RED0005)**

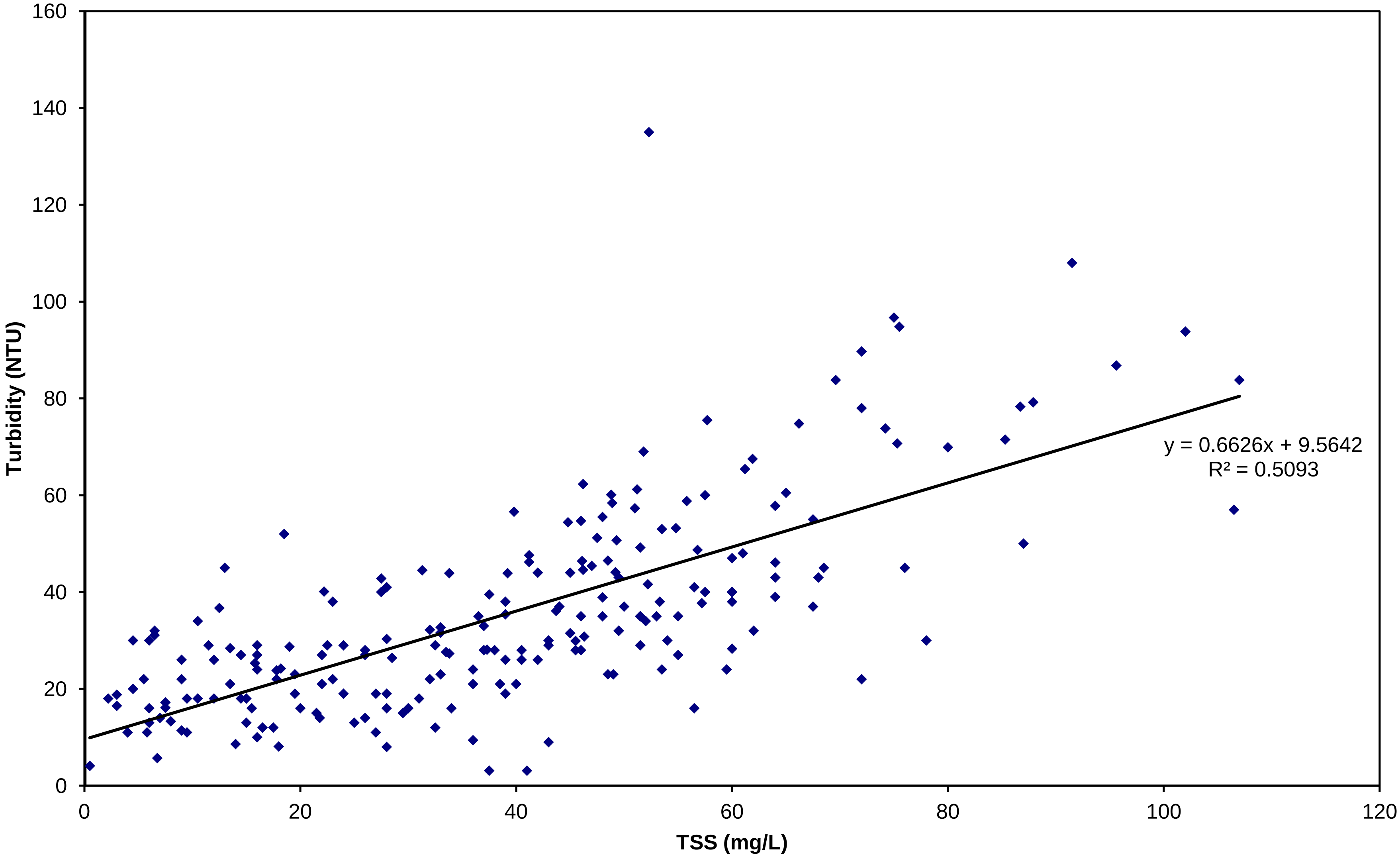


**Figure B.21 Turbidity versus TSS for Base Flows in Red River near Doddridge, AR (RED0009)**

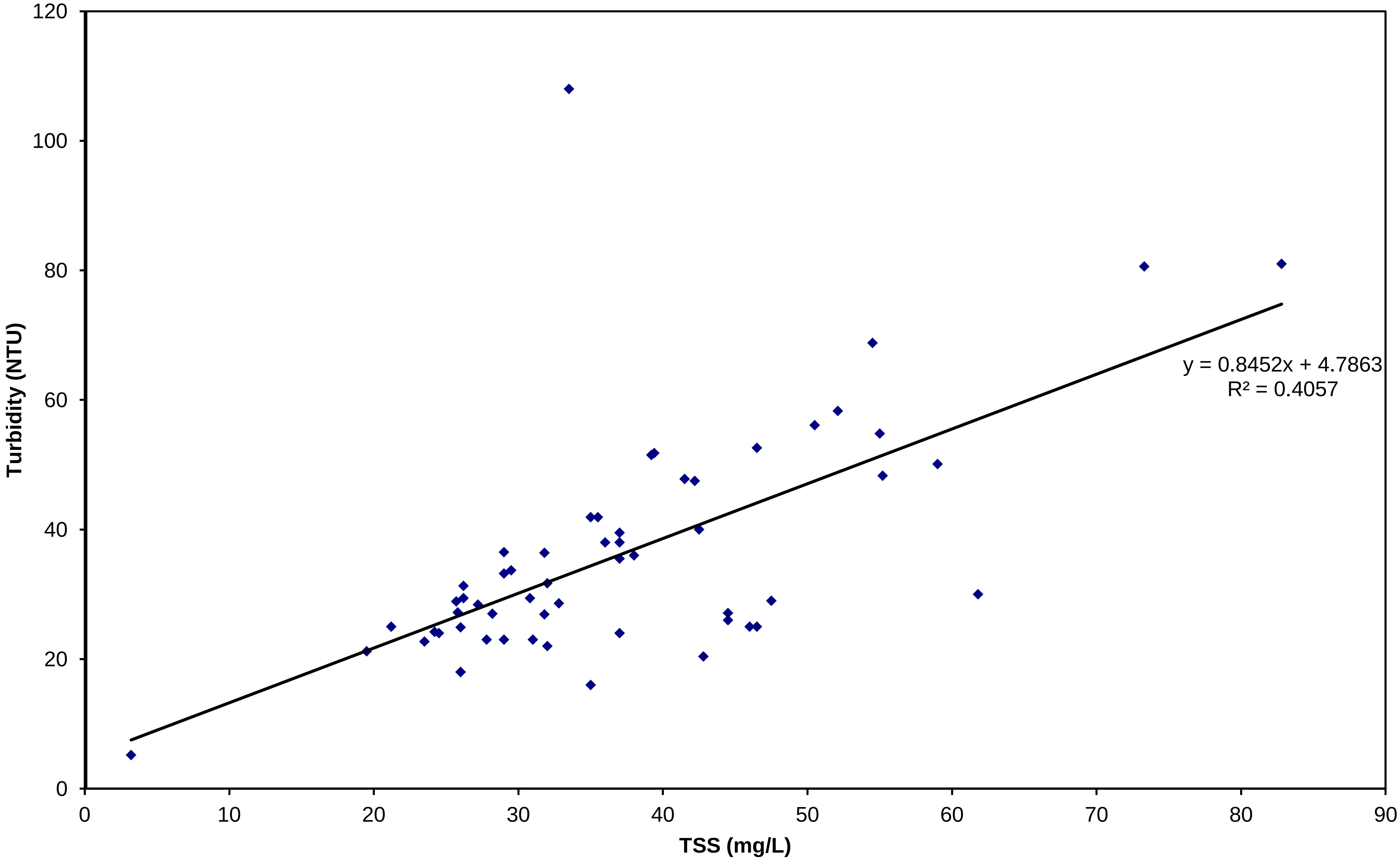
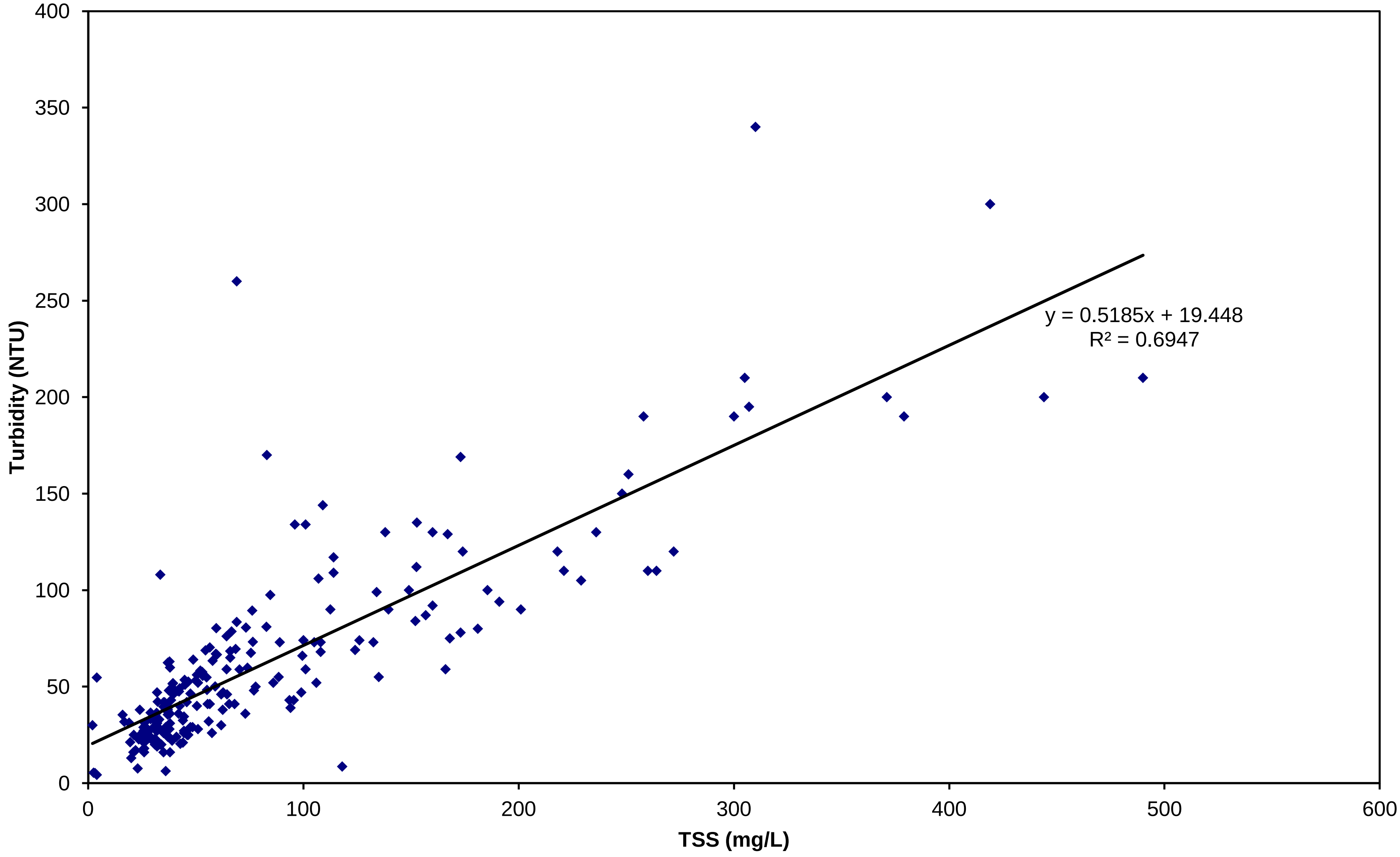


**Figure B.22 Turbidity versus TSS for All Flows in Red River near Doddridge, AR (RED0009)**



# APPENDIX C

## FTN Field Data

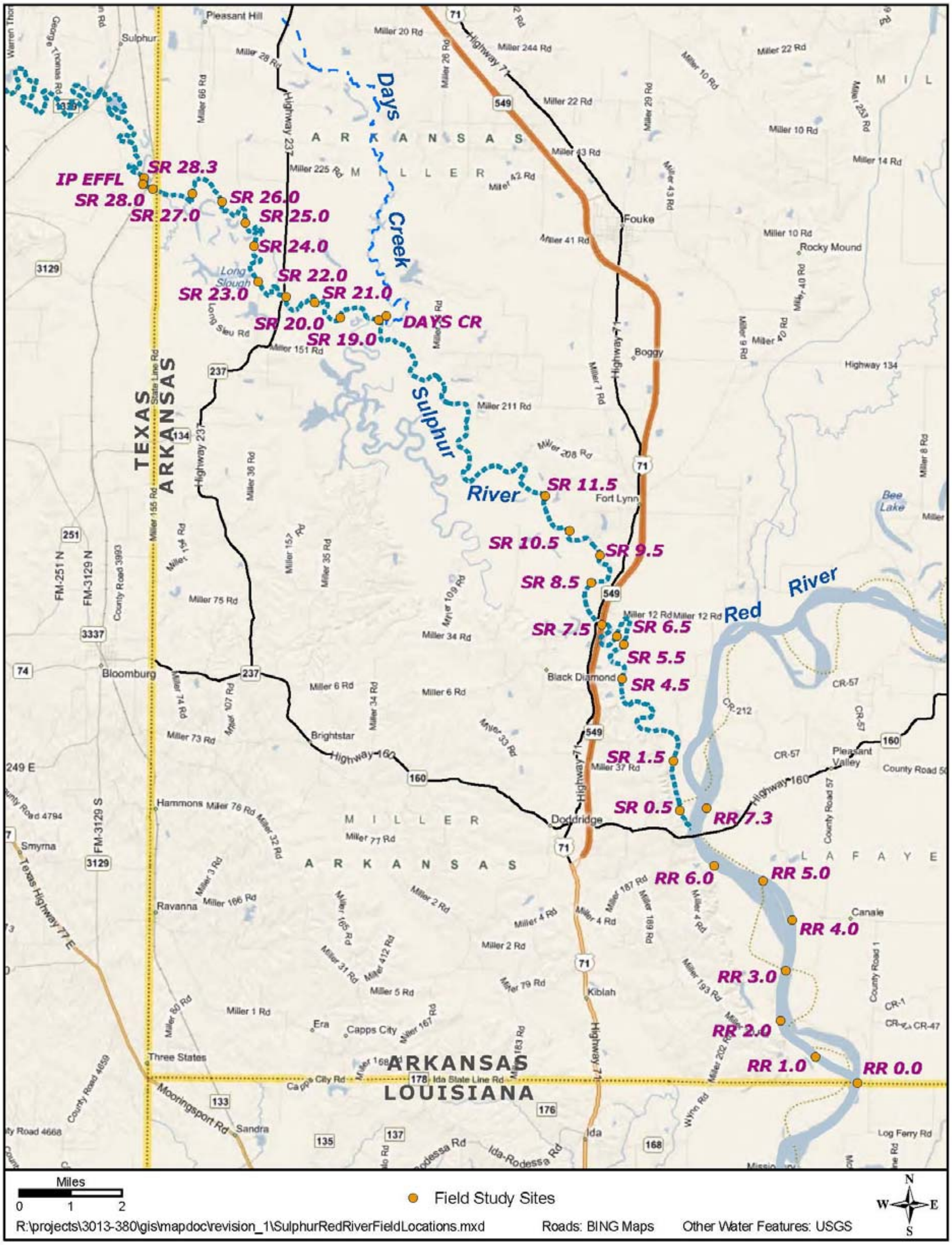
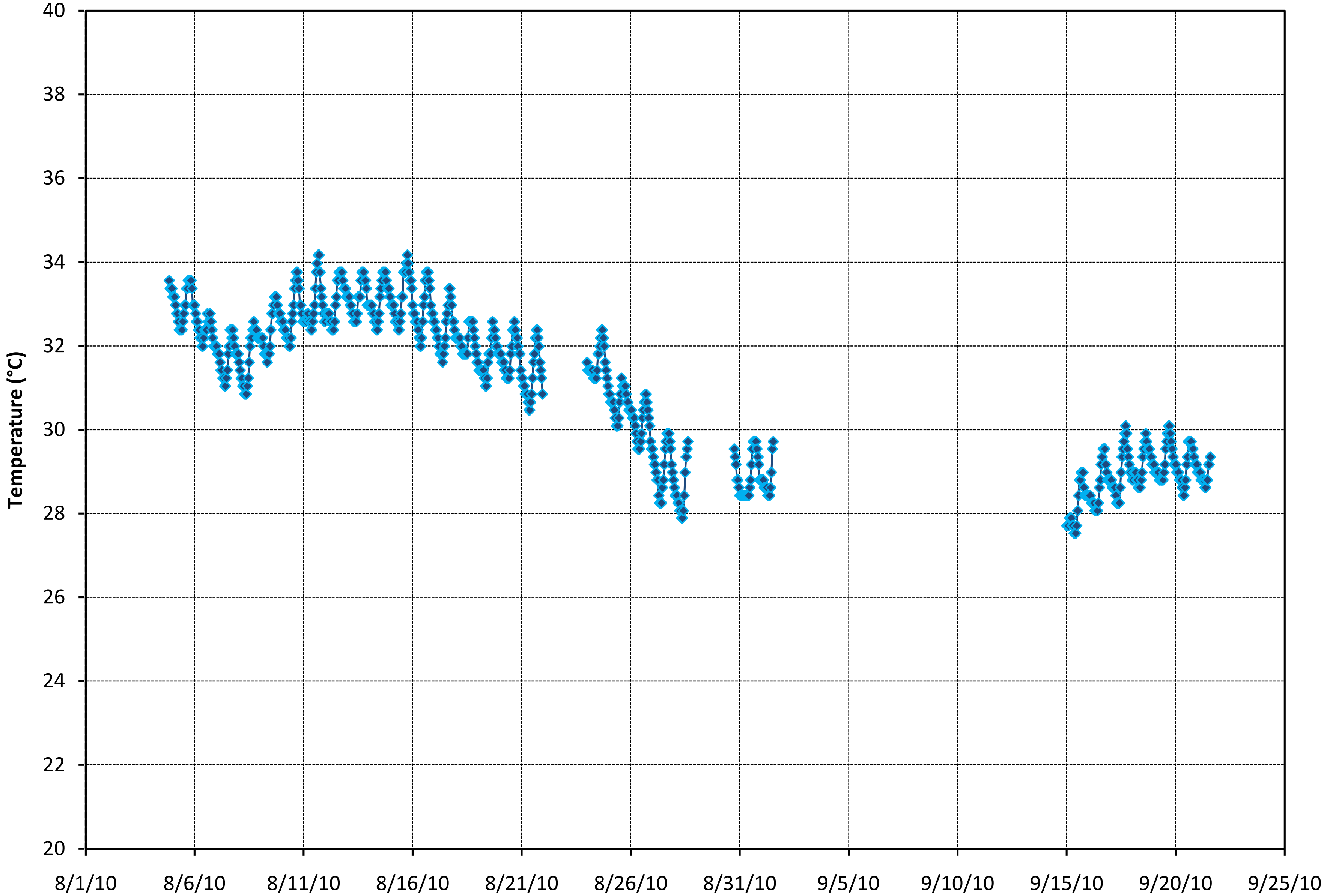



Figure C.1. Field study sampling site locations.

Figure C.2. Measured Water Temperatures at RR-7.3



## Figure C.3. Measured Water Temperatures at SR-11.5

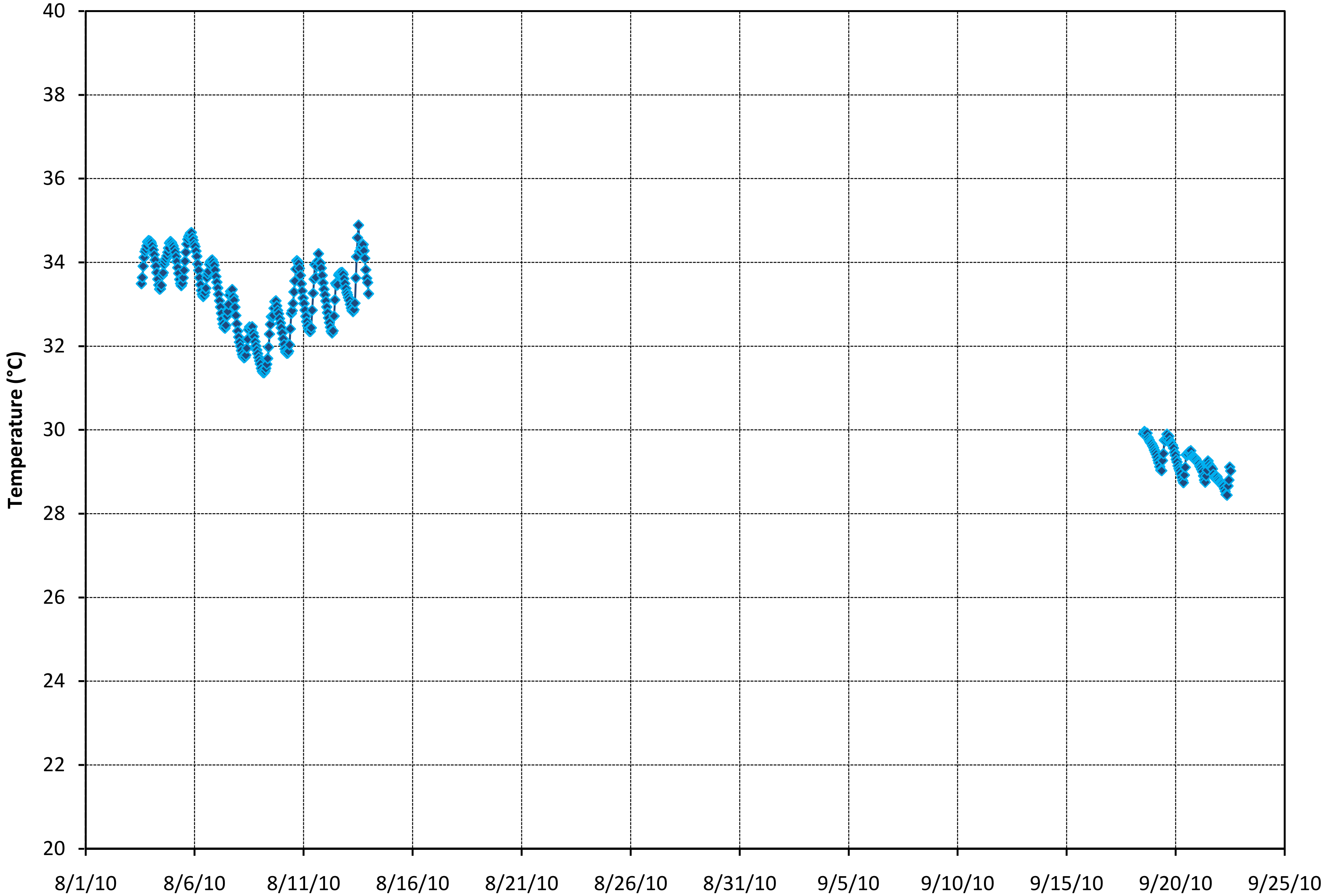
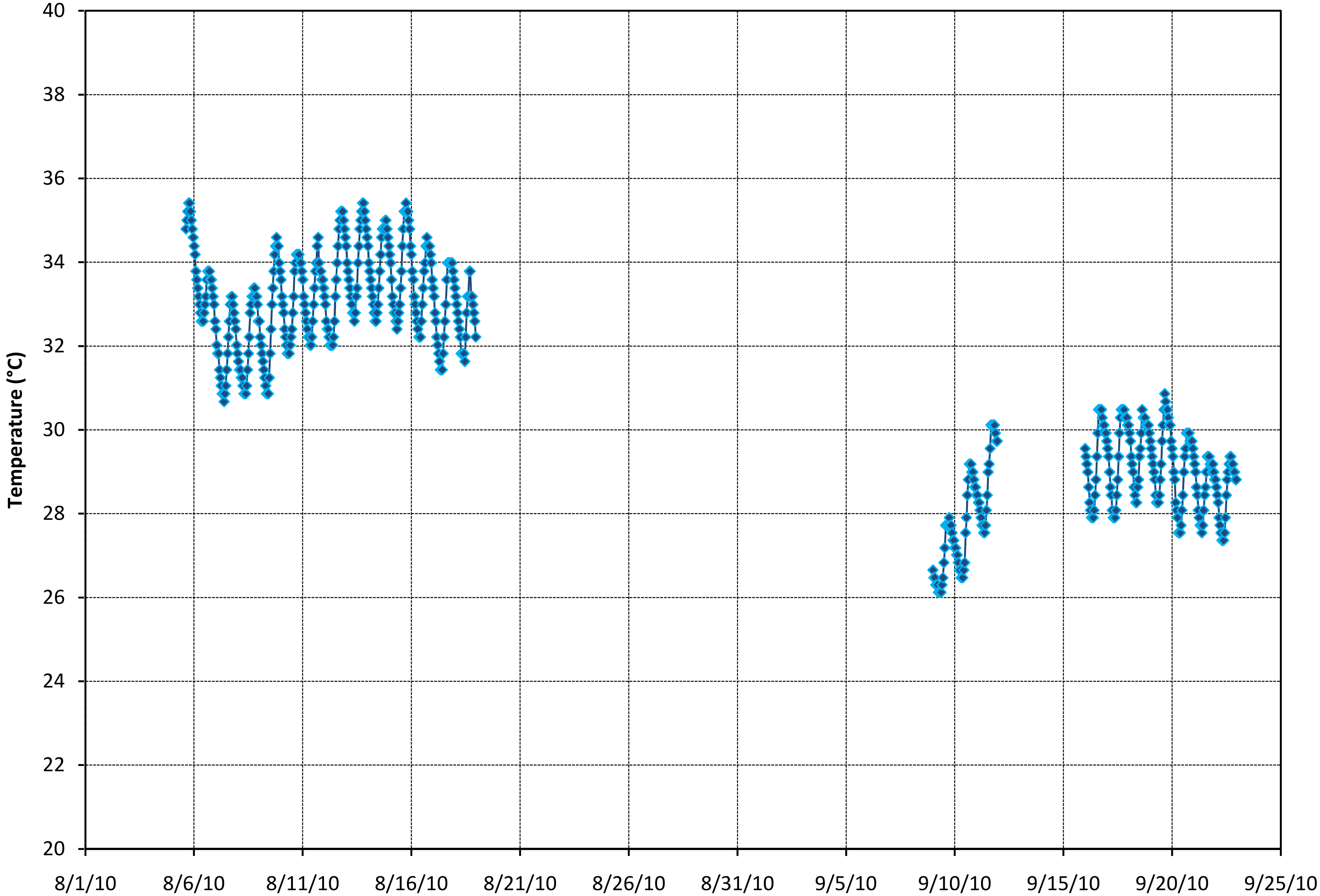


**Figure C.4. Measured Water Temperatures in Days Creek**



## Figure C.5. Measured Water Temperatures at SR-19

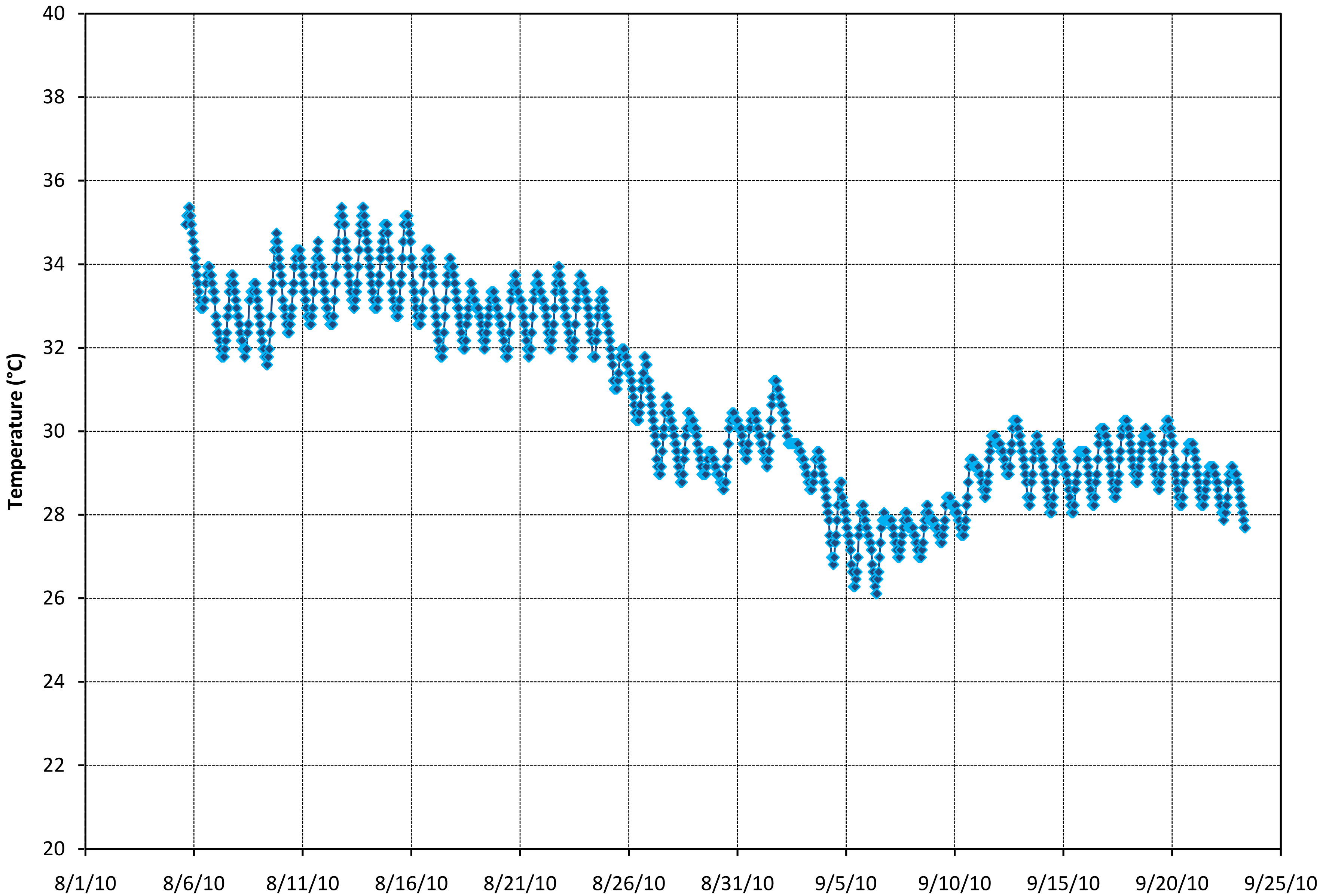


Figure C.6. Measured Water Temperatures at SR-28

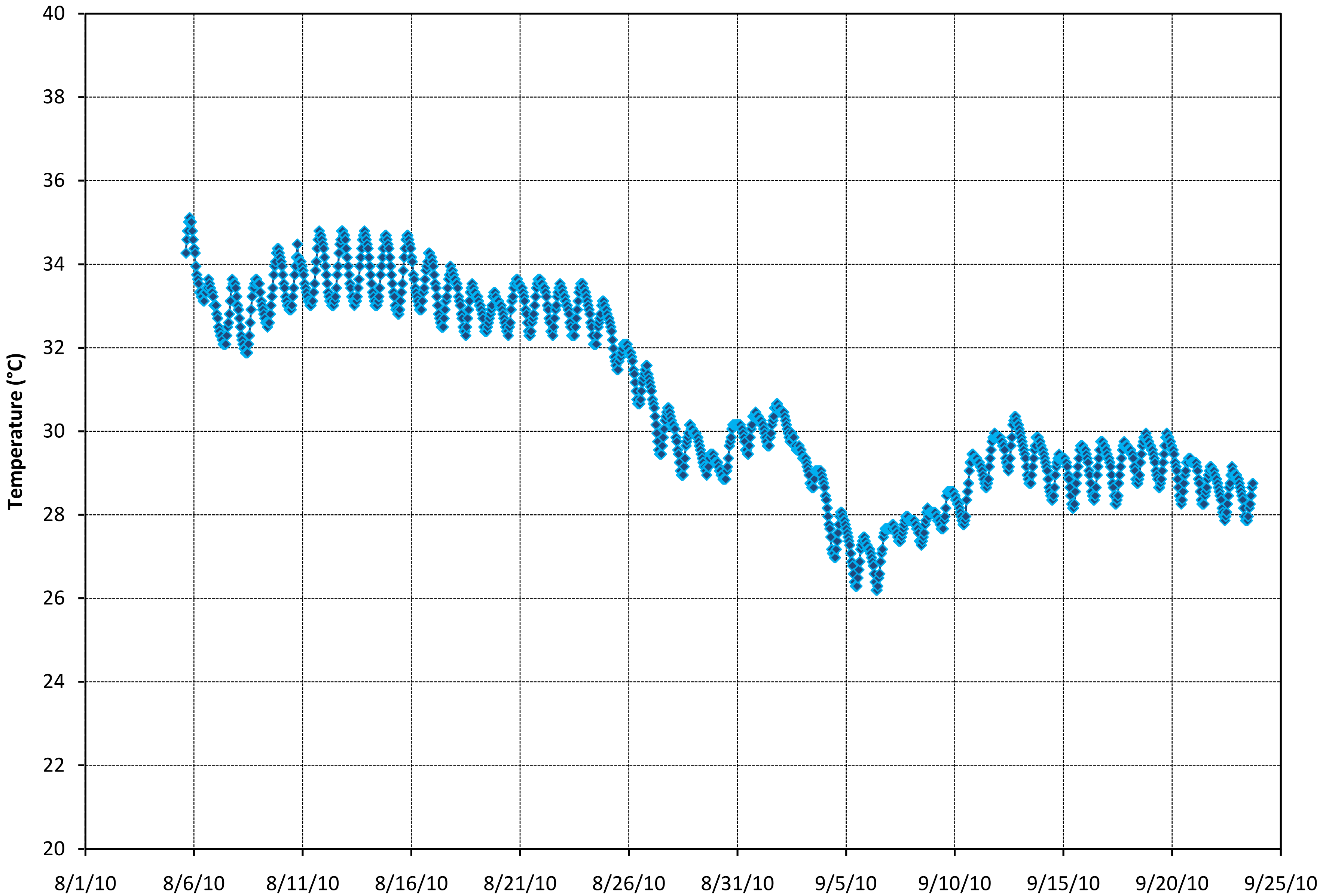


Table C.1 Summary of cross section data

| Site ID | River Mile | Width (ft) | Depth (ft) |
|---|---|---|---|
| RR 0.0 | 0.00 | 232.83 | 15.56 |
| RR 1.0 | 1.00 | 732.52 | 4.02 |
| RR 2.0 | 2.00 | 472.41 | 4.90 |
| RR 3.0 | 3.00 | 362.94 | 6.51 |
| RR 4.0 | 4.00 | 413.16 | 10.76 |
| RR 5.0 | 5.00 | 531.25 | 7.92 |
| RR 6.0 | 6.00 | 517.06 | 6.38 |
| SR 0.5 | 7.50 | 238.04 | 6.24 |
| SR 1.5 | 8.50 | 129.89 | 13.03 |
| SR 4.5 | 11.50 | 94.3 | 11.89 |
| SR 5.5 | 12.50 | 99.12 | 11.90 |
| SR 6.5 | 13.50 | 114.76 | 11.71 |
| SR 7.5 | 14.50 | 119.46 | 4.61 |
| SR 8.5 | 15.50 | 108.45 | 10.56 |
| SR 9.5 | 16.50 | 119.86 | 6.52 |
| SR 10.5 | 17.50 | 112.58 | 5.42 |
| SR 11.5 | 18.50 | 108.2 | 6.22 |
| SR 19.0 | 26.00 | 46.93 | 4.21 |
| SR 20.0 | 27.00 | 91.94 | 2.08 |
| SR 21.0 | 28.00 | 59.54 | 2.09 |
| SR 22.0 | 29.00 | 101.14 | 4.19 |
| SR 24.0 | 31.00 | 81.18 | 3.26 |
| SR 25.0 | 32.00 | 91.6 | 4.49 |
| SR 26.0 | 33.00 | 93.27 | 4.53 |
| SR 27.0 | 34.00 | 99.64 | 5.00 |
| SR 28.0 | 35.00 | 129.3 | 4.03 |

Table C.2 Summary of stream flow measurements

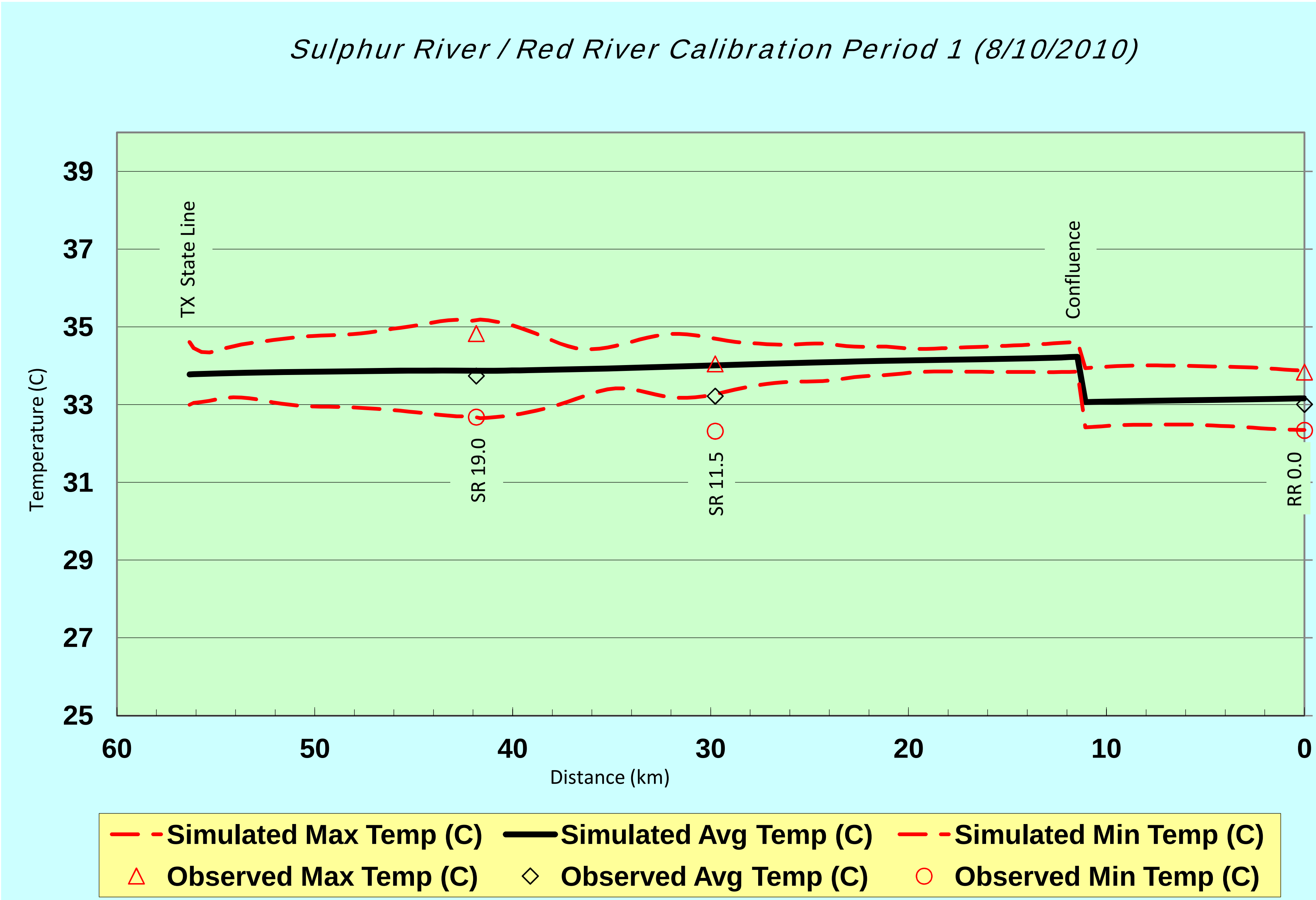
| Stream | Site ID | Stream Flow (cfs) | Average Depth (ft) |
|---|---|---|---|
| Days Creek | DAYS CR | 15 | 1.8 |
| Sulphur River | SR-19.0 | 141 | 3.0 |
| Sulphur River | SR-28.0 | 129 | 4.0 |

Table C.3 Temperature profile

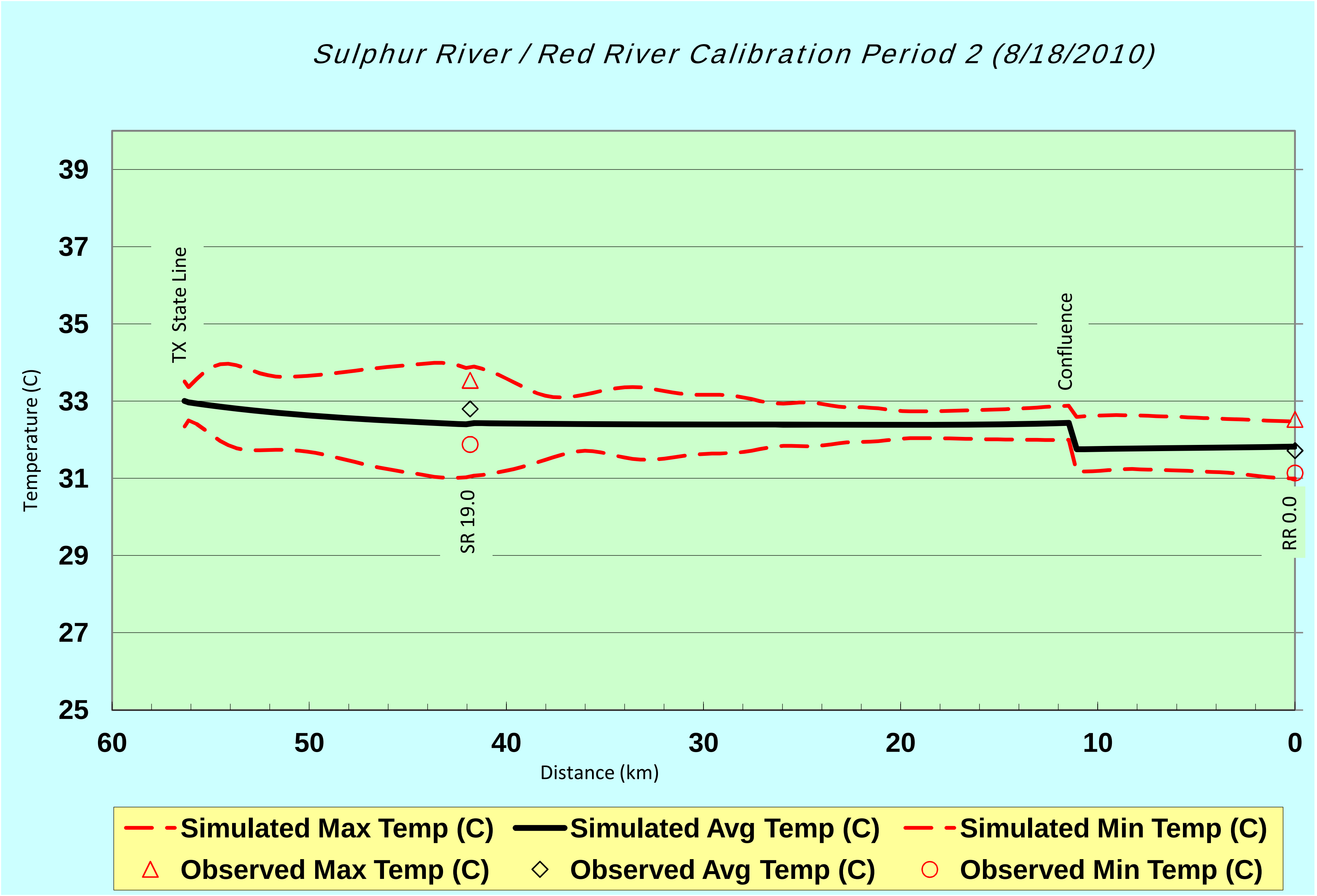
| Site ID | Date | Time | Depth (meters) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| SR 28.0 | 9/23/2010 | 16:15 | 28.5 | 28.1 | 28 | | | | |
| SR 27.0 | 9/23/2010 | 15:47 | 29 | 28.3 | 28 | 28 | | | |
| SR 26.0 | 9/23/2010 | 15:30 | 29.2 | 29 | 29 | | | | |
| SR 25.0 | 9/23/2010 | | 29.1 | 28.7 | 28.8 | | | | |
| SR 24.0 | 9/23/2010 | 14:52 | 30.9 | 30.5 | | | | | |
| SR 23.0 | 9/23/2010 | 14:30 | 29 | 28.5 | | | | | |
| SR 22.0 | 9/23/2010 | 13:30 | 29 | 28.9 | 28.9 | | | | |
| SR 21.0 | 9/23/2010 | 13:00 | 28.8 | 28.8 | | | | | |
| SR 20.0 | 9/23/2010 | 12:30 | 28 | 27.9 | | | | | |
| DAYS CR | 9/23/2010 | 11:25 | 25.8 | 25.6 | | | | | |
| SR 19.0 | 9/23/2010 | 9:20 | 27.1 | 27.1 | | | | | |
| SR 11.5 | 9/22/2010 | 12:40 | 28.5 | 28.2 | 28.1 | 28 | | | |
| SR 10.5 | 9/22/2010 | 12:10 | 28.2 | 28.1 | 28.1 | 28.1 | | | |
| SR 9.5 | 9/22/2010 | 11:30 | 28.5 | 28.1 | 28.1 | 28 | | | |
| SR 8.5 | 9/22/2010 | 11:15 | 29 | 28.7 | 28.5 | 28.5 | 28.5 | 28.5 | |
| SR 7.5 | 9/22/2010 | 10:45 | 28.6 | 28.2 | 28 | 28 | | | |
| SR 6.5 | 9/22/2010 | 10:25 | 28.8 | 28.3 | 28.1 | 28.1 | 28.1 | 28.1 | |
| SR 5.5 | 9/22/2010 | 9:30 | 29.7 | 29.5 | 29.5 | 29.4 | 29.4 | 29.3 | |
| SR 4.5 | 9/22/2010 | 9:00 | 28.4 | 28.4 | 28.4 | 28.5 | 28.8 | | |
| SR 1.5 | 9/21/2010 | 15:40 | 29.5 | 29 | 28.5 | 28 | 28 | 27 | 27 |
| SR 0.5 | 9/21/2010 | 15:15 | 29.1 | 29.2 | 28.5 | 28.1 | | | |
| RR 7.3 | 9/21/2010 | 14:45 | 29.6 | 29.5 | 29.5 | | | | |
| RR 6.0 | 9/21/2010 | 14:10 | 29 | 29 | 28.9 | 28.9 | | | |
| RR 5.0 | 9/21/2010 | 13:48 | 29.2 | 29 | 29 | 29 | 29 | 29 | |
| RR 4.0 | 9/21/2010 | 13:30 | 29.7 | 29.5 | 29.5 | 29.5 | 29.4 | | |
| RR 3.0 | 9/21/2010 | 13:10 | 29.3 | 29.2 | 29 | | | | |
| RR 2.0 | 9/21/2010 | 12:45 | 29.1 | 29 | 29 | 29 | | | |
| RR 1.0 | 9/21/2010 | 12:25 | 28.9 | 28.9 | 28.9 | 28.9 | | | |
| RR 0.0 | 9/21/2010 | 11:00 | 29.6 | 29.6 | 29.6 | 29.7 | 29.8 | 31 | 31.1 |

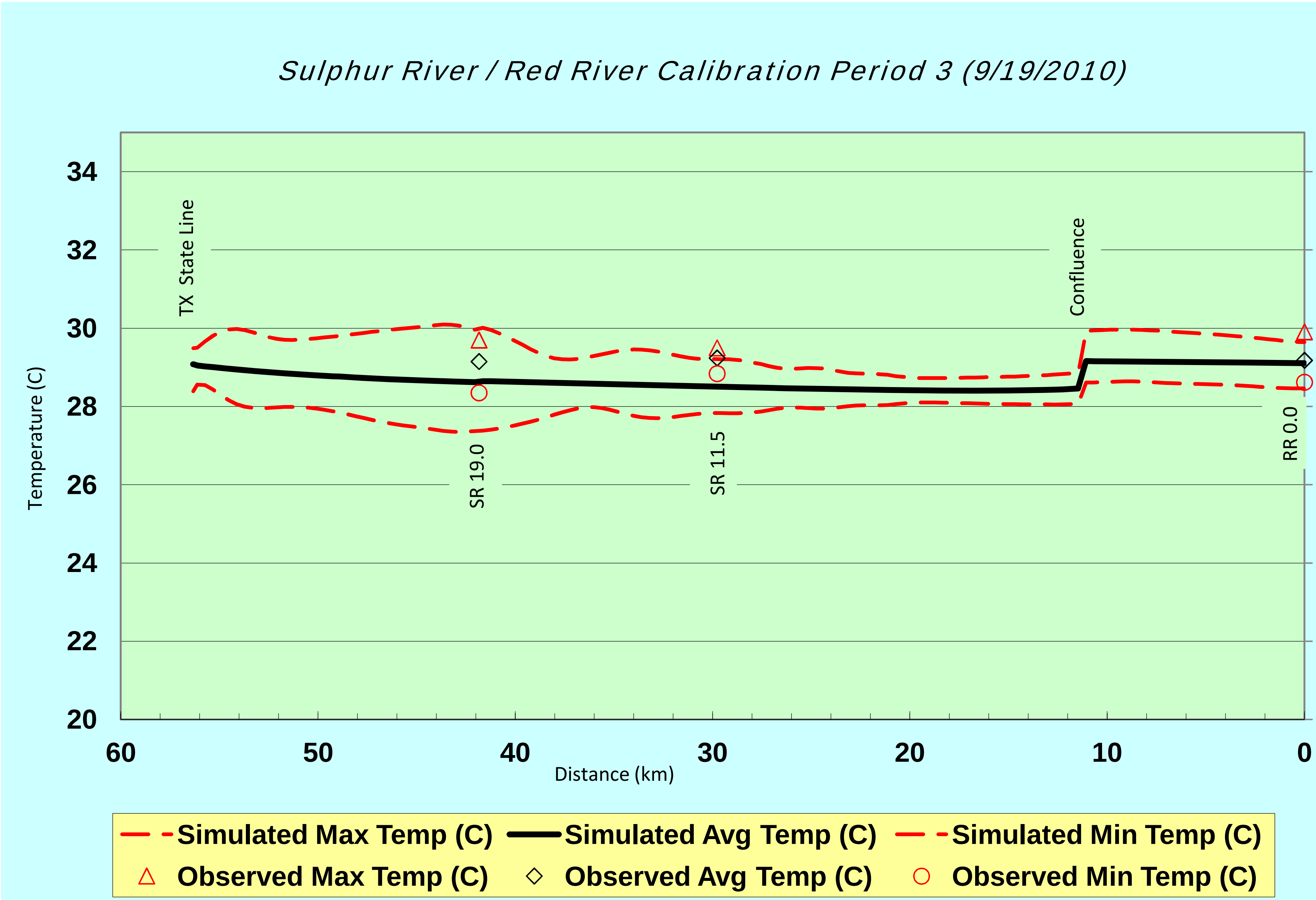
# APPENDIX D

## Temperature Modeling and TMDLs



Sulphur River / Red River Calibration Period 1 (8/10/2010)
Temperature (C)
39
37
35
33
31
29
27
25
60
50
40
30
20
10
0
Distance (km)
TX State Line
Confluence
SR 19.0
SR 11.5
RR 0.0
Simulated Max Temp (C)
Simulated Avg Temp (C)
Simulated Min Temp (C)
Observed Max Temp (C)
Observed Avg Temp (C)
Observed Min Temp (C)


Sulphur River / Red River Calibration Period 2 (8/18/2010)
Temperature (C)
39
37
35
33
31
29
27
25
60
50
40
30
20
10
0
Distance (km)
TX State Line
SR 19.0
Confluence
RR 0.0
Simulated Max Temp (C)
Simulated Avg Temp (C)
Simulated Min Temp (C)
Observed Max Temp (C)
Observed Avg Temp (C)
Observed Min Temp (C)



Sulphur River / Red River Calibration Period 3 (9/19/2010)
Temperature (C)
34
32
30
28
26
24
22
20
60
50
40
30
20
10
0
Distance (km)
TX State Line
SR 19.0
SR 11.5
Confluence
RR 0.0
Simulated Max Temp (C)
Simulated Avg Temp (C)
Simulated Min Temp (C)
Observed Max Temp (C)
Observed Avg Temp (C)
Observed Min Temp (C)

CALCULATION OF DAILY AVERAGE ATMOSPHERIC HEAT LOAD FOR SIMULATION PERIOD 1

Solar (short wave) radiation calculated by
QUAL2K model (from "Diel Output" tab)

| Hour | (cal/cm2 per day) | (W/m2) |
|---|---|---|
| 0.000 | 0 | 0 |
| 0.094 | 0 | 0 |
| 0.188 | 0 | 0 |
| 0.281 | 0 | 0 |
| 0.375 | 0 | 0 |
| 0.469 | 0 | 0 |
| 0.563 | 0 | 0 |
| 0.656 | 0 | 0 |
| 0.750 | 0 | 0 |
| 0.844 | 0 | 0 |
| 0.938 | 0 | 0 |
| 1.031 | 0 | 0 |
| 1.125 | 0 | 0 |
| 1.219 | 0 | 0 |
| 1.313 | 0 | 0 |
| 1.406 | 0 | 0 |
| 1.500 | 0 | 0 |
| 1.594 | 0 | 0 |
| 1.688 | 0 | 0 |
| 1.781 | 0 | 0 |
| 1.875 | 0 | 0 |
| 1.969 | 0 | 0 |
| 2.063 | 0 | 0 |
| 2.156 | 0 | 0 |
| 2.250 | 0 | 0 |
| 2.344 | 0 | 0 |
| 2.438 | 0 | 0 |
| 2.531 | 0 | 0 |
| 2.625 | 0 | 0 |
| 2.719 | 0 | 0 |
| 2.813 | 0 | 0 |
| 2.906 | 0 | 0 |
| 3.000 | 0 | 0 |
| 3.094 | 0 | 0 |
| 3.188 | 0 | 0 |
| 3.281 | 0 | 0 |
| 3.375 | 0 | 0 |
| 3.469 | 0 | 0 |
| 3.563 | 0 | 0 |
| 3.656 | 0 | 0 |
| 3.750 | 0 | 0 |
| 3.844 | 0 | 0 |
| 3.938 | 0 | 0 |
| 4.031 | 0 | 0 |
| 4.125 | 0 | 0 |
| 4.219 | 0 | 0 |

| Hour | (cal/cm2 per day) | (W/m2) |
|---|---|---|
| 4.313 | 0 | 0 |
| 4.406 | 0 | 0 |
| 4.500 | 0 | 0 |
| 4.594 | 0 | 0 |
| 4.688 | 0 | 0 |
| 4.781 | 0 | 0 |
| 4.875 | 0 | 0 |
| 4.969 | 0 | 0 |
| 5.063 | 0 | 0 |
| 5.156 | 0 | 0 |
| 5.250 | 0 | 0 |
| 5.344 | 0 | 0 |
| 5.438 | 0 | 0 |
| 5.531 | 0 | 0 |
| 5.625 | 0 | 0 |
| 5.719 | 0 | 0 |
| 5.813 | 0 | 0 |
| 5.906 | 0 | 0 |
| 6.000 | 0 | 0 |
| 6.094 | 0 | 0 |
| 6.188 | 0 | 0 |
| 6.281 | 0 | 0 |
| 6.375 | 0 | 0 |
| 6.469 | 0 | 0 |
| 6.563 | 0 | 0 |
| 6.656 | 0 | 0 |
| 6.750 | 0 | 0 |
| 6.844 | 0.06 | 0.03 |
| 6.938 | 0.76 | 0.37 |
| 7.031 | 2.63 | 1.27 |
| 7.125 | 6.21 | 3.01 |
| 7.219 | 11.92 | 5.78 |
| 7.313 | 19.95 | 9.67 |
| 7.406 | 30.35 | 14.71 |
| 7.500 | 43.07 | 20.87 |
| 7.594 | 58.03 | 28.12 |
| 7.688 | 75.07 | 36.38 |
| 7.781 | 94.04 | 45.57 |
| 7.875 | 114.80 | 55.63 |
| 7.969 | 137.18 | 66.48 |
| 8.063 | 161.03 | 78.03 |
| 8.156 | 186.21 | 90.24 |
| 8.250 | 212.59 | 103.02 |
| 8.344 | 240.03 | 116.31 |
| 8.438 | 268.41 | 130.07 |
| 8.531 | 297.64 | 144.23 |
| 8.625 | 327.59 | 158.74 |
| 8.719 | 358.17 | 173.56 |
| 8.813 | 389.29 | 188.64 |
| 8.906 | 420.86 | 203.94 |

| Hour | (cal/cm2 per day) | (W/m2) |
|---|---|---|
| 9.000 | 452.79 | 219.42 |
| 9.094 | 485.02 | 235.03 |
| 9.188 | 517.47 | 250.76 |
| 9.281 | 550.07 | 266.55 |
| 9.375 | 582.75 | 282.39 |
| 9.469 | 615.45 | 298.24 |
| 9.563 | 648.11 | 314.06 |
| 9.656 | 680.67 | 329.84 |
| 9.750 | 713.08 | 345.55 |
| 9.844 | 745.28 | 361.15 |
| 9.938 | 777.24 | 376.64 |
| 10.031 | 808.89 | 391.98 |
| 10.125 | 840.20 | 407.15 |
| 10.219 | 871.12 | 422.13 |
| 10.313 | 901.60 | 436.90 |
| 10.406 | 931.61 | 451.44 |
| 10.500 | 961.11 | 465.74 |
| 10.594 | 990.07 | 479.77 |
| 10.688 | 1018.43 | 493.52 |
| 10.781 | 1046.18 | 506.96 |
| 10.875 | 1073.28 | 520.09 |
| 10.969 | 1099.69 | 532.89 |
| 11.063 | 1125.39 | 545.35 |
| 11.156 | 1150.23 | 557.38 |
| 11.250 | 1173.79 | 568.80 |
| 11.344 | 1195.97 | 579.55 |
| 11.438 | 1216.73 | 589.61 |
| 11.531 | 1236.01 | 598.95 |
| 11.625 | 1265.61 | 613.29 |
| 11.719 | 1281.97 | 621.22 |
| 11.813 | 1296.70 | 628.36 |
| 11.906 | 1309.76 | 634.69 |
| 12.000 | 1321.11 | 640.19 |
| 12.094 | 1330.74 | 644.85 |
| 12.188 | 1345.66 | 652.08 |
| 12.281 | 1359.58 | 658.83 |
| 12.375 | 1372.50 | 665.09 |
| 12.469 | 1384.38 | 670.85 |
| 12.563 | 1395.23 | 676.11 |
| 12.656 | 1405.03 | 680.85 |
| 12.750 | 1413.76 | 685.08 |
| 12.844 | 1421.41 | 688.79 |
| 12.938 | 1427.98 | 691.98 |
| 13.031 | 1433.46 | 694.63 |
| 13.125 | 1439.17 | 697.40 |
| 13.219 | 1446.31 | 700.86 |
| 13.313 | 1452.14 | 703.68 |
| 13.406 | 1456.64 | 705.86 |
| 13.500 | 1459.80 | 707.39 |
| 13.594 | 1461.61 | 708.27 |

| Hour | (cal/cm2 per day) | (W/m2) |
|---|---|---|
| 13.688 | 1462.07 | 708.49 |
| 13.781 | 1461.17 | 708.06 |
| 13.875 | 1458.92 | 706.97 |
| 13.969 | 1455.32 | 705.23 |
| 14.063 | 1436.71 | 696.21 |
| 14.156 | 1429.13 | 692.53 |
| 14.250 | 1419.74 | 687.98 |
| 14.344 | 1409.26 | 682.91 |
| 14.438 | 1397.72 | 677.31 |
| 14.531 | 1385.13 | 671.21 |
| 14.625 | 1384.55 | 670.93 |
| 14.719 | 1369.76 | 663.76 |
| 14.813 | 1353.96 | 656.11 |
| 14.906 | 1337.16 | 647.97 |
| 15.000 | 1319.39 | 639.35 |
| 15.094 | 1300.65 | 630.27 |
| 15.188 | 1283.33 | 621.88 |
| 15.281 | 1253.02 | 607.19 |
| 15.375 | 1233.61 | 597.79 |
| 15.469 | 1213.11 | 587.85 |
| 15.563 | 1191.55 | 577.40 |
| 15.656 | 1168.95 | 566.46 |
| 15.750 | 1145.36 | 555.02 |
| 15.844 | 1120.81 | 543.13 |
| 15.938 | 1095.34 | 530.79 |
| 16.031 | 1068.99 | 518.02 |
| 16.125 | 1041.81 | 504.84 |
| 16.219 | 1013.94 | 491.34 |
| 16.313 | 985.44 | 477.53 |
| 16.406 | 956.36 | 463.44 |
| 16.500 | 926.74 | 449.08 |
| 16.594 | 896.60 | 434.48 |
| 16.688 | 865.98 | 419.64 |
| 16.781 | 834.94 | 404.60 |
| 16.875 | 803.51 | 389.37 |
| 16.969 | 771.74 | 373.97 |
| 17.063 | 739.68 | 358.43 |
| 17.156 | 707.44 | 342.81 |
| 17.250 | 675.03 | 327.11 |
| 17.344 | 642.46 | 311.33 |
| 17.438 | 609.81 | 295.50 |
| 17.531 | 577.11 | 279.66 |
| 17.625 | 544.43 | 263.82 |
| 17.719 | 511.84 | 248.03 |
| 17.813 | 479.41 | 232.31 |
| 17.906 | 447.20 | 216.70 |
| 18.000 | 415.29 | 201.24 |
| 18.094 | 383.76 | 185.96 |
| 18.188 | 352.69 | 170.91 |
| 18.281 | 322.18 | 156.12 |

| Hour | (cal/cm2 per day) | (W/m2) |
|---|---|---|
| 18.375 | 292.31 | 141.65 |
| 18.469 | 263.20 | 127.54 |
| 18.563 | 234.94 | 113.85 |
| 18.656 | 207.64 | 100.62 |
| 18.750 | 181.44 | 87.92 |
| 18.844 | 156.46 | 75.82 |
| 18.938 | 132.84 | 64.37 |
| 19.031 | 110.72 | 53.65 |
| 19.125 | 90.26 | 43.74 |
| 19.219 | 71.61 | 34.70 |
| 19.313 | 54.94 | 26.62 |
| 19.406 | 40.38 | 19.57 |
| 19.500 | 28.09 | 13.61 |
| 19.594 | 18.15 | 8.79 |
| 19.688 | 10.58 | 5.13 |
| 19.781 | 5.32 | 2.58 |
| 19.875 | 2.11 | 1.02 |
| 19.969 | 0.54 | 0.26 |
| 20.063 | 0.01 | 0.00 |
| 20.156 | 0 | 0 |
| 20.250 | 0 | 0 |
| 20.344 | 0 | 0 |
| 20.438 | 0 | 0 |
| 20.531 | 0 | 0 |
| 20.625 | 0 | 0 |
| 20.719 | 0 | 0 |
| 20.813 | 0 | 0 |
| 20.906 | 0 | 0 |
| 21.000 | 0 | 0 |
| 21.094 | 0 | 0 |
| 21.188 | 0 | 0 |
| 21.281 | 0 | 0 |
| 21.375 | 0 | 0 |
| 21.469 | 0 | 0 |
| 21.563 | 0 | 0 |
| 21.656 | 0 | 0 |
| 21.750 | 0 | 0 |
| 21.844 | 0 | 0 |
| 21.938 | 0 | 0 |
| 22.031 | 0 | 0 |
| 22.125 | 0 | 0 |
| 22.219 | 0 | 0 |
| 22.313 | 0 | 0 |
| 22.406 | 0 | 0 |
| 22.500 | 0 | 0 |
| 22.594 | 0 | 0 |
| 22.688 | 0 | 0 |
| 22.781 | 0 | 0 |
| 22.875 | 0 | 0 |
| 22.969 | 0 | 0 |

| Hour | (cal/cm2 per day) | (W/m2) |
|---|---|---|
| 23.063 | 0 | 0 |
| 23.156 | 0 | 0 |
| 23.250 | 0 | 0 |
| 23.344 | 0 | 0 |
| 23.438 | 0 | 0 |
| 23.531 | 0 | 0 |
| 23.625 | 0 | 0 |
| 23.719 | 0 | 0 |
| 23.813 | 0 | 0 |
| 23.906 | 0 | 0 |
| 24.000 | 0 | 0 |
| | | 209.1 = average |

Calculation of long wave radiation:

| Hour | Air temp. (°C) | Dew point temp. (°C) | Cloud cover (decimal) | Vapor pressure (mm Hg) | Emissivity without clouds (unitless) | Emissivity with clouds (unitless) | Long wave radiation (cal/cm2 per day) | Long wave radiation (W/m2) |
|---|---|---|---|---|---|---|---|---|
| 12:00 AM | 27.44 | 23.44 | 0.00 | 21.71 | 0.888 | 0.888 | 822.38 | 398.51 |
| 1:00 AM | 27.02 | 23.32 | 0.00 | 21.55 | 0.887 | 0.887 | 817.11 | 395.96 |
| 2:00 AM | 27.32 | 23.32 | 0.00 | 21.55 | 0.887 | 0.887 | 820.27 | 397.49 |
| 3:00 AM | 26.34 | 23.32 | 0.00 | 21.55 | 0.887 | 0.887 | 810.00 | 392.51 |
| 4:00 AM | 25.88 | 23.42 | 0.00 | 21.68 | 0.888 | 0.888 | 805.90 | 390.53 |
| 5:00 AM | 26.00 | 23.52 | 0.15 | 21.81 | 0.889 | 0.892 | 810.93 | 392.97 |
| 6:00 AM | 27.46 | 24.10 | 0.09 | 22.59 | 0.893 | 0.894 | 828.34 | 401.40 |
| 7:00 AM | 29.88 | 24.22 | 0.00 | 22.75 | 0.893 | 0.893 | 854.13 | 413.90 |
| 8:00 AM | 32.24 | 24.10 | 0.00 | 22.59 | 0.891 | 0.891 | 879.17 | 426.03 |
| 9:00 AM | 33.78 | 23.66 | 0.00 | 22.00 | 0.887 | 0.887 | 893.02 | 432.74 |
| 10:00 AM | 34.78 | 23.32 | 0.00 | 21.55 | 0.884 | 0.884 | 901.65 | 436.92 |
| 11:00 AM | 35.48 | 23.32 | 0.00 | 21.55 | 0.883 | 0.883 | 909.58 | 440.77 |
| 12:00 PM | 35.80 | 22.32 | 0.20 | 20.29 | 0.876 | 0.882 | 911.51 | 441.70 |
| 1:00 PM | 36.66 | 22.24 | 0.20 | 20.19 | 0.875 | 0.881 | 920.70 | 446.15 |
| 2:00 PM | 36.78 | 21.68 | 0.09 | 19.51 | 0.870 | 0.871 | 912.57 | 442.22 |
| 3:00 PM | 35.90 | 21.90 | 0.11 | 19.77 | 0.872 | 0.874 | 905.12 | 438.61 |
| 4:00 PM | 35.24 | 22.80 | 0.00 | 20.89 | 0.879 | 0.879 | 902.79 | 437.48 |
| 5:00 PM | 34.00 | 22.78 | 0.03 | 20.86 | 0.880 | 0.880 | 888.81 | 430.70 |
| 6:00 PM | 32.44 | 23.34 | 0.00 | 21.58 | 0.885 | 0.885 | 875.66 | 424.33 |
| 7:00 PM | 30.88 | 23.56 | 0.00 | 21.87 | 0.887 | 0.887 | 860.17 | 416.82 |
| 8:00 PM | 30.34 | 23.12 | 0.00 | 21.29 | 0.884 | 0.884 | 851.06 | 412.41 |
| 9:00 PM | 29.44 | 23.34 | 0.00 | 21.58 | 0.886 | 0.886 | 842.96 | 408.48 |
| 10:00 PM | 29.00 | 23.56 | 0.00 | 21.87 | 0.888 | 0.888 | 839.83 | 406.97 |
| 11:00 PM | 28.44 | 23.22 | 0.00 | 21.42 | 0.885 | 0.885 | 831.41 | 402.89 |
| | | | | | | | Average = | 417.9 |

Daily average total atmos. radiation (W/m2) = Daily avg short wave radiation + Daily avg long wave radiation

= 209.1 W/m2 + 417.9 W/m2

= 627.0 W/m2 for Simulation Period 1

CALCULATION OF DAILY AVERAGE ATMOSPHERIC HEAT LOAD FOR SIMULATION PERIOD 2

Solar (short wave) radiation calculated by
QUAL2K model (from "Diel Output" tab)

| Hour | (cal/cm2 per day) | (W/m2) |
|---|---|---|
| 0.000 | 0 | 0 |
| 0.094 | 0 | 0 |
| 0.188 | 0 | 0 |
| 0.281 | 0 | 0 |
| 0.375 | 0 | 0 |
| 0.469 | 0 | 0 |
| 0.563 | 0 | 0 |
| 0.656 | 0 | 0 |
| 0.750 | 0 | 0 |
| 0.844 | 0 | 0 |
| 0.938 | 0 | 0 |
| 1.031 | 0 | 0 |
| 1.125 | 0 | 0 |
| 1.219 | 0 | 0 |
| 1.313 | 0 | 0 |
| 1.406 | 0 | 0 |
| 1.500 | 0 | 0 |
| 1.594 | 0 | 0 |
| 1.688 | 0 | 0 |
| 1.781 | 0 | 0 |
| 1.875 | 0 | 0 |
| 1.969 | 0 | 0 |
| 2.063 | 0 | 0 |
| 2.156 | 0 | 0 |
| 2.250 | 0 | 0 |
| 2.344 | 0 | 0 |
| 2.438 | 0 | 0 |
| 2.531 | 0 | 0 |
| 2.625 | 0 | 0 |
| 2.719 | 0 | 0 |
| 2.813 | 0 | 0 |
| 2.906 | 0 | 0 |
| 3.000 | 0 | 0 |
| 3.094 | 0 | 0 |
| 3.188 | 0 | 0 |
| 3.281 | 0 | 0 |
| 3.375 | 0 | 0 |
| 3.469 | 0 | 0 |
| 3.563 | 0 | 0 |
| 3.656 | 0 | 0 |
| 3.750 | 0 | 0 |
| 3.844 | 0 | 0 |
| 3.938 | 0 | 0 |
| 4.031 | 0 | 0 |
| 4.125 | 0 | 0 |
| 4.219 | 0 | 0 |

| Hour | (cal/cm2 per day) | (W/m2) |
|---|---|---|
| 4.313 | 0 | 0 |
| 4.406 | 0 | 0 |
| 4.500 | 0 | 0 |
| 4.594 | 0 | 0 |
| 4.688 | 0 | 0 |
| 4.781 | 0 | 0 |
| 4.875 | 0 | 0 |
| 4.969 | 0 | 0 |
| 5.063 | 0 | 0 |
| 5.156 | 0 | 0 |
| 5.250 | 0 | 0 |
| 5.344 | 0 | 0 |
| 5.438 | 0 | 0 |
| 5.531 | 0 | 0 |
| 5.625 | 0 | 0 |
| 5.719 | 0 | 0 |
| 5.813 | 0 | 0 |
| 5.906 | 0 | 0 |
| 6.000 | 0 | 0 |
| 6.094 | 0 | 0 |
| 6.188 | 0 | 0 |
| 6.281 | 0 | 0 |
| 6.375 | 0 | 0 |
| 6.469 | 0 | 0 |
| 6.563 | 0 | 0 |
| 6.656 | 0 | 0 |
| 6.750 | 0 | 0 |
| 6.844 | 0 | 0 |
| 6.938 | 0 | 0 |
| 7.031 | 0.82 | 0.40 |
| 7.125 | 1.86 | 0.90 |
| 7.219 | 5.23 | 2.53 |
| 7.313 | 10.74 | 5.20 |
| 7.406 | 18.54 | 8.98 |
| 7.500 | 28.58 | 13.85 |
| 7.594 | 40.71 | 19.73 |
| 7.688 | 54.69 | 26.50 |
| 7.781 | 70.22 | 34.03 |
| 7.875 | 87.00 | 42.16 |
| 7.969 | 104.72 | 50.75 |
| 8.063 | 123.03 | 59.62 |
| 8.156 | 144.94 | 70.24 |
| 8.250 | 169.91 | 82.34 |
| 8.344 | 196.42 | 95.18 |
| 8.438 | 224.34 | 108.71 |
| 8.531 | 253.54 | 122.86 |
| 8.625 | 283.88 | 137.56 |
| 8.719 | 315.24 | 152.76 |
| 8.813 | 347.49 | 168.39 |
| 8.906 | 380.49 | 184.38 |

| Hour | (cal/cm2 per day) | (W/m2) |
|---|---|---|
| 9.000 | 414.12 | 200.68 |
| 9.094 | 448.25 | 217.21 |
| 9.188 | 481.02 | 233.09 |
| 9.281 | 514.05 | 249.10 |
| 9.375 | 547.29 | 265.21 |
| 9.469 | 580.64 | 281.37 |
| 9.563 | 614.05 | 297.56 |
| 9.656 | 647.45 | 313.74 |
| 9.750 | 680.77 | 329.89 |
| 9.844 | 713.94 | 345.96 |
| 9.938 | 746.92 | 361.94 |
| 10.031 | 779.64 | 377.80 |
| 10.125 | 811.32 | 393.15 |
| 10.219 | 841.05 | 407.56 |
| 10.313 | 870.19 | 421.68 |
| 10.406 | 898.71 | 435.50 |
| 10.500 | 926.55 | 448.99 |
| 10.594 | 953.68 | 462.14 |
| 10.688 | 980.05 | 474.92 |
| 10.781 | 1005.63 | 487.31 |
| 10.875 | 1030.39 | 499.31 |
| 10.969 | 1054.28 | 510.89 |
| 11.063 | 1077.27 | 522.03 |
| 11.156 | 1103.42 | 534.70 |
| 11.250 | 1130.77 | 547.95 |
| 11.344 | 1157.25 | 560.78 |
| 11.438 | 1182.83 | 573.18 |
| 11.531 | 1207.45 | 585.11 |
| 11.625 | 1231.09 | 596.57 |
| 11.719 | 1253.68 | 607.51 |
| 11.813 | 1275.21 | 617.95 |
| 11.906 | 1295.63 | 627.84 |
| 12.000 | 1314.90 | 637.18 |
| 12.094 | 1320.46 | 639.87 |
| 12.188 | 1346.81 | 652.64 |
| 12.281 | 1359.47 | 658.78 |
| 12.375 | 1370.96 | 664.34 |
| 12.469 | 1381.28 | 669.35 |
| 12.563 | 1390.39 | 673.76 |
| 12.656 | 1398.31 | 677.60 |
| 12.750 | 1405.00 | 680.84 |
| 12.844 | 1410.48 | 683.50 |
| 12.938 | 1414.72 | 685.55 |
| 13.031 | 1417.73 | 687.01 |
| 13.125 | 1418.70 | 687.48 |
| 13.219 | 1416.61 | 686.47 |
| 13.313 | 1412.97 | 684.70 |
| 13.406 | 1407.79 | 682.19 |
| 13.500 | 1401.09 | 678.94 |
| 13.594 | 1392.88 | 674.97 |

| Hour | (cal/cm2 per day) | (W/m2) |
|---|---|---|
| 13.688 | 1383.18 | 670.27 |
| 13.781 | 1372.01 | 664.85 |
| 13.875 | 1359.40 | 658.74 |
| 13.969 | 1345.38 | 651.95 |
| 14.063 | 1329.98 | 644.49 |
| 14.156 | 1330.14 | 644.56 |
| 14.250 | 1336.30 | 647.55 |
| 14.344 | 1339.80 | 649.24 |
| 14.438 | 1340.65 | 649.66 |
| 14.531 | 1338.87 | 648.79 |
| 14.625 | 1334.49 | 646.67 |
| 14.719 | 1327.53 | 643.30 |
| 14.813 | 1318.05 | 638.71 |
| 14.906 | 1293.84 | 626.97 |
| 15.000 | 1279.63 | 620.09 |
| 15.094 | 1263.09 | 612.07 |
| 15.188 | 1241.48 | 601.60 |
| 15.281 | 1217.80 | 590.13 |
| 15.375 | 1203.29 | 583.09 |
| 15.469 | 1175.43 | 569.59 |
| 15.563 | 1145.76 | 555.22 |
| 15.656 | 1114.39 | 540.01 |
| 15.750 | 1081.45 | 524.05 |
| 15.844 | 1047.04 | 507.38 |
| 15.938 | 1011.30 | 490.06 |
| 16.031 | 974.36 | 472.16 |
| 16.125 | 943.32 | 457.12 |
| 16.219 | 924.83 | 448.16 |
| 16.313 | 904.76 | 438.43 |
| 16.406 | 883.18 | 427.97 |
| 16.500 | 860.16 | 416.82 |
| 16.594 | 835.79 | 405.01 |
| 16.688 | 810.15 | 392.59 |
| 16.781 | 783.32 | 379.58 |
| 16.875 | 755.39 | 366.05 |
| 16.969 | 726.46 | 352.03 |
| 17.063 | 696.62 | 337.57 |
| 17.156 | 665.22 | 322.35 |
| 17.250 | 628.84 | 304.73 |
| 17.344 | 596.93 | 289.26 |
| 17.438 | 564.88 | 273.73 |
| 17.531 | 532.76 | 258.17 |
| 17.625 | 500.65 | 242.61 |
| 17.719 | 468.61 | 227.08 |
| 17.813 | 436.73 | 211.63 |
| 17.906 | 405.09 | 196.30 |
| 18.000 | 373.79 | 181.13 |
| 18.094 | 342.91 | 166.17 |
| 18.188 | 312.47 | 151.42 |
| 18.281 | 282.70 | 136.99 |

| Hour | (cal/cm2 per day) | (W/m2) |
|---|---|---|
| 18.375 | 253.71 | 122.94 |
| 18.469 | 225.59 | 109.32 |
| 18.563 | 198.48 | 96.18 |
| 18.656 | 172.51 | 83.60 |
| 18.750 | 147.81 | 71.63 |
| 18.844 | 124.52 | 60.34 |
| 18.938 | 102.81 | 49.82 |
| 19.031 | 82.83 | 40.14 |
| 19.125 | 64.76 | 31.38 |
| 19.219 | 48.75 | 23.62 |
| 19.313 | 34.96 | 16.94 |
| 19.406 | 23.52 | 11.40 |
| 19.500 | 14.51 | 7.03 |
| 19.594 | 7.90 | 3.83 |
| 19.688 | 3.58 | 1.73 |
| 19.781 | 1.18 | 0.57 |
| 19.875 | 0.18 | 0.09 |
| 19.969 | 0 | 0 |
| 20.063 | 0 | 0 |
| 20.156 | 0 | 0 |
| 20.250 | 0 | 0 |
| 20.344 | 0 | 0 |
| 20.438 | 0 | 0 |
| 20.531 | 0 | 0 |
| 20.625 | 0 | 0 |
| 20.719 | 0 | 0 |
| 20.813 | 0 | 0 |
| 20.906 | 0 | 0 |
| 21.000 | 0 | 0 |
| 21.094 | 0 | 0 |
| 21.188 | 0 | 0 |
| 21.281 | 0 | 0 |
| 21.375 | 0 | 0 |
| 21.469 | 0 | 0 |
| 21.563 | 0 | 0 |
| 21.656 | 0 | 0 |
| 21.750 | 0 | 0 |
| 21.844 | 0 | 0 |
| 21.938 | 0 | 0 |
| 22.031 | 0 | 0 |
| 22.125 | 0 | 0 |
| 22.219 | 0 | 0 |
| 22.313 | 0 | 0 |
| 22.406 | 0 | 0 |
| 22.500 | 0 | 0 |
| 22.594 | 0 | 0 |
| 22.688 | 0 | 0 |
| 22.781 | 0 | 0 |
| 22.875 | 0 | 0 |
| 22.969 | 0 | 0 |

| Hour | (cal/cm2 per day) | (W/m2) |
|---|---|---|
| 23.063 | 0 | 0 |
| 23.156 | 0 | 0 |
| 23.250 | 0 | 0 |
| 23.344 | 0 | 0 |
| 23.438 | 0 | 0 |
| 23.531 | 0 | 0 |
| 23.625 | 0 | 0 |
| 23.719 | 0 | 0 |
| 23.813 | 0 | 0 |
| 23.906 | 0 | 0 |
| 24.000 | 0 | 0 |
| | | 199.0 = average |

Calculation of long wave radiation:

| Hour | Air temp. (°C) | Dew point temp. (°C) | Cloud cover (decimal) | Vapor pressure (mm Hg) | Emissivity without clouds (unitless) | Emissivity with clouds (unitless) | Long wave radiation (cal/cm2 per day) | Long wave radiation (W/m2) |
|---|---|---|---|---|---|---|---|---|
| 12:00 AM | 27.08 | 23.20 | 0.25 | 21.40 | 0.886 | 0.895 | 825.58 | 400.06 |
| 1:00 AM | 26.55 | 23.33 | 0.25 | 21.57 | 0.887 | 0.897 | 820.89 | 397.79 |
| 2:00 AM | 26.00 | 23.33 | 0.28 | 21.57 | 0.887 | 0.899 | 817.35 | 396.07 |
| 3:00 AM | 25.55 | 23.48 | 0.14 | 21.76 | 0.889 | 0.892 | 805.60 | 390.38 |
| 4:00 AM | 25.28 | 23.48 | 0.03 | 21.76 | 0.889 | 0.889 | 800.23 | 387.78 |
| 5:00 AM | 25.15 | 23.48 | 0.03 | 21.76 | 0.889 | 0.889 | 798.88 | 387.12 |
| 6:00 AM | 26.68 | 23.63 | 0.19 | 21.96 | 0.889 | 0.895 | 820.62 | 397.66 |
| 7:00 AM | 28.45 | 23.45 | 0.09 | 21.72 | 0.887 | 0.889 | 834.41 | 404.34 |
| 8:00 AM | 30.00 | 23.30 | 0.44 | 21.53 | 0.885 | 0.914 | 876.38 | 424.68 |
| 9:00 AM | 30.95 | 22.93 | 0.22 | 21.05 | 0.882 | 0.889 | 863.25 | 418.32 |
| 10:00 AM | 33.18 | 22.90 | 0.14 | 21.01 | 0.881 | 0.884 | 883.49 | 428.12 |
| 11:00 AM | 34.43 | 22.35 | 0.22 | 20.32 | 0.876 | 0.884 | 897.46 | 434.89 |
| 12:00 PM | 35.43 | 21.80 | 0.09 | 19.65 | 0.872 | 0.873 | 898.46 | 435.38 |
| 1:00 PM | 36.53 | 21.40 | 0.17 | 19.18 | 0.868 | 0.873 | 910.89 | 441.40 |
| 2:00 PM | 36.38 | 21.40 | 0.33 | 19.18 | 0.868 | 0.884 | 921.19 | 446.39 |
| 3:00 PM | 35.40 | 21.53 | 0.03 | 19.33 | 0.870 | 0.870 | 894.81 | 433.61 |
| 4:00 PM | 35.68 | 21.25 | 0.33 | 19.00 | 0.868 | 0.883 | 911.98 | 441.93 |
| 5:00 PM | 34.60 | 21.95 | 0.11 | 19.83 | 0.873 | 0.875 | 890.80 | 431.66 |
| 6:00 PM | 32.63 | 21.83 | 0.03 | 19.69 | 0.873 | 0.873 | 866.49 | 419.88 |
| 7:00 PM | 31.13 | 21.95 | 0.03 | 19.83 | 0.875 | 0.875 | 851.09 | 412.43 |
| 8:00 PM | 30.13 | 21.95 | 0.00 | 19.83 | 0.875 | 0.875 | 840.22 | 407.16 |
| 9:00 PM | 29.58 | 21.95 | 0.03 | 19.83 | 0.875 | 0.875 | 834.49 | 404.38 |
| 10:00 PM | 28.75 | 22.35 | 0.00 | 20.32 | 0.879 | 0.879 | 828.44 | 401.45 |
| 11:00 PM | 27.63 | 22.65 | 0.03 | 20.70 | 0.881 | 0.882 | 818.91 | 396.83 |
| | | | | | | | Average = | 414.2 |

Daily average total atmos. radiation (W/m2) = Daily avg short wave radiation + Daily avg long wave radiation

= 199.0 W/m2 + 414.2 W/m2

= 613.2 W/m2 for Simulation Period 2

CALCULATION OF DAILY AVERAGE ATMOSPHERIC HEAT LOAD FOR SIMULATION PERIOD 3

Solar (short wave) radiation calculated by
QUAL2K model (from "Diel Output" tab)

| Hour | (cal/cm2 per day) | (W/m2) |
|---|---|---|
| 0.000 | 0 | 0 |
| 0.094 | 0 | 0 |
| 0.188 | 0 | 0 |
| 0.281 | 0 | 0 |
| 0.375 | 0 | 0 |
| 0.469 | 0 | 0 |
| 0.563 | 0 | 0 |
| 0.656 | 0 | 0 |
| 0.750 | 0 | 0 |
| 0.844 | 0 | 0 |
| 0.938 | 0 | 0 |
| 1.031 | 0 | 0 |
| 1.125 | 0 | 0 |
| 1.219 | 0 | 0 |
| 1.313 | 0 | 0 |
| 1.406 | 0 | 0 |
| 1.500 | 0 | 0 |
| 1.594 | 0 | 0 |
| 1.688 | 0 | 0 |
| 1.781 | 0 | 0 |
| 1.875 | 0 | 0 |
| 1.969 | 0 | 0 |
| 2.063 | 0 | 0 |
| 2.156 | 0 | 0 |
| 2.250 | 0 | 0 |
| 2.344 | 0 | 0 |
| 2.438 | 0 | 0 |
| 2.531 | 0 | 0 |
| 2.625 | 0 | 0 |
| 2.719 | 0 | 0 |
| 2.813 | 0 | 0 |
| 2.906 | 0 | 0 |
| 3.000 | 0 | 0 |
| 3.094 | 0 | 0 |
| 3.188 | 0 | 0 |
| 3.281 | 0 | 0 |
| 3.375 | 0 | 0 |
| 3.469 | 0 | 0 |
| 3.563 | 0 | 0 |
| 3.656 | 0 | 0 |
| 3.750 | 0 | 0 |
| 3.844 | 0 | 0 |
| 3.938 | 0 | 0 |
| 4.031 | 0 | 0 |
| 4.125 | 0 | 0 |
| 4.219 | 0 | 0 |

| Hour | (cal/cm2 per day) | (W/m2) |
|---|---|---|
| 4.313 | 0 | 0 |
| 4.406 | 0 | 0 |
| 4.500 | 0 | 0 |
| 4.594 | 0 | 0 |
| 4.688 | 0 | 0 |
| 4.781 | 0 | 0 |
| 4.875 | 0 | 0 |
| 4.969 | 0 | 0 |
| 5.063 | 0 | 0 |
| 5.156 | 0 | 0 |
| 5.250 | 0 | 0 |
| 5.344 | 0 | 0 |
| 5.438 | 0 | 0 |
| 5.531 | 0 | 0 |
| 5.625 | 0 | 0 |
| 5.719 | 0 | 0 |
| 5.813 | 0 | 0 |
| 5.906 | 0 | 0 |
| 6.000 | 0 | 0 |
| 6.094 | 0 | 0 |
| 6.188 | 0 | 0 |
| 6.281 | 0 | 0 |
| 6.375 | 0 | 0 |
| 6.469 | 0 | 0 |
| 6.563 | 0 | 0 |
| 6.656 | 0 | 0 |
| 6.750 | 0 | 0 |
| 6.844 | 0 | 0 |
| 6.938 | 0 | 0 |
| 7.031 | 0 | 0 |
| 7.125 | 0 | 0 |
| 7.219 | 0 | 0 |
| 7.313 | 0.20 | 0.10 |
| 7.406 | 1.31 | 0.63 |
| 7.500 | 3.94 | 1.91 |
| 7.594 | 8.66 | 4.20 |
| 7.688 | 15.80 | 7.66 |
| 7.781 | 25.46 | 12.34 |
| 7.875 | 37.62 | 18.23 |
| 7.969 | 52.15 | 25.27 |
| 8.063 | 68.90 | 33.39 |
| 8.156 | 87.68 | 42.49 |
| 8.250 | 108.31 | 52.49 |
| 8.344 | 130.58 | 63.28 |
| 8.438 | 154.34 | 74.79 |
| 8.531 | 179.40 | 86.93 |
| 8.625 | 205.62 | 99.64 |
| 8.719 | 232.83 | 112.83 |
| 8.813 | 260.91 | 126.43 |
| 8.906 | 289.73 | 140.40 |

| Hour | (cal/cm2 per day) | (W/m2) |
|---|---|---|
| 9.000 | 319.17 | 154.66 |
| 9.094 | 349.12 | 169.18 |
| 9.188 | 379.47 | 183.88 |
| 9.281 | 410.13 | 198.74 |
| 9.375 | 441.00 | 213.70 |
| 9.469 | 472.00 | 228.72 |
| 9.563 | 503.05 | 243.77 |
| 9.656 | 534.07 | 258.80 |
| 9.750 | 564.99 | 273.78 |
| 9.844 | 595.74 | 288.69 |
| 9.938 | 626.27 | 303.48 |
| 10.031 | 656.50 | 318.13 |
| 10.125 | 686.44 | 332.64 |
| 10.219 | 716.09 | 347.01 |
| 10.313 | 745.32 | 361.17 |
| 10.406 | 774.07 | 375.10 |
| 10.500 | 802.30 | 388.78 |
| 10.594 | 829.98 | 402.19 |
| 10.688 | 857.05 | 415.31 |
| 10.781 | 883.47 | 428.11 |
| 10.875 | 909.22 | 440.59 |
| 10.969 | 934.25 | 452.72 |
| 11.063 | 958.54 | 464.49 |
| 11.156 | 982.04 | 475.88 |
| 11.250 | 1004.73 | 486.88 |
| 11.344 | 1026.58 | 497.46 |
| 11.438 | 1047.56 | 507.63 |
| 11.531 | 1067.65 | 517.37 |
| 11.625 | 1086.81 | 526.65 |
| 11.719 | 1105.03 | 535.48 |
| 11.813 | 1122.29 | 543.84 |
| 11.906 | 1138.56 | 551.73 |
| 12.000 | 1153.82 | 559.12 |
| 12.094 | 1168.05 | 566.02 |
| 12.188 | 1181.48 | 572.53 |
| 12.281 | 1193.84 | 578.51 |
| 12.375 | 1205.10 | 583.97 |
| 12.469 | 1215.26 | 588.89 |
| 12.563 | 1224.29 | 593.27 |
| 12.656 | 1232.20 | 597.10 |
| 12.750 | 1238.96 | 600.38 |
| 12.844 | 1244.57 | 603.10 |
| 12.938 | 1249.03 | 605.26 |
| 13.031 | 1252.32 | 606.85 |
| 13.125 | 1254.44 | 607.88 |
| 13.219 | 1255.42 | 608.36 |
| 13.313 | 1255.25 | 608.27 |
| 13.406 | 1253.93 | 607.63 |
| 13.500 | 1251.47 | 606.44 |
| 13.594 | 1247.86 | 604.69 |

| Hour | (cal/cm2 per day) | (W/m2) |
|---|---|---|
| 13.688 | 1243.12 | 602.40 |
| 13.781 | 1237.25 | 599.55 |
| 13.875 | 1230.25 | 596.16 |
| 13.969 | 1222.13 | 592.22 |
| 14.063 | 1212.91 | 587.76 |
| 14.156 | 1202.53 | 582.73 |
| 14.250 | 1190.79 | 577.04 |
| 14.344 | 1177.70 | 570.69 |
| 14.438 | 1163.29 | 563.71 |
| 14.531 | 1147.59 | 556.10 |
| 14.625 | 1130.62 | 547.88 |
| 14.719 | 1112.41 | 539.06 |
| 14.813 | 1103.02 | 534.51 |
| 14.906 | 1082.24 | 524.44 |
| 15.000 | 1060.33 | 513.82 |
| 15.094 | 1037.34 | 502.68 |
| 15.188 | 1017.95 | 493.28 |
| 15.281 | 997.49 | 483.37 |
| 15.375 | 976.00 | 472.95 |
| 15.469 | 953.50 | 462.05 |
| 15.563 | 922.09 | 446.83 |
| 15.656 | 898.01 | 435.16 |
| 15.750 | 873.05 | 423.07 |
| 15.844 | 847.27 | 410.57 |
| 15.938 | 820.71 | 397.70 |
| 16.031 | 793.41 | 384.47 |
| 16.125 | 764.88 | 370.65 |
| 16.219 | 734.29 | 355.82 |
| 16.313 | 707.84 | 343.01 |
| 16.406 | 674.95 | 327.07 |
| 16.500 | 641.32 | 310.77 |
| 16.594 | 607.10 | 294.19 |
| 16.688 | 572.44 | 277.39 |
| 16.781 | 537.50 | 260.46 |
| 16.875 | 502.42 | 243.46 |
| 16.969 | 467.38 | 226.48 |
| 17.063 | 432.53 | 209.60 |
| 17.156 | 401.55 | 194.58 |
| 17.250 | 372.54 | 180.53 |
| 17.344 | 343.76 | 166.58 |
| 17.438 | 315.31 | 152.79 |
| 17.531 | 287.28 | 139.21 |
| 17.625 | 259.76 | 125.88 |
| 17.719 | 232.87 | 112.84 |
| 17.813 | 206.73 | 100.18 |
| 17.906 | 181.45 | 87.93 |
| 18.000 | 157.18 | 76.17 |
| 18.094 | 134.06 | 64.96 |
| 18.188 | 112.24 | 54.39 |
| 18.281 | 91.90 | 44.53 |

| Hour | (cal/cm2 per day) | (W/m2) |
|---|---|---|
| 18.375 | 73.21 | 35.48 |
| 18.469 | 56.35 | 27.31 |
| 18.563 | 41.50 | 20.11 |
| 18.656 | 28.85 | 13.98 |
| 18.750 | 18.52 | 8.97 |
| 18.844 | 10.61 | 5.14 |
| 18.938 | 5.08 | 2.46 |
| 19.031 | 1.75 | 0.85 |
| 19.125 | 0.19 | 0.09 |
| 19.219 | 0 | 0 |
| 19.313 | 0 | 0 |
| 19.406 | 0 | 0 |
| 19.500 | 0 | 0 |
| 19.594 | 0 | 0 |
| 19.688 | 0 | 0 |
| 19.781 | 0 | 0 |
| 19.875 | 0 | 0 |
| 19.969 | 0 | 0 |
| 20.063 | 0 | 0 |
| 20.156 | 0 | 0 |
| 20.250 | 0 | 0 |
| 20.344 | 0 | 0 |
| 20.438 | 0 | 0 |
| 20.531 | 0 | 0 |
| 20.625 | 0 | 0 |
| 20.719 | 0 | 0 |
| 20.813 | 0 | 0 |
| 20.906 | 0 | 0 |
| 21.000 | 0 | 0 |
| 21.094 | 0 | 0 |
| 21.188 | 0 | 0 |
| 21.281 | 0 | 0 |
| 21.375 | 0 | 0 |
| 21.469 | 0 | 0 |
| 21.563 | 0 | 0 |
| 21.656 | 0 | 0 |
| 21.750 | 0 | 0 |
| 21.844 | 0 | 0 |
| 21.938 | 0 | 0 |
| 22.031 | 0 | 0 |
| 22.125 | 0 | 0 |
| 22.219 | 0 | 0 |
| 22.313 | 0 | 0 |
| 22.406 | 0 | 0 |
| 22.500 | 0 | 0 |
| 22.594 | 0 | 0 |
| 22.688 | 0 | 0 |
| 22.781 | 0 | 0 |
| 22.875 | 0 | 0 |
| 22.969 | 0 | 0 |

| Hour | (cal/cm2 per day) | (W/m2) |
|---|---|---|
| 23.063 | 0 | 0 |
| 23.156 | 0 | 0 |
| 23.250 | 0 | 0 |
| 23.344 | 0 | 0 |
| 23.438 | 0 | 0 |
| 23.531 | 0 | 0 |
| 23.625 | 0 | 0 |
| 23.719 | 0 | 0 |
| 23.813 | 0 | 0 |
| 23.906 | 0 | 0 |
| 24.000 | 0 | 0 |
| | | 162.3 = average |

Calculation of long wave radiation:

| Hour | Air temp. (°C) | Dew point temp. (°C) | Cloud cover (decimal) | Vapor pressure (mm Hg) | Emissivity without clouds (unitless) | Emissivity with clouds (unitless) | Long wave radiation (cal/cm2 per day) | Long wave radiation (W/m2) |
|---|---|---|---|---|---|---|---|---|
| 12:00 AM | 23.13 | 18.70 | 0.00 | 16.23 | 0.853 | 0.853 | 746.18 | 361.59 |
| 1:00 AM | 21.87 | 18.70 | 0.00 | 16.23 | 0.854 | 0.854 | 733.95 | 355.66 |
| 2:00 AM | 21.47 | 18.87 | 0.00 | 16.40 | 0.855 | 0.855 | 731.21 | 354.33 |
| 3:00 AM | 21.50 | 18.90 | 0.00 | 16.43 | 0.855 | 0.855 | 731.74 | 354.59 |
| 4:00 AM | 19.80 | 18.70 | 0.00 | 16.23 | 0.855 | 0.855 | 714.32 | 346.15 |
| 5:00 AM | 20.17 | 19.07 | 0.00 | 16.60 | 0.857 | 0.857 | 720.12 | 348.96 |
| 6:00 AM | 21.30 | 19.27 | 0.00 | 16.81 | 0.858 | 0.858 | 732.22 | 354.82 |
| 7:00 AM | 24.07 | 19.63 | 0.00 | 17.20 | 0.860 | 0.860 | 761.59 | 369.05 |
| 8:00 AM | 26.67 | 20.20 | 0.00 | 17.81 | 0.863 | 0.863 | 791.57 | 383.58 |
| 9:00 AM | 28.87 | 20.00 | 0.00 | 17.59 | 0.861 | 0.861 | 812.77 | 393.85 |
| 10:00 AM | 30.57 | 20.00 | 0.04 | 17.59 | 0.860 | 0.860 | 830.80 | 402.59 |
| 11:00 AM | 32.03 | 18.70 | 0.04 | 16.23 | 0.850 | 0.850 | 836.66 | 405.43 |
| 12:00 PM | 33.73 | 17.43 | 0.04 | 14.99 | 0.839 | 0.840 | 845.12 | 409.53 |
| 1:00 PM | 33.70 | 16.67 | 0.00 | 14.28 | 0.834 | 0.834 | 838.67 | 406.41 |
| 2:00 PM | 34.07 | 15.93 | 0.00 | 13.62 | 0.828 | 0.828 | 836.94 | 405.57 |
| 3:00 PM | 33.53 | 15.90 | 0.15 | 13.59 | 0.828 | 0.831 | 834.10 | 404.19 |
| 4:00 PM | 33.33 | 16.13 | 0.04 | 13.80 | 0.830 | 0.830 | 831.02 | 402.70 |
| 5:00 PM | 31.50 | 16.87 | 0.33 | 14.46 | 0.836 | 0.852 | 832.63 | 403.48 |
| 6:00 PM | 27.60 | 17.37 | 0.33 | 14.92 | 0.841 | 0.857 | 795.86 | 385.66 |
| 7:00 PM | 26.83 | 16.47 | 0.33 | 14.09 | 0.835 | 0.850 | 781.66 | 378.78 |
| 8:00 PM | 26.50 | 16.30 | 0.15 | 13.95 | 0.834 | 0.837 | 765.49 | 370.94 |
| 9:00 PM | 25.37 | 16.87 | 0.00 | 14.46 | 0.838 | 0.838 | 755.54 | 366.12 |
| 10:00 PM | 25.00 | 16.67 | 0.00 | 14.28 | 0.837 | 0.837 | 750.61 | 363.73 |
| 11:00 PM | 24.43 | 17.97 | 0.15 | 15.50 | 0.847 | 0.850 | 756.64 | 366.66 |
| | | | | | | | Average = | 378.9 |

Daily average total atmos. radiation (W/m2) = Daily avg short wave radiation + Daily avg long wave radiation

= 162.3 W/m2 + 378.9 W/m2

= 541.3 W/m2 for Simulation Period 3

CALCULATIONS FOR MAXIMUM ATMOSPHERIC RADIATION TO MEET TEMPERATURE CRITERIA

| Simulation Period | Daily avg total atmospheric radiation (W/m2) | Highest daily average predicted temp. (°C) Sulphur River | Red River |
|---|---|---|---|
| 1 | 627.0 | 34.23 | 33.16 |
| 2 | 613.2 | 32.97 | 31.82 |
| 3 | 541.3 | 29.05 | 29.16 |

Calculation for Red River (criterion = 32°C)

Criterion of 32°C falls between Red River predicted temperatures for Simulation Periods 1 and 2; therefore, we need to interpolate between the atmospheric radiation values for these two periods:

Interpolated atmospheric radiaton value =

= 613.2 + (627.0 - 613.2) * (32.00 - 31.82) / (33.16 - 31.82)

= 615.0 W/m2

Calculation for Sulphur River (criterion = 30°C)

Criterion of 30°C falls between Sulphur River predicted temperatures for Simulation Periods 2 and 3; therefore, we need to interpolate between the atmospheric radiation values for these two periods:

Interpolated atmospheric radiaton value =

= 541.3 + (613.2 - 541.3) * (30.00 - 29.05) / (32.97 - 29.05)

= 558.7 W/m2

Calculation for Sulphur River (alternative target = 32°C)

Target of 32°C falls between Sulphur River predicted temperatures for Simulation Periods 2 and 3; therefore, we need to interpolate between the atmospheric radiation values for these two periods:

Interpolated atmospheric radiaton value

= 541.3 + (613.2 - 541.3) * (32.00 - 29.05) / (32.97 - 29.05)

= 595.4 W/m2

# 4 TEMPERATURE MODEL

As in Figure 14, the heat balance takes into account heat transfers from adjacent elements, loads, withdrawals, the atmosphere, and the sediments. A heat balance can be written for element *i* as

$$\frac{dT_i}{dt} = \frac{Q_{i-1}}{V_i}T_{i-1} - \frac{Q_i}{V_i}T_i - \frac{Q_{out,i}}{V_i}T_i + \frac{E'_{i-1}}{V_i}\left(T_{i-1} - T_i\right) + \frac{E'_i}{V_i}\left(T_{i+1} - T_i\right)$$

$$+ \frac{W_{h,i}}{\rho_w C_{pw} V_i}\left(\frac{\text{m}^3}{10^6\ \text{cm}^3}\right) + \frac{J_{a,i}}{\rho_w C_{pw} H_i}\left(\frac{\text{m}}{100\ \text{cm}}\right) + \frac{J_{s,i}}{\rho_w C_{pw} H_i}\left(\frac{\text{m}}{100\ \text{cm}}\right) \tag{26}$$

where $T_i$ = temperature in element *i* [$^o$C], $t$ = time [d], $E'_i$ = the bulk dispersion coefficient between elements *i* and *i* + 1 [m$^3$/d], $W_{h,i}$ = the net heat load from point and non-point sources into element *i* [cal/d], $\rho_w$ = the density of water [g/cm$^3$], $C_{pw}$ = the specific heat of water [cal/(g $^o$C)], $J_{a,i}$ = the air-water heat flux [cal/(cm$^2$ d)], and $J_{s,i}$ = the sediment-water heat flux [cal/(cm$^2$ d)].

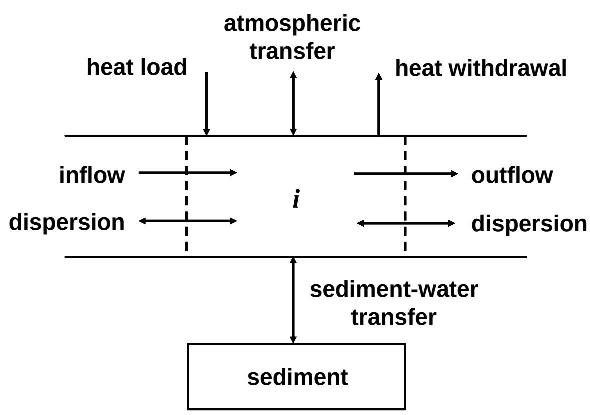



**Figure 14 Heat balance for an element.**

The bulk dispersion coefficient is computed as

$$E'_i = \frac{E_i A_{c,i}}{\left(\Delta x_i + \Delta x_{i+1}\right)/2} \tag{27}$$

Note that two types of boundary condition are used at the river's downstream terminus: (1) a zero dispersion condition (natural boundary condition) and (2) a prescribed downstream boundary condition (Dirichlet boundary condition). The choice between these options is made on the **Downstream Worksheet**.

The net heat load from sources is computed as (recall Eq. 2)

$$W_{h,i} = \rho C_p\left[\sum_{j=1}^{psi} Q_{ps,i,j}T_{psi,j} + \sum_{j=1}^{npsi} Q_{nps,i,j}T_{npsi,j}\right] \tag{28}$$

where $T_{ps,i,j}$ is the temperature of the $j$th point source for element $i$ [$^oC$], and $T_{nps,i,j}$ is the temperature of the $j$th non-point source temperature for element $i$ [$^oC$].

## 4.1 Surface Heat Flux

As depicted in Figure 15, surface heat exchange is modeled as a combination of five processes:

$$J_h = I(0) + J_{an} - J_{br} - J_c - J_e \tag{29}$$

where $I(0)$ = net solar shortwave radiation at the water surface, $J_{an}$ = net atmospheric longwave radiation, $J_{br}$ = longwave back radiation from the water, $J_c$ = conduction, and $J_e$ = evaporation. All fluxes are expressed as cal/cm$^2$/d.

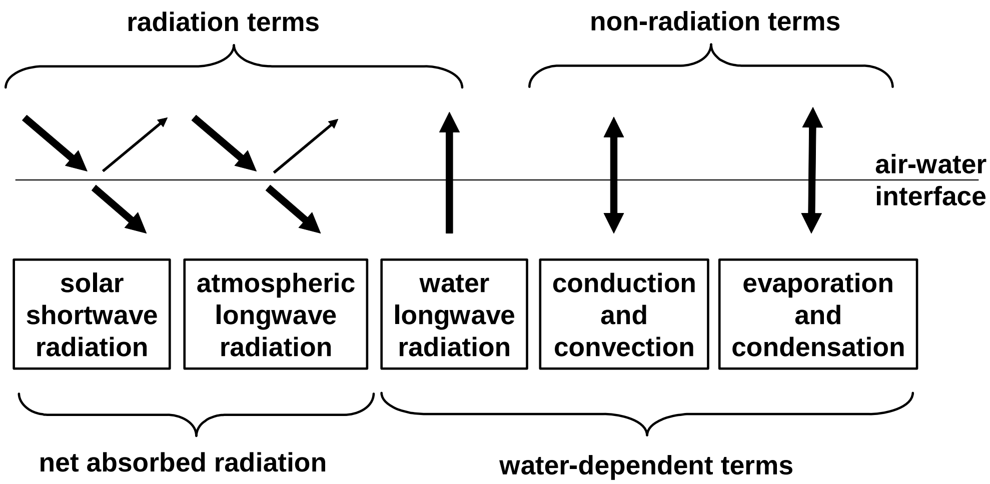



**Figure 15 The components of surface heat exchange.**

### 4.1.1 Solar Radiation

The model computes the amount of solar radiation entering the water at a particular latitude ($L_{at}$) and longitude ($L_{lm}$) on the earth's surface. This quantity is a function of the radiation at the top of the earth's atmosphere which is attenuated by atmospheric transmission, cloud cover, reflection, and shade,

$$I(0) = \underset{\substack{\text{extraterrestrial}\\\text{radiation}}}{I_0} \quad \underset{\substack{\text{atmospheric}\\\text{attenuation}}}{a_t} \quad \underset{\substack{\text{cloud}\\\text{attenuation}}}{a_c} \quad \underset{\text{reflection}}{(1-R_s)} \quad \underset{\text{shading}}{(1-S_f)} \tag{30}$$

where $I(0)$ = solar radiation at the water surface [cal/cm$^2$/d], $I_0$ = extraterrestrial radiation (i.e., at the top of the earth's atmosphere) [cal/cm$^2$/d], $a_t$ = atmospheric attenuation, $a_c$ = cloud attenuation, $R_s$ = albedo (fraction reflected), and $S_f$ = effective shade (fraction blocked by vegetation and topography).

**Extraterrestrial radiation.** The extraterrestrial radiation is computed as (TVA 1972)

$$I_0 = \frac{W_0}{r^2} \sin\alpha \tag{31}$$

where $W_0$ = the solar constant [1367 W/m$^2$ or 2823 cal/cm$^2$/d], $r$ = normalized radius of the earth's orbit (i.e., the ratio of actual earth-sun distance to mean earth-sun distance), and $\alpha$ = the sun's altitude [radians], which can be computed as

$$\sin\alpha = \sin\delta \sin L_{at} + \cos\delta \cos L_{at} \cos(\tau) \tag{32}$$

where $\delta$ = solar declination [radians], $L_{at}$ = local latitude [radians], and $\tau$ = the local hour angle of the sun [radians].

The local hour angle in radians is given by

$$\tau = \left( \frac{trueSolarTime}{4} - 180 \right) \frac{\pi}{180} \tag{33}$$

where:

$$trueSolarTime = localTime + eqtime - 4 \times L_{lm} - 60 \times timezone \tag{34}$$

where *trueSolarTime* is the solar time determined from the actual position of the sun in the sky [minutes], *localTime* is the local time in minutes (local standard time), $L_{lm}$ is the local longitude (positive decimal degrees for the western hemisphere), and *timezone* is the local time zone in hours relative to Greenwich Mean Time (e.g. –8 hours for Pacific Standard Time; the local time zone is selected on the **QUAL2K Worksheet**). The value of *eqtime* represents the difference between true solar time and mean solar time in minutes of time.

QUAL2K calculates the solar declination, hour angle, solar altitude, and normalized radius (distance between the earth and sun), as well as the times of sunrise and sunset using the Meeus (1999) algorithms as implemented by NOAA's Surface Radiation Research Branch (www.srrb.noaa.gov/highlights/sunrise/azel.html). The NOAA method for solar position that is used in QUAL2K also includes a correction for the effect of atmospheric refraction. The complete calculation method that is used to determine the solar position, sunrise, and sunset is presented in Appendix B.

The photoperiod $f$ [hours] is computed as

$$f = t_{ss} - t_{sr} \tag{35}$$

where $t_{ss}$ = time of sunset [hours] and $t_{sr}$ = time of sunrise [hours].

**Atmospheric attenuation.** Various methods have been published to estimate the fraction of the atmospheric attenuation from a clear sky ($a_t$). Two alternative methods are available in QUAL2K to estimate $a_t$ (Note that the solar radiation model is selected on the **Light and Heat Worksheet** of QUAL2K):

**1) Bras (default)**

The Bras (1990) method computes $a_t$ as:

$$a_t = e^{-n_{fac} a_1 m} \tag{36}$$

where $n_{fac}$ is an atmospheric turbidity factor that varies from approximately 2 for clear skies to 4 or 5 for smoggy urban areas. The molecular scattering coefficient ($a_1$) is calculated as

$$a_1 = 0.128 - 0.054 \log_{10} m \tag{37}$$

where $m$ is the optical air mass, calculated as

$$m = \frac{1}{\sin\alpha + 0.15(\alpha_d + 3.885)^{-1.253}} \tag{38}$$

where $\alpha_d$ is the sun's altitude in degrees from the horizon = $\alpha \times (180^{\circ}/\pi)$.

**2) Ryan and Stolzenbach**

The Ryan and Stolzenbach (1972) model computes $a_t$ from ground surface elevation and solar altitude as:

$$a_t = a_{tc}^{\,m\left(\frac{288 - 0.0065 elev}{288}\right)^{5.256}} \tag{39}$$

where $a_{tc}$ is the atmospheric transmission coefficient (0.70-0.91, typically approximately 0.8), and $elev$ is the ground surface elevation in meters.

Direct measurements of solar radiation are available at some locations. For example, NOAA's Integrated Surface Irradiance Study (ISIS) has data from various stations across the United States (http://www.atdd.noaa.gov/isis.htm). The selection of either the Bras or Ryan-Stolzenbach solar radiation model and the appropriate atmospheric turbidity factor or atmospheric transmission coefficient for a particular application should ideally be guided by a comparison of predicted solar radiation with measured values at a reference location.

**Cloud Attenuation.** Attenuation of solar radiation due to cloud cover is computed with

$$a_c = 1 - 0.65 C_L^2 \tag{40}$$

where $C_L$ = fraction of the sky covered with clouds.

**Reflectivity.** Reflectivity is calculated as

$$R_s = A \alpha_d^{\,B} \tag{41}$$

where $A$ and $B$ are coefficients related to cloud cover (Table 3).

**Table 3 Coefficients used to calculate reflectivity based on cloud cover.**

| Cloudiness | Clear | | Scattered | | Broken | | Overcast | |
|---|---|---|---|---|---|---|---|---|
| $C_L$ | 0 | | 0.1-0.5 | | 0.5-0.9 | | 1.0 | |
| Coefficients | *A* | *B* | *A* | *B* | *A* | *B* | *A* | *B* |
| | 1.18 | –0.77 | 2.20 | –0.97 | 0.95 | –0.75 | 0.35 | –0.45 |

**Shade.** Shade is an input variable for the QUAL2K model. Shade is defined as the fraction of potential solar radiation that is blocked by topography and vegetation. An Excel/VBA program named 'Shade.xls' is available from the Washington Department of Ecology to estimate shade from topography and riparian vegetation (Ecology 2003). Input values of integrated hourly estimates of shade for each reach are entered on the **Shade Worksheet** of QUAL2K.

### 4.1.2 Atmospheric Long-wave Radiation

The downward flux of longwave radiation from the atmosphere is one of the largest terms in the surface heat balance. This flux can be calculated using the Stefan-Boltzmann law

$$J_{an} = \sigma(T_{air} + 273)^4 \quad \varepsilon_{sky} \quad (1 - R_L) \tag{42}$$

where $\sigma$ = the Stefan-Boltzmann constant = 11.7x10$^{-8}$ cal/(cm$^2$ d K$^4$), $T_{air}$ = air temperature [$^o$C], $\varepsilon_{sky}$ = effective emissivity of the atmosphere [dimensionless], and $R_L$ = longwave reflection coefficient [dimensionless]. Emissivity is the ratio of the longwave radiation from an object compared with the radiation from a perfect emitter at the same temperature. The reflection coefficient is generally small and is assumed to equal 0.03.

The atmospheric longwave radiation model is selected on the **Light and Heat Worksheet** of QUAL2K. Three alternative methods are available for use in QUAL2K to represent the effective emissivity ($\varepsilon_{sky}$):

**1) Brunt (default)**

Brunt's (1932) equation is an empirical model that has been commonly used in water-quality models (Thomann and Mueller 1987),

$$\varepsilon_{clear} = A_a + A_b\sqrt{e_{air}}$$

where $A_a$ and $A_b$ are empirical coefficients. Values of $A_a$ have been reported to range from about 0.5 to 0.7 and values of $A_b$ have been reported to range from about 0.031 to 0.076 mmHg$^{-0.5}$ for a wide range of atmospheric conditions. QUAL2K uses a default mid-range value of $A_a$ = 0.6 together with a value of $A_b$ = 0.031 mmHg$^{-0.5}$ if the Brunt method is selected on the **Light and Heat Worksheet**.

**2) Brutsaert**

The Brutsaert equation is physically-based instead of empirically derived and has been shown to yield satisfactory results over a wide range of atmospheric conditions of air temperature and humidity at intermediate latitudes for conditions above freezing (Brutsaert, 1982).

$$\varepsilon_{clear} = 1.24\left(\frac{1.333224 e_{air}}{T_a}\right)^{1/7}$$

where $e_{air}$ is the air vapor pressure [mm Hg], and $T_a$ is the air temperature in °K. The factor of 1.333224 converts the vapor pressure from mm Hg to millibars. The air vapor pressure [in mm Hg] is computed as (Raudkivi 1979):

$$e_{air} = 4.596 e^{\frac{17.27 T_d}{237.3 + T_d}} \quad (43)$$

where $T_d$ = the dew-point temperature [°C].

**3) Koberg**

Koberg (1964) reported that the $A_a$ in Brunt's formula depends on both air temperature and the ratio of the incident solar radiation to the clear-sky radiation ($R_{sc}$). As in Figure 16, he presented a series of curves indicating that $A_a$ increases with $T_{air}$ and decreases with $R_{sc}$ with $A_b$ held constant at 0.0263 millibars$^{-0.5}$ (about 0.031 mmHg$^{-0.5}$).

The following polynomial is used in Q2K to provide a continuous approximation of Koberg's curves.

$$A_a = a_k T_{air}^2 + b_k T_{air} + c_k$$

where

$$a_k = -0.00076437 R_{sc}^3 + 0.00121134 R_{sc}^2 - 0.00073087 R_{sc} + 0.0001106$$
$$b_k = 0.12796842\, R_{sc}^3 - 0.2204455 R_{sc}^2 + 0.13397992\, R_{sc} - 0.02586655$$
$$c_k = -3.25272249 R_{sc}^3 + 5.65909609 R_{sc}^2 - 3.43402413 R_{sc} + 1.43052757$$

The fit of this polynomial to points sampled from Koberg's curves are depicted in Figure 16. Note that an upper limit of 0.735 is prescribed for $A_a$.

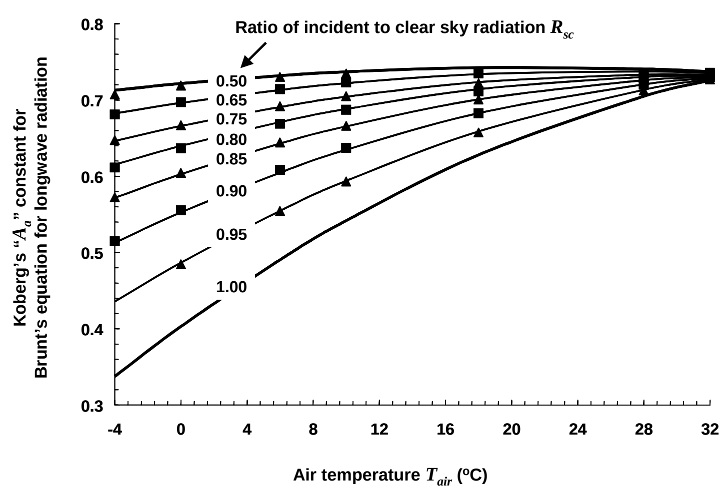


**Figure 16 The points are sampled from Koberg's family of curves for determining the value of the $A_a$ constant in Brunt's equation for atmospheric longwave radiation (Koberg, 1964). The lines are the functional representation used in Q2K.**

For cloudy conditions the atmospheric emissivity may increase as a result of increased water vapor content. High cirrus clouds may have a negligible effect on atmospheric emissivity, but lower stratus and cumulus clouds may have a significant effect. The Koberg method accounts for the effect of clouds on the emissivity of longwave radiation in the determination of the $A_a$ coefficient. The Brunt and Brutsaert methods determine emissivity of a clear sky and do not account for the effect of clouds. Therefore, if the Brunt or Brutsaert methods are selected, then the effective atmospheric emissivity for cloudy skies ($\varepsilon_{sky}$) is estimated from the clear sky emissivity by using a nonlinear function of the fractional cloud cover ($C_L$) of the form (TVA, 1972):

$$\varepsilon_{sky} = \varepsilon_{clear}(1 + 0.17 C_L^2) \tag{44}$$

The selection of the longwave model for a particular application should ideally be guided by a comparison of predicted results with measured values at a reference location. However, direct measurements are rarely collected. The Brutsaert method is recommended to represent a wide range of atmospheric conditions.

### 4.1.3 Water Long-wave Radiation

The back radiation from the water surface is represented by the Stefan-Boltzmann law,

$$J_{br} = \varepsilon\sigma(T + 273)^4 \tag{45}$$

where $\varepsilon$ = emissivity of water (= 0.97) and $T$ = the water temperature [$^o$C].

### 4.1.4 Conduction and Convection

*Conduction* is the transfer of heat from molecule to molecule when matter of different temperatures are brought into contact. *Convection* is heat transfer that occurs due to mass movement of fluids. Both can occur at the air-water interface and can be described by,

$$J_c = c_1 f(U_w)(T_s - T_{air}) \tag{46}$$

where $c_1$ = Bowen's coefficient (= 0.47 mmHg/$^o$C). The term, $f(U_w)$, defines the dependence of the transfer on wind velocity over the water surface where $U_w$ is the wind speed measured a fixed distance above the water surface.

Many relationships exist to define the wind dependence. Bras (1990), Edinger et al. (1974), and Shanahan (1984) provide reviews of various methods. Some researchers have proposed that conduction/convection and evaporation are negligible in the absence of wind (e.g. Marciano and Harbeck, 1952), which is consistent with the assumption that only molecular processes contribute to the transfer of mass and heat without wind (Edinger et al. 1974). Others have shown that significant conduction/convection and evaporation can occur in the absence of wind (e.g. Brady Graves and Geyer 1969, Harbeck 1962, Ryan and Harleman 1971, Helfrich et al. 1982, and

Adams et al. 1987). This latter opinion has gained favor (Edinger et al. 1974), especially for waterbodies that exhibit water temperatures that are greater than the air temperature.

Brady, Graves, and Geyer (1969) pointed out that if the water surface temperature is warmer than the air temperature, then "the air adjacent to the water surface would tend to become both warmer and more moist than that above it, thereby (due to both of these factors) becoming less dense. The resulting vertical convective air currents … might be expected to achieve much higher rates of heat and mass transfer from the water surface [even in the absence of wind] than would be possible by molecular diffusion alone" (Edinger et al. 1974). Water temperatures in natural waterbodies are frequently greater than the air temperature, especially at night.

Edinger et al. (1974) recommend that the relationship that was proposed by Brady, Graves and Geyer (1969) based on data from cooling ponds, could be representative of most environmental conditions. Shanahan (1984) recommends that the Lake Hefner equation (Marciano and Harbeck, 1952) is appropriate for natural waters in which the water temperature is less than the air temperature. Shanahan also recommends that the Ryan and Harleman (1971) equation as recalibrated by Helfrich et al. (1982) is best suited for waterbodies that experience water temperatures that are greater than the air temperature. Adams et al. (1987) revisited the Ryan and Harleman and Helfrich et al. models and proposed another recalibration using additional data for waterbodies that exhibit water temperatures that are greater than the air temperature.

Three options are available on the **Light and Heat Worksheet** in QUAL2K to calculate $f(U_w)$:

**1) Brady, Graves, and Geyer (default)**

$$f(U_w) = 19.0 + 0.95U_w^2$$

where $U_w$ = wind speed at a height of 7 m [m/s].

**2) Adams 1**

Adams et al. (1987) updated the work of Ryan and Harleman (1971) and Helfrich et al. (1982) to derive an empirical model of the wind speed function for heated waters that accounts for the enhancement of convection currents when the virtual temperature difference between the water and air ($\Delta\theta_v$ in degrees F) is greater than zero. Two wind functions reported by Adams et al., also known as the East Mesa method, are implemented in QUAL2K (wind speed in these equations is at a height of 2m).

This formulation uses an empirical function to estimate the effect of convection currents caused by virtual temperature differences between water and air, and the Harbeck (1962) equation is used to represent the contribution to conduction/convection and evaporation that is not due to convection currents caused by high virtual water temperature.

$$f(U_w) = 0.271\sqrt{(22.4\Delta\theta_v^{1/3})^2 + (24.2A_{acres,i}^{-0.05}U_{w,mph})^2}$$

where $U_{w,mph}$ is wind speed in mph and $A_{acres,i}$ is surface area of element i in acres. The constant 0.271 converts the original units of BTU ft$^{-2}$ day$^{-1}$ mmHg$^{-1}$ to cal cm$^{-2}$ day$^{-1}$ mmHg$^{-1}$.

**3) Adams 2**

This formulation uses an empirical function of virtual temperature differences with the Marciano and Harbeck (1952) equation for the contribution to conduction/convection and evaporation that is not due to the high virtual water temperature

$$f(U_w) = 0.271\sqrt{(22.4\Delta\theta_v^{1/3})^2 + (17U_{w,mph})^2}$$

Virtual temperature is defined as the temperature of dry air that has the same density as air under the in situ conditions of humidity. The virtual temperature difference between the water and air ( $\Delta\theta_v$ in °F) accounts for the buoyancy of the moist air above a heated water surface. The virtual temperature difference is estimated from water temperature ($T_{w,f}$ in °F), air temperature ($T_{air,f}$ in °F), vapor pressure of water and air ($e_s$ and $e_{air}$ in mmHg), and the atmospheric pressure ($p_{atm}$ is estimated as standard atmospheric pressure of 760 mmHg in QUAL2K):

$$\Delta\theta_v = \left(\frac{T_{w,f} + 460}{1 + 0.378e_s / p_{atm}} - 460\right) - \left(\frac{T_{air,f} + 460}{1 + 0.378e_{air} / p_{atm}} - 460\right) \quad (47)$$

The height of wind speed measurements is also an important consideration for estimating conduction/convection and evaporation. QUAL2K internally adjusts the wind speed to the correct height for the wind function that is selected on the **Light and Heat Worksheet**. The input values for wind speed on the **Wind Speed Worksheet** in QUAL2K are assumed to be representative of conditions at a height of 7 meters above the water surface. To convert wind speed measurements ($U_{w,z}$ in m/s) taken at any height ($z_w$ in meters) to the equivalent conditions at a height of $z$ = 7 m for input to the **Wind Speed Worksheet** of QUAL2K, the exponential wind law equation may be used (TVA, 1972):

$$U_w = U_{wz}\left(\frac{z}{z_w}\right)^{0.15} \quad (48)$$

For example, if wind speed data were collected from a height of 2 m, then the wind speed at 7 m for input to the **Wind Speed Worksheet** of QUAL2K would be estimated by multiplying the measured wind speed by a factor of 1.2.

### 4.1.5 Evaporation and Condensation

The heat loss due to evaporation can be represented by Dalton's law,

$$J_e = f(U_w)(e_s - e_{air}) \quad (49)$$

where $e_s$ = the saturation vapor pressure at the water surface [mmHg], and $e_{air}$ = the air vapor pressure [mmHg]. The saturation vapor pressure is computed as

$$e_{air} = 4.596e^{\frac{17.27T}{237.3+T}} \quad (50)$$

## 4.2 Sediment-Water Heat Transfer

A heat balance for bottom sediment underlying a water element *i* can be written as

$$\frac{dT_{s,i}}{dt} = -\frac{J_{s,i}}{\rho_s C_{ps} H_{sed,i}} \tag{51}$$

where $T_{s,i}$ = the temperature of the bottom sediment below element *i* [$^o$C], $J_{s,i}$ = the sediment-water heat flux [cal/(cm$^2$ d)], $\rho_s$ = the density of the sediments [g/cm$^3$], $C_{ps}$ = the specific heat of the sediments [cal/(g $^o$C)], and $H_{sed,i}$ = the effective thickness of the sediment layer [cm].

The flux from the sediments to the water can be computed as

$$J_{s,i} = \rho_s C_{ps} \frac{\alpha_s}{H_{sed,i}/2}\left(T_{si} - T_i\right) \times \frac{86{,}400\ \text{s}}{\text{d}} \tag{52}$$

where $\alpha_s$ = the sediment thermal diffusivity [cm$^2$/s].

The thermal properties of some natural sediments along with its components are summarized in Table 4. Note that soft, gelatinous sediments found in the deposition zones of lakes are very porous and approach the values for water. Some very slow, impounded rivers may approach such a state. However, rivers tend to have coarser sediments with significant fractions of sands, gravels and stones. Upland streams can have bottoms that are dominated by boulders and rock substrates.

**Table 4 Thermal properties for natural sediments and the materials that comprise natural sediments.**

Table 4. Thermal properties of various materials

| Type of material | thermal conductivity | | thermal diffusivity | | $\rho$ | $C_p$ | $\rho Cp$ | reference |
|---|---|---|---|---|---|---|---|---|
| | w/m/°C | cal/s/cm/°C | $m^2/s$ | $cm^2/s$ | g/cm3 | cal/(g °C) | cal/(cm^3 °C) | |
| *Sediment samples* | | | | | | | | |
| Mud Flat | 1.82 | 0.0044 | 4.80E-07 | 0.0048 | | | 0.906 | (1) |
| Sand | 2.50 | 0.0060 | 7.90E-07 | 0.0079 | | | 0.757 | " |
| Mud Sand | 1.80 | 0.0043 | 5.10E-07 | 0.0051 | | | 0.844 | " |
| Mud | 1.70 | 0.0041 | 4.50E-07 | 0.0045 | | | 0.903 | " |
| Wet Sand | 1.67 | 0.0040 | 7.00E-07 | 0.0070 | | | 0.570 | (2) |
| Sand 23% saturation with water | 1.82 | 0.0044 | 1.26E-06 | 0.0126 | | | 0.345 | (3) |
| Wet Peat | 0.36 | 0.0009 | 1.20E-07 | 0.0012 | | | 0.717 | (2) |
| Rock | 1.76 | 0.0042 | 1.18E-06 | 0.0118 | | | 0.357 | (4) |
| Loam 75% saturation with water | 1.78 | 0.0043 | 6.00E-07 | 0.0060 | | | 0.709 | (3) |
| Lake, gelatinous sediments | 0.46 | 0.0011 | 2.00E-07 | 0.0020 | | | 0.550 | (5) |
| Concrete canal | 1.55 | 0.0037 | 8.00E-07 | 0.0080 | 2.200 | 0.210 | 0.460 | " |
| *Average of sediment samples:* | *1.57* | *0.0037* | *6.45E-07* | *0.0064* | | | *0.647* | |
| *Miscellaneous measurements:* | | | | | | | | |
| Lake, shoreline | 0.59 | 0.0014 | | | | | | (5) |
| Lake soft sediments | | | 3.25E-07 | 0.0033 | | | | " |
| Lake, with sand | | | 4.00E-07 | 0.0040 | | | | " |
| River, sand bed | | | 7.70E-07 | 0.0077 | | | | " |
| *Component materials:* | | | | | | | | |
| Water | 0.59 | 0.0014 | 1.40E-07 | 0.0014 | 1.000 | 0.999 | 1.000 | (6) |
| Clay | 1.30 | 0.0031 | 9.80E-07 | 0.0098 | 1.490 | 0.210 | 0.310 | " |
| Soil, dry | 1.09 | 0.0026 | 3.70E-07 | 0.0037 | 1.500 | 0.465 | 0.700 | " |
| Sand | 0.59 | 0.0014 | 4.70E-07 | 0.0047 | 1.520 | 0.190 | 0.290 | " |
| Soil, wet | 1.80 | 0.0043 | 4.50E-07 | 0.0045 | 1.810 | 0.525 | 0.950 | " |
| Granite | 2.89 | 0.0069 | 1.27E-06 | 0.0127 | 2.700 | 0.202 | 0.540 | " |
| *Average of composite materials:* | *1.37* | *0.0033* | *6.13E-07* | *0.0061* | *1.670* | *0.432* | *0.632* | |

(1) Andrews and Rodvey (1980)
(2) Geiger (1965)
(3) Nakshabandi and Kohnke (1965)
(4) Chow (1964) and Carslaw and Jaeger (1959)
(5) Hutchinson 1957, Jobson 1977, and Likens and Johnson 1969
(6) Cengel, Grigull, Mills, Bejan, Kreith and Bohn

Inspection of the component properties of Table 4 suggests that the presence of solid material in stream sediments leads to a higher coefficient of thermal diffusivity than that for water or porous lake sediments. In Q2K, we suggest a default value of 0.005 $cm^2/s$ for this quantity.

In addition, specific heat tends to decrease with density. Thus, the product of these two quantities tends to be more constant than the multiplicands. Nevertheless, it appears that the presence of solid material in stream sediments leads to a lower product than that for water or gelatinous lake sediments. In Q2K, we suggest default values of $\rho_s$ = 1.6 g/cm$^3$ and $C_{ps}$ = 0.4 cal/(g $^o$C). This corresponds to a product of 0.64 cal/(cm$^3$ $^o$C) for this quantity. Finally, as derived in Appendix C, the sediment thickness is set by default to 10 cm in order to capture the effect of the sediments on the diel heat budget for the water.

# REFERENCES


Adams, E.E., D. J. Cosler, and K.R. Helfrich. 1987. "Analysis of evaporation data from heated ponds", cs-5171, research project 2385-1, Electric Power Research Institute, Palo Alto, California 94304. April.

Andrews and Rodvey, 1980. Heat exchange between water and tidal flats. D.G.M 24(2). (in German).

APHA, 1995. Standard methods for the examination of water and wastewater, 19th Edn. American Public Health Association, American Water Works Association and Water Environment Federation: Washington, D.C.

Asaeda, T., and T. Van Bon, Modelling the effects of macrophytes on algal blooming in eutrophic shallow lakes. Ecol. Model., 104: 261-287, 1997.

Baker, K.S. and Frouin, R. 1987. Relation between photosynthetically available radiation and total insolation at the ocean surface under clear skies. Limnol. Oceanogr. 1370-1377.

Baly, E.C.C. 1935. The Kinetics of Photosynthesis. *Proc. Royal Soc. London Ser. B*, 117:218-239.

Banks, R. B. 1975. "Some Features of Wind Action on Shallow Lakes." *J. Environ Engr. Div. ASCE*. 101(EE5): 813-827.

Banks, R. B. and Herrera, F. F. 1977. "Effect of Wind and Rain on Surface Reaeration." *J. Environ Engr. Div. ASCE*. 103(EE3): 489-504.

Barnwell, T.O., Brown, L.C., and Mareck, W. 1989). Application of Expert Systems Technology in Water Quality Modeling. *Water Sci. Tech.* 21(8-9):1045-1056.

Bejan, A. 1993. *Heat Transfer.* Wiley, New York, NY.

Bowie, G.L., Mills, W.B., Porcella, D.B., Campbell, C.L., Pagenkopf, J.R., Rupp, G.L., Johnson, K.M., Chan, P.W.H., Gherini, S.A. and Chamberlin, C.E. 1985. Rates, Constants, and Kinetic Formulations in Surface Water Quality Modeling. U.S. Envir. Prot. Agency, ORD, Athens, GA, ERL, EPA/600/3-85/040.

Brady, D.K., Graves, W.L., and Geyer, J.C. 1969. Surface Heat Exchange at Power Plant Cooling Lakes, Cooling Water Discharge Project Report, No. 5, Edison Electric Inst. Pub. No. 69-901, New York, NY.

Bras, R.L. 1990. Hydrology. Addison-Wesley, Reading, MA.

Brown, L.C., and Barnwell, T.O. 1987. The Enhanced Stream Water Quality Models QUAL2E and QUAL2E-UNCAS, EPA/600/3-87-007, U.S. Environmental Protection Agency, Athens, GA, 189 pp.

Brunt, D. 1932. Notes on radiation in the atmosphere: I. Quart J Royal Meteorol Soc 58:389-420.

Brutsaert, W. 1982. Evaporation into the atmosphere: theory, history, and applications. D.Reidel Publishing Co., Hingham MA, 299 p.

Butts, T. A. and Evans, R. L. 1983. Effects of Channel Dams on Dissolved Oxygen Concentrations in Northeastern Illinois Streams, Circular 132, State of Illinois, Dept. of Reg. and Educ., Illinois Water Survey, Urbana, IL.

Carslaw, H.S. and Jaeger, J.C. 1959. Conduction of Heat in Solids, Oxford Press, Oxford, UK, 510 pp.

Cengel, Y.A. 1998 *Heat Transfer: A Practical Approach.* New York, McGraw-Hill.

Chapra and Canale 2006. *Numerical Methods for Engineers, 5$^{th}$ Ed.* New York, McGraw-Hill.

Chapra, S.C. 1997. *Surface water quality modeling*. New York, McGraw-Hill.

Chapra, S.C. 2007. Applied Numerical Methods with MATLAB for Engineering and Science, 2nd Ed., WCB/McGraw-Hill, New York, N.Y.

Chow, V.T., Maidment, D.R., and Mays, L.W. 1988. *Applied Hydrology*. New York, McGraw-Hill, 592 pp.

Churchill, M.A., Elmore, H.L., and Buckingham, R.A. 1962. The prediction of stream reaeration rates. *J. Sanit. Engrg. Div.* , ASCE, 88{4),1-46.
Coffaro, G. and A. Sfriso, Simulation model of Ulva rigida growth in shallow water of the Lagoon of Venice. Ecol. Model., 102: 55-66, 1997.
Covar, A. P. 1976. "Selecting the Proper Reaeration Coefficient for Use in Water Quality Models." Presented at the U.S. EPA Conference on Environmental Simulation and Modeling, April 19-22, 1976, Cincinnati, OH.
Di Toro, D. M. and J. F. Fitzpatrick. 1993. Chesapeake Bay sediment flux model. Tech. Report EL-93-2, U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi, 316 pp.
Di Toro, D.M, Paquin, P.R., Subburamu, K. and Gruber, D.A. 1991. Sediment Oxygen Demand Model: Methane and Ammonia Oxidation. J. Environ. Eng., 116(5):945-986.
Di Toro, D.M. 1978. Optics of Turbid Estuarine Waters: Approximations and Applications. Water Res. 12:1059-1068.
Di Toro, D.M. 2001. *Sediment Flux Modeling*. Wiley-Interscience, New York, NY.
Droop, M.R. 1974. The nutrient status of algal cells in continuous culture. J.Mar.Biol.Assoc. UK 54:825-855.
Ecology. 2003. Shade.xls - a tool for estimating shade from riparian vegetation. Washington State Department of Ecology. http://www.ecy.wa.gov/programs/eap/models/
Edinger, J.E., Brady, D.K., and Geyer, J.C. 1974. Heat Exchange and Transport in the Environment. Report No. 14, EPRI Pub. No. EA-74-049-00-3, Electric Power Research Institute, Palo Alto, CA.
Finlayson-Pitts, B.J. and Pitts, J.N., Jr. 2000. Chemistry of the upper and lower atmosphere : theory, experiments, and applications. Academic Press.
Finnemore, E.J. and Franzini, J.B. 2002. Fluid Mechanics with Engineering Applications, $10^{th}$ Ed. New York, McGraw, Hill.
Geiger, R. 1965. The climate near the ground. Harvard University Press. Cambridge, MA.
Gordon, N.D, T.A. McMahon, and B.L. Finlayson. 1992. Stream Hydrology, An Introduction for Ecologists. Published by John Wiley and Sons.
Grigull, U. and Sandner, H. 1984. *Heat Conduction.* Springer-Verlag, New York, NY.
Hamilton, D.P., and S.G. Schladow, Prediction of water quality in lakes and reservoirs. 1. Model description. Ecol. Model., 96: 91-110, 1997.
Harbeck, G. E., 1962, A practical field technique for measuring reservoir evaporation utilizing mass-transfer theory. US Geological Survey Professional Paper 272-E, 101-5.
Harned, H.S., and Hamer, W.J. 1933. “The Ionization Constant of Water.” *J. Am., Chem. Soc.* 51:2194.
Helfrich, K.R., E.E. Adams, A.L. Godbey, and D.R.F. Harleman. 1982. Evaluation of models for predicting evaporative water loss in cooling impoundments. Report CS-2325, Research project 1260-17. Electric Power Research Institute, Pala Alto, CA. March 1982.
Hellweger, F/L., K.L. Farley, U. Lall, and D.M. DiToro. 2003. Greedy algae reduce arsenate. Limnol.Oceanogr. 48(6), 2003, 2275-2288.
Holland, H.D. 1978. The Chemistry of the Atmosphere and Oceans. Wiley-Interscience, NY, NY.
Hutchinson, G.E. 1957. *A Treatise on Limnology, Vol. 1, Physics and Chemistry*. Wiley, New York, NY.
Jobson, H.E. 1977. Bed Conduction Computation for Thermal Models. J. Hydraul. Div. ASCE. 103(10):1213-1217.
Koberg, G.E. 1964. Methods to compute long-wave radiation from the atmosphere and reflected solar radiation from a water surface. US Geological Survey Professional Paper 272-F.
Kreith, F. and Bohn, M.S. 1986. *Principles of Heat Transfer, $4^{th}$ Ed.* Harper and Row, New York, NY.

Laws, E. A. and Chalup, M. S. 1990. A Microalgal Growth Model. *Limnol. Oceanogr.* 35(3):597-608.
LI-COR, 2003. Radiation Measurement Instruments, LI-COR, Lincoln, NE, 30 pp.
Likens, G. E., and Johnson, N. M. (1969). "Measurements and analysis of the annual heat budget for sediments of two Wisconsin lakes." *Limnol. Oceanogr.*, 14(1):115-135.
Mackay, D. and Yeun, A.T.K. 1983. Mass Transfer Coefficient Correlations for Volatilization of Organic Solutes from Water. *Environ. Sci. Technol.* 17:211-233.
Marciano, J.K. and G.E. Harbeck. 1952. Mass transfer studies in water loss investigation: Lake Hefner studies. Geological Circular 229. U.S. Geological Survey, Washington DC.
McIntyre, C. D. 1973. Periphyton dynamics in laboratory streams: A simulation model and its implications. *Ecol. Monogr.* 43:399-420.
Meeus, J. 1999. Astronomical algorithms. Second edition. Willmann-Bell, Inc. Richmond, VA.
Melching, C.S. and Flores, H.E. 1999. Reaeration Equations from U.S. Geological Survey Database. *J. Environ. Engin.*, 125(5):407-414.
Mills, A.F. 1992. *Heat Transfer*. Irwin, Homewood, IL.
Moog, D.B., and Iirka, G.H. 1998. Analysis of reaeration equations using mean multiplicative error. *J. Environ. Engrg.*, ASCE, 124(2), 104-110.
Nakshabandi, G.A. and H. Kohnke. 1965. Thermal conductivity and diffusivity of soils as related to moisture tension and other physical properties. Agr. Met. Vol 2.
O'Connor, D.J., and Dobbins, W.E. 1958. Mechanism of reaeration in natural streams. *Trans. ASCE*, 123, 641-684.
Owens, M., Edwards, R.W., and Gibbs, J.W. 1964. Some reaeration studies in streams. *Int. J. Air and Water Pollution*, 8, 469-486.
Plummer, L.N. and Busenberg, E. 1982. The Solubilities of Calcite, Aragonite and Vaterite in CO2-H2O Solutions Between 0 and 90 $^oC$, and an Evaluation of the Aqueous Model for the System $CaCO_3–CO_2–H_2O$. *Geochim. Cosmochim.* 46:1011-1040.
Raudkivi, A. I. 1979. *Hydrology*. Pergamon, Oxford, England.
Redfield, A.C., Ketchum, B.H. and Richards, F.A. 1963. The Influence of Organisms on the Composition of Seawater, in *The Sea*, M.N. Hill, ed. Vol. 2, pp. 27-46, Wiley-Interscience, NY.
Riley, G.A. 1956. Oceanography of Long Island Sound 1952-1954. II. Physical Oceanography, Bull. Bingham Oceanog. Collection 15, pp. 15-16.
Rosgen, D. 1996. Applied river morphology. Wildland Hydrology publishers. Pagosa Springs, CO.
Rutherford, J.C., Scarsbrook, M.R. and Broekhuizen, N. 2000. Grazer Control of Stream Algae: Modeling Temperature and Flood Effects. *J. Environ. Eng.* 126(4):331-339.
Ryan, P.J. and D.R.F. Harleman. 1971. Prediction of the annual cycle of temperature changes in a stratified lake or reservoir. Mathematical model and user’s manual. Ralph M. Parsons Laboratory Report No. 137. Massachusetts Institute of Technology. Cambridge, MA.
Ryan, P.J. and K.D. Stolzenbach.1972. Engineering aspects of heat disposal from power generation, (D.R.F. Harleman, ed.). R.M. Parson Laboratory for Water Resources and Hydrodynamics, Department of Civil Engineering, Massachusetts Institute of Technology, Cambridge, MA
Schwarzenbach, R.P., Gschwend, P.M., and Imboden, D.M. 1993. Environmental Organic Chemistry. Wiley-Interscience, 681 pp.
Shanahan, P. 1984. Water temperature modeling: a practical guide. In: Proceedings of stormwater and water quality model users group meeting, April 12-13, 1984. USEPA, EPA-600/9-85-003. (users.rcn.com/shanahan.ma.ultranet/TempModeling.pdf).
Smith, E.L. 1936. Photosynthesis in Relation to Light and Carbon Dioxide. Proc. Natl. Acad. Sci. 22:504-511.

Steele, J.H. 1962. Environmental Control of Photosynthesis in the Sea. Limnol. Oceanogr. 7:137-150.
Stumm, W. and Morgan, J.J. 1996. Aquatic Chemistry, 3rd Ed., New York, Wiley-Interscience, 1022 pp.
Szeicz, G. 1974. Solar radiation for plant growth. J. Appl. Ecol. 11:617-636.
Thackston, E. L., and Dawson, J.W. III. 2001. Recalibration of a Reaeration Equation. *J. Environ. Engrg.*, 127(4):317-320.
Thackston, E. L., and Krenkel, P. A. 1969. Reaeration-prediction in natural streams. *J. Sanit. Engrg. Div.*, ASCE, 95(1), 65-94.
Tsivoglou, E. C., and Neal, L.A. 1976. Tracer Measurement of Reaeration. III. Predicting the Reaeration Capacity of Inland Streams. Journal of the Water Pollution Control Federation, 48(12):2669-2689.
Thomann, R.V. and Mueller, J.A. 1987. Principles of Surface Water Quality Modeling and Control. New York, Harper-Collins.
TVA, 1972. Heat and mass transfer between a water surface and the atmosphere. Water Resources Research, Laboratory Report No. 14. Engineering Laboratory, Division of Water Control Planning, Tennessee Valley Authority, Norris TN.
Wanninkhof, R., Ledwell, I. R., and Crusius, I. 1991. "Gas Transfer Velocities on Lakes Measured with Sulfur Hexafluoride." In Symposium Volume of the Second International Conference on Gas Transfer at Water Surfaces, S.C. Wilhelms and I.S. Gulliver, eds., Minneapolis, MN .
Wood, K.G. 1974. Carbon Dioxide Diffusivity Across the Air-Water Interface. *Archiv für Hydrobiol.* 73(1):57-69.

# APPENDIX E

**Turbidity TMDLs for the Sulphur River**

TABLE E.1 ALLOWABLE LOADS OF TSS FOR SULPHUR RIVER REACH 11140302-008

Turbidity: base flow criterion = 21 NTU; storm flow criterion = 32 NTU

Allowable release from International Paper Texarkana Mill (included as a portion of the upstream flow):

Minimum release from Lake Wright Patman for IP to discharge = 50 cfs

Allowable discharge as percentage of Lake Wright Patman release = 100%

Maximum allowable release at any time = 646.3 MGD = 1000 cfs

| Percent exceedance for flow | Calculated ambient flow at downstream end of reach 11140302-008 (Lake WP releases + inflow d/s of dam) (cfs) | Flow Category | Target TSS (mg/L) | Upstream flow from Int'l Paper discharge (cfs) | Point source flow entering this reach (cfs) | Ambient flow + Int'l Paper discharge + point sources in this reach (cfs) | TSS assimilative capacity, or TMDL (tons/day) |
|---|---|---|---|---|---|---|---|
| 99.9 | 10.9 | Base | 24 | 0 | 0 | 11 | 0.7 |
| 99 | 11.8 | Base | 24 | 0 | 0 | 12 | 0.8 |
| 98 | 14.0 | Base | 24 | 0 | 0 | 14 | 0.9 |
| 96 | 26.8 | Base | 24 | 0 | 0 | 27 | 1.7 |
| 94 | 52.1 | Base | 24 | 52 | 0 | 104 | 6.7 |
| 92 | 55.5 | Base | 24 | 56 | 0 | 111 | 7.2 |
| 90 | 87.1 | Base | 24 | 87 | 0 | 174 | 11.3 |
| 88 | 105.8 | Base | 24 | 106 | 0 | 212 | 13.7 |
| 86 | 108.2 | Base | 24 | 108 | 0 | 216 | 14.0 |
| 84 | 109.4 | Base | 24 | 109 | 0 | 219 | 14.2 |
| 82 | 110.2 | Base | 24 | 110 | 0 | 220 | 14.3 |
| 80 | 111.2 | Base | 24 | 111 | 0 | 222 | 14.4 |
| 78 | 113.0 | Base | 24 | 113 | 0 | 226 | 14.6 |
| 76 | 114.5 | Base | 24 | 114 | 0 | 229 | 14.8 |
| 74 | 116.1 | Base | 24 | 116 | 0 | 232 | 15.0 |
| 72 | 120.6 | Base | 24 | 121 | 0 | 241 | 15.6 |
| 70 | 131.4 | Base | 24 | 131 | 0 | 263 | 17.0 |
| 68 | 151.7 | Base | 24 | 152 | 0 | 303 | 19.6 |
| 66 | 210.7 | Base | 24 | 211 | 0 | 421 | 27.3 |
| 64 | 225.2 | Base | 24 | 225 | 0 | 450 | 29.2 |
| 62 | 229.1 | Base | 24 | 229 | 0 | 458 | 29.7 |
| 60 | 242.5 | Base | 24 | 242 | 0 | 485 | 31.4 |
| 59.9 | 244.0 | Storm | 34 | 244 | 0 | 488 | 44.8 |
| 58 | 323.8 | Storm | 34 | 324 | 0 | 648 | 59.4 |
| 56 | 499.0 | Storm | 34 | 499 | 0 | 998 | 91.5 |
| 54 | 537.2 | Storm | 34 | 537 | 0 | 1,074 | 98.5 |
| 52 | 554.6 | Storm | 34 | 555 | 0 | 1,109 | 101.7 |
| 50 | 650.2 | Storm | 34 | 650 | 0 | 1,300 | 119.2 |
| 48 | 878.1 | Storm | 34 | 878 | 0 | 1,756 | 161.0 |
| 46 | 1,062.8 | Storm | 34 | 1,000 | 0 | 2,063 | 189.2 |
| 44 | 1,141.7 | Storm | 34 | 1,000 | 0 | 2,142 | 196.4 |
| 42 | 1,414.9 | Storm | 34 | 1,000 | 0 | 2,415 | 221.4 |
| 40 | 1,767.1 | Storm | 34 | 1,000 | 0 | 2,767 | 253.7 |
| 38 | 2,128.6 | Storm | 34 | 1,000 | 0 | 3,129 | 286.9 |
| 36 | 2,590.7 | Storm | 34 | 1,000 | 0 | 3,591 | 329.2 |
| 34 | 2,997.2 | Storm | 34 | 1,000 | 0 | 3,997 | 366.5 |
| 32 | 3,635.9 | Storm | 34 | 1,000 | 0 | 4,636 | 425.1 |
| 30 | 4,022.9 | Storm | 34 | 1,000 | 0 | 5,023 | 460.6 |
| 28 | 4,637.4 | Storm | 34 | 1,000 | 0 | 5,637 | 516.9 |
| 26 | 6,131.6 | Storm | 34 | 1,000 | 0 | 7,132 | 653.9 |
| 24 | 6,842.3 | Storm | 34 | 1,000 | 0 | 7,842 | 719.1 |
| 22 | 7,645.6 | Storm | 34 | 1,000 | 0 | 8,646 | 792.8 |

| Percent exceedance for flow | Calculated ambient flow at downstream end of reach 11140302-008 (Lake WP releases + inflow d/s of dam) (cfs) | Flow Category | Target TSS (mg/L) | Upstream flow from Int'l Paper discharge (cfs) | Point source flow entering this reach (cfs) | Ambient flow + Int'l Paper discharge + point sources in this reach (cfs) | TSS assimilative capacity, or TMDL (tons/day) |
|---|---|---|---|---|---|---|---|
| 20 | 9,104.9 | Storm | 34 | 1,000 | 0 | 10,105 | 926.6 |
| 18 | 9,543.5 | Storm | 34 | 1,000 | 0 | 10,544 | 966.8 |
| 16 | 9,726.1 | Storm | 34 | 1,000 | 0 | 10,726 | 983.5 |
| 14 | 9,836.4 | Storm | 34 | 1,000 | 0 | 10,836 | 993.6 |
| 12 | 9,948.9 | Storm | 34 | 1,000 | 0 | 10,949 | 1,004.0 |
| 10 | 10,019.0 | Storm | 34 | 1,000 | 0 | 11,019 | 1,010.4 |
| 9 | 10,052.2 | Storm | 34 | 1,000 | 0 | 11,052 | 1,013.4 |
| 8 | 10,087.2 | Storm | 34 | 1,000 | 0 | 11,087 | 1,016.6 |
| 7 | 10,125.8 | Storm | 34 | 1,000 | 0 | 11,126 | 1,020.2 |
| 6 | 10,178.9 | Storm | 34 | 1,000 | 0 | 11,179 | 1,025.0 |
| 5 | 10,235.6 | Storm | 34 | 1,000 | 0 | 11,236 | 1,030.2 |
| 4 | 10,305.0 | Storm | 34 | 1,000 | 0 | 11,305 | 1,036.6 |
| 3 | 10,437.3 | Storm | 34 | 1,000 | 0 | 11,437 | 1,048.7 |
| 2 | 10,633.2 | Storm | 34 | 1,000 | 0 | 11,633 | 1,066.7 |
| 1 | 10,968.2 | Storm | 34 | 1,000 | 0 | 11,968 | 1,097.4 |
| 0.5 | 11,344.5 | Storm | 34 | 1,000 | 0 | 12,345 | 1,131.9 |
| 0.1 | 11,983.9 | Storm | 34 | 1,000 | 0 | 12,984 | 1,190.6 |
| 0.01 | 13,607.2 | Storm | 34 | 1,000 | 0 | 14,607 | 1,339.4 |

FILE: R:\PROJECTS\3013-380\TECH\ADEQ_WQ_DATA\RED RIVER\RED0005 SULPHUR RIVER REVISED TMDL METHOD.XLSX

TABLE E.2 ALLOWABLE LOADS OF TSS FOR SULPHUR RIVER REACH 11140302-006

Turbidity: base flow criterion = 21 NTU; storm flow criterion = 32 NTU

Flow entering this reach from non-storm point sources to be included in WLA = 0 MGD

| Percent exceedance for flow | Calculated ambient flow at downstream end of reach 11140302-006 (Lake WP releases + inflow d/s of dam) (cfs) | Flow Category | Target TSS (mg/L) | Upstream flow from Int'l Paper discharge (cfs) | Point source flow entering this reach (cfs) | Ambient flow + Int'l Paper discharge + point sources in this reach (cfs) | TSS assimilative capacity, or TMDL (tons/day) |
|---|---|---|---|---|---|---|---|
| 99.9 | 11.5 | Base | 24 | 0 | 0 | 12 | 0.7 |
| 99 | 13.1 | Base | 24 | 0 | 0 | 13 | 0.8 |
| 98 | 17.3 | Base | 24 | 0 | 0 | 17 | 1.1 |
| 96 | 37.3 | Base | 24 | 0 | 0 | 37 | 2.4 |
| 94 | 53.2 | Base | 24 | 52 | 0 | 105 | 6.8 |
| 92 | 57.8 | Base | 24 | 56 | 0 | 113 | 7.3 |
| 90 | 88.1 | Base | 24 | 87 | 0 | 175 | 11.3 |
| 88 | 107.2 | Base | 24 | 106 | 0 | 213 | 13.8 |
| 86 | 109.3 | Base | 24 | 108 | 0 | 218 | 14.1 |
| 84 | 110.2 | Base | 24 | 109 | 0 | 220 | 14.2 |
| 82 | 111.2 | Base | 24 | 110 | 0 | 221 | 14.3 |
| 80 | 112.4 | Base | 24 | 111 | 0 | 224 | 14.5 |
| 78 | 114.3 | Base | 24 | 113 | 0 | 227 | 14.7 |
| 76 | 115.7 | Base | 24 | 114 | 0 | 230 | 14.9 |
| 74 | 120.0 | Base | 24 | 116 | 0 | 236 | 15.3 |
| 72 | 130.4 | Base | 24 | 121 | 0 | 251 | 16.2 |
| 70 | 150.1 | Base | 24 | 131 | 0 | 281 | 18.2 |
| 68 | 179.4 | Base | 24 | 152 | 0 | 331 | 21.4 |
| 66 | 222.4 | Base | 24 | 211 | 0 | 433 | 28.0 |
| 64 | 227.9 | Base | 24 | 225 | 0 | 453 | 29.3 |
| 62 | 237.1 | Base | 24 | 229 | 0 | 466 | 30.2 |
| 60 | 277.0 | Base | 24 | 242 | 0 | 519 | 33.6 |
| 59.9 | 279.9 | Storm | 34 | 244 | 0 | 524 | 48.0 |
| 58 | 383.5 | Storm | 34 | 324 | 0 | 707 | 64.9 |
| 56 | 514.9 | Storm | 34 | 499 | 0 | 1,014 | 93.0 |
| 54 | 547.3 | Storm | 34 | 537 | 0 | 1,084 | 99.4 |
| 52 | 593.4 | Storm | 34 | 555 | 0 | 1,148 | 105.3 |
| 50 | 725.0 | Storm | 34 | 650 | 0 | 1,375 | 126.1 |
| 48 | 932.0 | Storm | 34 | 878 | 0 | 1,810 | 166.0 |
| 46 | 1,086.3 | Storm | 34 | 1,000 | 0 | 2,086 | 191.3 |
| 44 | 1,169.6 | Storm | 34 | 1,000 | 0 | 2,170 | 198.9 |
| 42 | 1,466.4 | Storm | 34 | 1,000 | 0 | 2,466 | 226.2 |
| 40 | 1,819.4 | Storm | 34 | 1,000 | 0 | 2,819 | 258.5 |
| 38 | 2,227.9 | Storm | 34 | 1,000 | 0 | 3,228 | 296.0 |
| 36 | 2,626.7 | Storm | 34 | 1,000 | 0 | 3,627 | 332.5 |
| 34 | 3,045.6 | Storm | 34 | 1,000 | 0 | 4,046 | 371.0 |
| 32 | 3,688.0 | Storm | 34 | 1,000 | 0 | 4,688 | 429.9 |
| 30 | 4,105.9 | Storm | 34 | 1,000 | 0 | 5,106 | 468.2 |
| 28 | 4,785.8 | Storm | 34 | 1,000 | 0 | 5,786 | 530.5 |
| 26 | 6,230.2 | Storm | 34 | 1,000 | 0 | 7,230 | 663.0 |
| 24 | 6,926.9 | Storm | 34 | 1,000 | 0 | 7,927 | 726.9 |
| 22 | 7,836.6 | Storm | 34 | 1,000 | 0 | 8,837 | 810.3 |

| Percent exceedance for flow | Calculated ambient flow at downstream end of reach 11140302-006 (Lake WP releases + inflow d/s of dam) (cfs) | Flow Category | Target TSS (mg/L) | Upstream flow from Int'l Paper discharge (cfs) | Point source flow entering this reach (cfs) | Ambient flow + Int'l Paper discharge + point sources in this reach (cfs) | TSS assimilative capacity, or TMDL (tons/day) |
|---|---|---|---|---|---|---|---|
| 20 | 9,177.3 | Storm | 34 | 1,000 | 0 | 10,177 | 933.2 |
| 18 | 9,619.4 | Storm | 34 | 1,000 | 0 | 10,619 | 973.7 |
| 16 | 9,794.6 | Storm | 34 | 1,000 | 0 | 10,795 | 989.8 |
| 14 | 9,928.4 | Storm | 34 | 1,000 | 0 | 10,928 | 1,002.1 |
| 12 | 10,037.8 | Storm | 34 | 1,000 | 0 | 11,038 | 1,012.1 |
| 10 | 10,118.9 | Storm | 34 | 1,000 | 0 | 11,119 | 1,019.5 |
| 9 | 10,172.7 | Storm | 34 | 1,000 | 0 | 11,173 | 1,024.5 |
| 8 | 10,218.5 | Storm | 34 | 1,000 | 0 | 11,218 | 1,028.7 |
| 7 | 10,276.4 | Storm | 34 | 1,000 | 0 | 11,276 | 1,034.0 |
| 6 | 10,349.5 | Storm | 34 | 1,000 | 0 | 11,350 | 1,040.7 |
| 5 | 10,450.3 | Storm | 34 | 1,000 | 0 | 11,450 | 1,049.9 |
| 4 | 10,581.3 | Storm | 34 | 1,000 | 0 | 11,581 | 1,061.9 |
| 3 | 10,731.5 | Storm | 34 | 1,000 | 0 | 11,731 | 1,075.7 |
| 2 | 10,998.3 | Storm | 34 | 1,000 | 0 | 11,998 | 1,100.2 |
| 1 | 11,486.0 | Storm | 34 | 1,000 | 0 | 12,486 | 1,144.9 |
| 0.5 | 11,962.6 | Storm | 34 | 1,000 | 0 | 12,963 | 1,188.6 |
| 0.1 | 13,650.8 | Storm | 34 | 1,000 | 0 | 14,651 | 1,343.4 |
| 0.01 | 16,674.9 | Storm | 34 | 1,000 | 0 | 17,675 | 1,620.7 |

FILE: R:\PROJECTS\3013-380\TECH\ADEQ_WQ_DATA\RED RIVER\RED0005 SULPHUR RIVER REVISED TMDL METHOD.XLSX

TABLE E.3 ALLOWABLE LOADS OF TSS FOR SULPHUR RIVER REACH 11140302-004

Turbidity: base flow criterion = 21 NTU; storm flow criterion = 32 NTU

Flow entering this reach from non-storm point sources to be included in WLA = 0 MGD

| Percent exceedance for flow | Calculated ambient flow at downstream end of reach 11140302-004 (Lake WP releases + inflow d/s of dam) (cfs) | Flow Category | Target TSS (mg/L) | Upstream flow from Int'l Paper discharge (cfs) | Point source flow entering this reach (cfs) | Ambient flow + Int'l Paper discharge + point sources in this reach (cfs) | TSS assimilative capacity, or TMDL (tons/day) |
|---|---|---|---|---|---|---|---|
| 99.9 | 11.6 | Base | 24 | 0 | 0 | 12 | 0.8 |
| 99 | 13.5 | Base | 24 | 0 | 0 | 14 | 0.9 |
| 98 | 18.4 | Base | 24 | 0 | 0 | 18 | 1.2 |
| 96 | 40.7 | Base | 24 | 0 | 0 | 41 | 2.6 |
| 94 | 53.6 | Base | 24 | 52 | 0 | 106 | 6.8 |
| 92 | 60.4 | Base | 24 | 56 | 0 | 116 | 7.5 |
| 90 | 88.2 | Base | 24 | 87 | 0 | 175 | 11.3 |
| 88 | 107.9 | Base | 24 | 106 | 0 | 214 | 13.8 |
| 86 | 109.6 | Base | 24 | 108 | 0 | 218 | 14.1 |
| 84 | 110.4 | Base | 24 | 109 | 0 | 220 | 14.2 |
| 82 | 111.3 | Base | 24 | 110 | 0 | 222 | 14.3 |
| 80 | 112.7 | Base | 24 | 111 | 0 | 224 | 14.5 |
| 78 | 114.5 | Base | 24 | 113 | 0 | 228 | 14.7 |
| 76 | 116.1 | Base | 24 | 114 | 0 | 231 | 14.9 |
| 74 | 121.6 | Base | 24 | 116 | 0 | 238 | 15.4 |
| 72 | 135.1 | Base | 24 | 121 | 0 | 256 | 16.5 |
| 70 | 155.9 | Base | 24 | 131 | 0 | 287 | 18.6 |
| 68 | 186.8 | Base | 24 | 152 | 0 | 339 | 21.9 |
| 66 | 223.3 | Base | 24 | 211 | 0 | 434 | 28.1 |
| 64 | 228.9 | Base | 24 | 225 | 0 | 454 | 29.4 |
| 62 | 240.8 | Base | 24 | 229 | 0 | 470 | 30.4 |
| 60 | 289.5 | Base | 24 | 242 | 0 | 532 | 34.4 |
| 59.9 | 296.9 | Storm | 34 | 244 | 0 | 541 | 49.6 |
| 58 | 403.9 | Storm | 34 | 324 | 0 | 728 | 66.7 |
| 56 | 520.5 | Storm | 34 | 499 | 0 | 1,020 | 93.5 |
| 54 | 551.1 | Storm | 34 | 537 | 0 | 1,088 | 99.8 |
| 52 | 609.5 | Storm | 34 | 555 | 0 | 1,164 | 106.7 |
| 50 | 736.6 | Storm | 34 | 650 | 0 | 1,387 | 127.2 |
| 48 | 953.3 | Storm | 34 | 878 | 0 | 1,831 | 167.9 |
| 46 | 1,090.1 | Storm | 34 | 1,000 | 0 | 2,090 | 191.7 |
| 44 | 1,178.7 | Storm | 34 | 1,000 | 0 | 2,179 | 199.8 |
| 42 | 1,487.0 | Storm | 34 | 1,000 | 0 | 2,487 | 228.0 |
| 40 | 1,849.8 | Storm | 34 | 1,000 | 0 | 2,850 | 261.3 |
| 38 | 2,256.6 | Storm | 34 | 1,000 | 0 | 3,257 | 298.6 |
| 36 | 2,651.9 | Storm | 34 | 1,000 | 0 | 3,652 | 334.9 |
| 34 | 3,078.9 | Storm | 34 | 1,000 | 0 | 4,079 | 374.0 |
| 32 | 3,706.6 | Storm | 34 | 1,000 | 0 | 4,707 | 431.6 |
| 30 | 4,125.1 | Storm | 34 | 1,000 | 0 | 5,125 | 469.9 |
| 28 | 4,869.9 | Storm | 34 | 1,000 | 0 | 5,870 | 538.2 |
| 26 | 6,258.8 | Storm | 34 | 1,000 | 0 | 7,259 | 665.6 |
| 24 | 6,937.8 | Storm | 34 | 1,000 | 0 | 7,938 | 727.8 |
| 22 | 7,903.8 | Storm | 34 | 1,000 | 0 | 8,904 | 816.4 |

| Percent exceedance for flow | Calculated ambient flow at downstream end of reach 11140302-004 (Lake WP releases + inflow d/s of dam) (cfs) | Flow Category | Target TSS (mg/L) | Upstream flow from Int'l Paper discharge (cfs) | Point source flow entering this reach (cfs) | Ambient flow + Int'l Paper discharge + point sources in this reach (cfs) | TSS assimilative capacity, or TMDL (tons/day) |
|---|---|---|---|---|---|---|---|
| 20 | 9,194.0 | Storm | 34 | 1,000 | 0 | 10,194 | 934.7 |
| 18 | 9,637.9 | Storm | 34 | 1,000 | 0 | 10,638 | 975.4 |
| 16 | 9,812.4 | Storm | 34 | 1,000 | 0 | 10,812 | 991.4 |
| 14 | 9,952.4 | Storm | 34 | 1,000 | 0 | 10,952 | 1,004.3 |
| 12 | 10,062.2 | Storm | 34 | 1,000 | 0 | 11,062 | 1,014.3 |
| 10 | 10,156.2 | Storm | 34 | 1,000 | 0 | 11,156 | 1,023.0 |
| 9 | 10,207.0 | Storm | 34 | 1,000 | 0 | 11,207 | 1,027.6 |
| 8 | 10,266.7 | Storm | 34 | 1,000 | 0 | 11,267 | 1,033.1 |
| 7 | 10,322.2 | Storm | 34 | 1,000 | 0 | 11,322 | 1,038.2 |
| 6 | 10,407.6 | Storm | 34 | 1,000 | 0 | 11,408 | 1,046.0 |
| 5 | 10,520.0 | Storm | 34 | 1,000 | 0 | 11,520 | 1,056.3 |
| 4 | 10,654.0 | Storm | 34 | 1,000 | 0 | 11,654 | 1,068.6 |
| 3 | 10,841.9 | Storm | 34 | 1,000 | 0 | 11,842 | 1,085.8 |
| 2 | 11,122.6 | Storm | 34 | 1,000 | 0 | 12,123 | 1,111.6 |
| 1 | 11,688.4 | Storm | 34 | 1,000 | 0 | 12,688 | 1,163.5 |
| 0.5 | 12,302.2 | Storm | 34 | 1,000 | 0 | 13,302 | 1,219.7 |
| 0.1 | 14,220.1 | Storm | 34 | 1,000 | 0 | 15,220 | 1,395.6 |
| 0.01 | 17,697.4 | Storm | 34 | 1,000 | 0 | 18,697 | 1,714.4 |

FILE: R:\PROJECTS\3013-380\TECH\ADEQ_WQ_DATA\RED RIVER\RED0005 SULPHUR RIVER REVISED TMDL METHOD.XLSX

TABLE E.4 ALLOWABLE LOADS OF TSS FOR SULPHUR RIVER REACH 11140302-002

Turbidity: base flow criterion = 21 NTU; storm flow criterion = 32 NTU

Flow entering this reach from non-storm point sources to be included in WLA = 0 MGD

Non-ambient flow from Days Crk w'shed (sum of avg eff flows for non-storm pt sources) = 14.5 MGD = 22.4 cfs

| Percent exceedance for flow | Calculated ambient flow at downstream end of reach 11140302-002 (Lake WP releases + inflow d/s of dam) (cfs) | Flow Category | Target TSS (mg/L) | Upstream flow from Int'l Paper discharge (cfs) | Point source flow entering this reach (cfs) | Ambient flow + Int'l Paper discharge + point sources this reach + Days Crk PS (cfs) | TSS assimilative capacity, or TMDL (tons/day) |
|---|---|---|---|---|---|---|---|
| 99.9 | 12.5 | Base | 24 | 0 | 0 | 35 | 2.3 |
| 99 | 16.8 | Base | 24 | 0 | 0 | 39 | 2.5 |
| 98 | 25.5 | Base | 24 | 0 | 0 | 48 | 3.1 |
| 96 | 52.4 | Base | 24 | 0 | 0 | 75 | 4.8 |
| 94 | 56.2 | Base | 24 | 52 | 0 | 131 | 8.5 |
| 92 | 87.6 | Base | 24 | 56 | 0 | 166 | 10.7 |
| 90 | 93.9 | Base | 24 | 87 | 0 | 203 | 13.2 |
| 88 | 110.0 | Base | 24 | 106 | 0 | 238 | 15.4 |
| 86 | 110.9 | Base | 24 | 108 | 0 | 241 | 15.6 |
| 84 | 112.1 | Base | 24 | 109 | 0 | 244 | 15.8 |
| 82 | 113.5 | Base | 24 | 110 | 0 | 246 | 15.9 |
| 80 | 115.2 | Base | 24 | 111 | 0 | 249 | 16.1 |
| 78 | 117.3 | Base | 24 | 113 | 0 | 253 | 16.4 |
| 76 | 123.0 | Base | 24 | 114 | 0 | 260 | 16.8 |
| 74 | 138.4 | Base | 24 | 116 | 0 | 277 | 17.9 |
| 72 | 164.1 | Base | 24 | 121 | 0 | 307 | 19.9 |
| 70 | 202.9 | Base | 24 | 131 | 0 | 357 | 23.1 |
| 68 | 225.7 | Base | 24 | 152 | 0 | 400 | 25.9 |
| 66 | 231.8 | Base | 24 | 211 | 0 | 465 | 30.1 |
| 64 | 252.6 | Base | 24 | 225 | 0 | 500 | 32.4 |
| 62 | 290.2 | Base | 24 | 229 | 0 | 542 | 35.1 |
| 60 | 367.4 | Base | 24 | 242 | 0 | 632 | 40.9 |
| 59.9 | 375.4 | Storm | 34 | 244 | 0 | 642 | 58.9 |
| 58 | 502.6 | Storm | 34 | 324 | 0 | 849 | 77.8 |
| 56 | 552.3 | Storm | 34 | 499 | 0 | 1,074 | 98.5 |
| 54 | 615.5 | Storm | 34 | 537 | 0 | 1,175 | 107.8 |
| 52 | 745.4 | Storm | 34 | 555 | 0 | 1,322 | 121.3 |
| 50 | 911.1 | Storm | 34 | 650 | 0 | 1,584 | 145.2 |
| 48 | 1,069.1 | Storm | 34 | 878 | 0 | 1,970 | 180.6 |
| 46 | 1,168.6 | Storm | 34 | 1,000 | 0 | 2,191 | 200.9 |
| 44 | 1,340.8 | Storm | 34 | 1,000 | 0 | 2,363 | 216.7 |
| 42 | 1,629.5 | Storm | 34 | 1,000 | 0 | 2,652 | 243.2 |
| 40 | 2,017.3 | Storm | 34 | 1,000 | 0 | 3,040 | 278.7 |
| 38 | 2,489.1 | Storm | 34 | 1,000 | 0 | 3,511 | 322.0 |
| 36 | 2,811.4 | Storm | 34 | 1,000 | 0 | 3,834 | 351.5 |
| 34 | 3,421.3 | Storm | 34 | 1,000 | 0 | 4,444 | 407.5 |
| 32 | 3,947.6 | Storm | 34 | 1,000 | 0 | 4,970 | 455.7 |
| 30 | 4,350.5 | Storm | 34 | 1,000 | 0 | 5,373 | 492.7 |
| 28 | 5,273.2 | Storm | 34 | 1,000 | 0 | 6,296 | 577.3 |
| 26 | 6,496.4 | Storm | 34 | 1,000 | 0 | 7,519 | 689.4 |
| 24 | 7,158.0 | Storm | 34 | 1,000 | 0 | 8,180 | 750.1 |
| 22 | 8,519.2 | Storm | 34 | 1,000 | 0 | 9,542 | 874.9 |

| Percent exceedance for flow | Calculated ambient flow at downstream end of reach 11140302-002 (Lake WP releases + inflow d/s of dam) (cfs) | Flow Category | Target TSS (mg/L) | Upstream flow from Int'l Paper discharge (cfs) | Point source flow entering this reach (cfs) | Ambient flow + Int'l Paper discharge + point sources this reach + Days Crk PS (cfs) | TSS assimilative capacity, or TMDL (tons/day) |
|---|---|---|---|---|---|---|---|
| 20 | 9,425.9 | Storm | 34 | 1,000 | 0 | 10,448 | 958.1 |
| 18 | 9,766.4 | Storm | 34 | 1,000 | 0 | 10,789 | 989.3 |
| 16 | 9,974.6 | Storm | 34 | 1,000 | 0 | 10,997 | 1,008.4 |
| 14 | 10,134.7 | Storm | 34 | 1,000 | 0 | 11,157 | 1,023.0 |
| 12 | 10,279.8 | Storm | 34 | 1,000 | 0 | 11,302 | 1,036.3 |
| 10 | 10,444.7 | Storm | 34 | 1,000 | 0 | 11,467 | 1,051.5 |
| 9 | 10,544.6 | Storm | 34 | 1,000 | 0 | 11,567 | 1,060.6 |
| 8 | 10,677.1 | Storm | 34 | 1,000 | 0 | 11,700 | 1,072.8 |
| 7 | 10,805.3 | Storm | 34 | 1,000 | 0 | 11,828 | 1,084.5 |
| 6 | 10,955.1 | Storm | 34 | 1,000 | 0 | 11,978 | 1,098.3 |
| 5 | 11,181.5 | Storm | 34 | 1,000 | 0 | 12,204 | 1,119.0 |
| 4 | 11,385.4 | Storm | 34 | 1,000 | 0 | 12,408 | 1,137.7 |
| 3 | 11,682.8 | Storm | 34 | 1,000 | 0 | 12,705 | 1,165.0 |
| 2 | 12,305.1 | Storm | 34 | 1,000 | 0 | 13,327 | 1,222.1 |
| 1 | 13,567.4 | Storm | 34 | 1,000 | 0 | 14,590 | 1,337.8 |
| 0.5 | 14,975.9 | Storm | 34 | 1,000 | 0 | 15,998 | 1,466.9 |
| 0.1 | 19,072.3 | Storm | 34 | 1,000 | 0 | 20,095 | 1,842.6 |
| 0.01 | 26,413.5 | Storm | 34 | 1,000 | 0 | 27,436 | 2,515.7 |

FILE: R:\PROJECTS\3013-380\TECH\ADEQ_WQ_DATA\RED RIVER\RED0005 SULPHUR RIVER REVISED TMDL METHOD.XLSX

TABLE E.5 ALLOWABLE LOADS OF TSS FOR SULPHUR RIVER REACH 11140302-001

Turbidity: base flow criterion = 21 NTU; storm flow criterion = 32 NTU

Flow entering this reach from non-storm point sources to be included in WLA = 0 MGD

| Percent exceedance for flow | Calculated ambient flow at downstream end of reach 11140302-001 (Lake WP releases + inflow d/s of dam) (cfs) | Flow Category | Target TSS (mg/L) | Upstream flow from Int'l Paper discharge (cfs) | Point source flow entering this reach (cfs) | Ambient flow + Int'l Paper discharge + point sources this reach + Days Crk PS (cfs) | TSS assimilative capacity, or TMDL (tons/day) |
|---|---|---|---|---|---|---|---|
| 99.9 | 12.6 | Base | 24 | 0 | 0 | 35 | 2.3 |
| 99 | 16.9 | Base | 24 | 0 | 0 | 39 | 2.5 |
| 98 | 25.6 | Base | 24 | 0 | 0 | 48 | 3.1 |
| 96 | 52.4 | Base | 24 | 0 | 0 | 75 | 4.8 |
| 94 | 56.3 | Base | 24 | 52 | 0 | 131 | 8.5 |
| 92 | 87.8 | Base | 24 | 56 | 0 | 166 | 10.7 |
| 90 | 94.1 | Base | 24 | 87 | 0 | 204 | 13.2 |
| 88 | 110.1 | Base | 24 | 106 | 0 | 238 | 15.4 |
| 86 | 110.9 | Base | 24 | 108 | 0 | 241 | 15.6 |
| 84 | 112.1 | Base | 24 | 109 | 0 | 244 | 15.8 |
| 82 | 113.6 | Base | 24 | 110 | 0 | 246 | 15.9 |
| 80 | 115.2 | Base | 24 | 111 | 0 | 249 | 16.1 |
| 78 | 117.4 | Base | 24 | 113 | 0 | 253 | 16.4 |
| 76 | 123.2 | Base | 24 | 114 | 0 | 260 | 16.8 |
| 74 | 138.9 | Base | 24 | 116 | 0 | 277 | 18.0 |
| 72 | 164.8 | Base | 24 | 121 | 0 | 308 | 19.9 |
| 70 | 204.9 | Base | 24 | 131 | 0 | 359 | 23.2 |
| 68 | 225.9 | Base | 24 | 152 | 0 | 400 | 25.9 |
| 66 | 232.0 | Base | 24 | 211 | 0 | 465 | 30.1 |
| 64 | 253.6 | Base | 24 | 225 | 0 | 501 | 32.4 |
| 62 | 291.4 | Base | 24 | 229 | 0 | 543 | 35.1 |
| 60 | 369.9 | Base | 24 | 242 | 0 | 635 | 41.1 |
| 59.9 | 379.2 | Storm | 34 | 244 | 0 | 646 | 59.2 |
| 58 | 504.2 | Storm | 34 | 324 | 0 | 850 | 78.0 |
| 56 | 554.1 | Storm | 34 | 499 | 0 | 1,076 | 98.6 |
| 54 | 618.2 | Storm | 34 | 537 | 0 | 1,178 | 108.0 |
| 52 | 752.0 | Storm | 34 | 555 | 0 | 1,329 | 121.9 |
| 50 | 916.9 | Storm | 34 | 650 | 0 | 1,589 | 145.7 |
| 48 | 1,071.1 | Storm | 34 | 878 | 0 | 1,972 | 180.8 |
| 46 | 1,171.3 | Storm | 34 | 1,000 | 0 | 2,194 | 201.2 |
| 44 | 1,348.9 | Storm | 34 | 1,000 | 0 | 2,371 | 217.4 |
| 42 | 1,630.6 | Storm | 34 | 1,000 | 0 | 2,653 | 243.3 |
| 40 | 2,022.9 | Storm | 34 | 1,000 | 0 | 3,045 | 279.2 |
| 38 | 2,491.9 | Storm | 34 | 1,000 | 0 | 3,514 | 322.2 |
| 36 | 2,814.6 | Storm | 34 | 1,000 | 0 | 3,837 | 351.8 |
| 34 | 3,424.9 | Storm | 34 | 1,000 | 0 | 4,447 | 407.8 |
| 32 | 3,954.1 | Storm | 34 | 1,000 | 0 | 4,976 | 456.3 |
| 30 | 4,365.2 | Storm | 34 | 1,000 | 0 | 5,388 | 494.0 |
| 28 | 5,306.0 | Storm | 34 | 1,000 | 0 | 6,328 | 580.3 |
| 26 | 6,503.2 | Storm | 34 | 1,000 | 0 | 7,526 | 690.1 |
| 24 | 7,169.6 | Storm | 34 | 1,000 | 0 | 8,192 | 751.2 |
| 22 | 8,553.5 | Storm | 34 | 1,000 | 0 | 9,576 | 878.1 |

| Percent exceedance for flow | Calculated ambient flow at downstream end of reach 11140302-001 (Lake WP releases + inflow d/s of dam) (cfs) | Flow Category | Target TSS (mg/L) | Upstream flow from Int'l Paper discharge (cfs) | Point source flow entering this reach (cfs) | Ambient flow + Int'l Paper discharge + point sources this reach + Days Crk PS (cfs) | TSS assimilative capacity, or TMDL (tons/day) |
|---|---|---|---|---|---|---|---|
| 20 | 9,427.5 | Storm | 34 | 1,000 | 0 | 10,450 | 958.2 |
| 18 | 9,766.7 | Storm | 34 | 1,000 | 0 | 10,789 | 989.3 |
| 16 | 9,982.4 | Storm | 34 | 1,000 | 0 | 11,005 | 1,009.1 |
| 14 | 10,140.1 | Storm | 34 | 1,000 | 0 | 11,162 | 1,023.5 |
| 12 | 10,288.0 | Storm | 34 | 1,000 | 0 | 11,310 | 1,037.1 |
| 10 | 10,456.2 | Storm | 34 | 1,000 | 0 | 11,479 | 1,052.5 |
| 9 | 10,555.7 | Storm | 34 | 1,000 | 0 | 11,578 | 1,061.6 |
| 8 | 10,691.1 | Storm | 34 | 1,000 | 0 | 11,713 | 1,074.1 |
| 7 | 10,822.3 | Storm | 34 | 1,000 | 0 | 11,845 | 1,086.1 |
| 6 | 10,973.8 | Storm | 34 | 1,000 | 0 | 11,996 | 1,100.0 |
| 5 | 11,202.2 | Storm | 34 | 1,000 | 0 | 12,225 | 1,120.9 |
| 4 | 11,421.5 | Storm | 34 | 1,000 | 0 | 12,444 | 1,141.0 |
| 3 | 11,707.8 | Storm | 34 | 1,000 | 0 | 12,730 | 1,167.3 |
| 2 | 12,335.0 | Storm | 34 | 1,000 | 0 | 13,357 | 1,224.8 |
| 1 | 13,635.6 | Storm | 34 | 1,000 | 0 | 14,658 | 1,344.1 |
| 0.5 | 15,103.2 | Storm | 34 | 1,000 | 0 | 16,126 | 1,478.6 |
| 0.1 | 19,234.9 | Storm | 34 | 1,000 | 0 | 20,257 | 1,857.5 |
| 0.01 | 26,705.6 | Storm | 34 | 1,000 | 0 | 27,728 | 2,542.5 |

FILE: R:\PROJECTS\3013-380\TECH\ADEQ_WQ_DATA\RED RIVER\RED0005 SULPHUR RIVER REVISED TMDL METHOD.XLSX

TABLE E.6  EXISTING NPS LOADS OF TSS FOR SULPHUR RIVER REACH 11140302-006

Table of raw data for concentration and reach flow:

| Date | TSS from RED0005 (mg/L) | Flow at downstream end of reach 11140302-006 (cfs) | Hydraulic range |
|---|---|---|---|
| 1/10/2006 | 51.0 | 12.81652893 | low flows |
| 7/21/1998 | 49.5 | 13.58181818 | low flows |
| 8/11/1998 | 57.5 | 14.7553719 | low flows |
| 3/5/1996 | 41.0 | 17.74545455 | low flows |
| 1/2/1996 | 21.5 | 19.38842975 | low flows |
| 6/10/2003 | 57.7 | 22.81652893 | low flows |
| 7/27/1999 | 72.0 | 24.05619835 | low flows |
| 9/22/1998 | 43.0 | 36.81818182 | low flows |
| 4/2/1996 | 60.0 | 39.57355372 | low flows |
| 10/18/2005 | 33.8 | 52.08214876 | low flows |
| 12/13/2005 | 17.8 | 52.64297521 | low flows |
| 11/15/2005 | 51.2 | 53.12661157 | low flows |
| 8/30/2005 | 75.0 | 54.65719008 | low flows |
| 7/26/2005 | 75.5 | 54.75107438 | low flows |
| 6/28/2005 | 72.0 | 55.86842975 | low flows |
| 9/27/2005 | 46.2 | 57.22479339 | low flows |
| 5/17/2005 | 48.8 | 63.98016529 | low flows |
| 3/14/2006 | 61.2 | 77.99173554 | low flows |
| 2/13/1996 | 37.5 | 79.91900826 | low flows |
| 10/3/2006 | 46.2 | 87.14552066 | low flows |
| 10/31/2006 | 47.5 | 87.37553719 | low flows |
| 12/19/2006 | 54.8 | 88.20628099 | dry cond. |
| 9/5/2006 | 48.0 | 89.30512397 | dry cond. |
| 8/1/2006 | 66.2 | 90.42247934 | dry cond. |
| 12/3/2002 | 18.2 | 106.1593388 | dry cond. |
| 1/18/2000 | 52.0 | 108.0512397 | dry cond. |
| 10/24/2000 | 49.5 | 108.2581818 | dry cond. |
| 2/15/2000 | 42 | 108.3471074 | dry cond. |
| 12/16/2003 | 33.0 | 108.9900826 | dry cond. |
| 9/21/2004 | 95.6 | 109.0305124 | dry cond. |
| 9/28/1999 | 51.5 | 109.218281 | dry cond. |
| 12/14/1999 | 48 | 109.3471074 | dry cond. |
| 11/4/2008 | 47.0 | 109.4224793 | dry cond. |
| 10/15/2007 | 49.2 | 109.4459504 | dry cond. |
| 10/12/1999 | 64.0 | 109.4694215 | dry cond. |
| 9/7/1993 | 46 | 110.328595 | dry cond. |
| 10/1/2002 | 67.5 | 110.328595 | dry cond. |
| 9/26/2000 | 60.0 | 110.3520661 | dry cond. |
| 11/16/1999 | 45.5 | 110.5818182 | dry cond. |
| 10/12/1993 | 46 | 110.6102479 | dry cond. |
| 3/27/2007 | 74.2 | 111.1239669 | dry cond. |
| 11/18/2003 | 86.7 | 111.1636364 | dry cond. |
| 9/15/1997 | 50.0 | 111.2112397 | dry cond. |
| 9/23/2003 | 45.0 | 111.3001653 | dry cond. |
| 9/11/2007 | 46.1 | 111.305124 | dry cond. |
| 8/31/1999 | 39.0 | 111.4459504 | dry cond. |

| Average TSS conc. w/in each zone (mg/L) | |
|---|---|
| low flows | 51 |
| dry cond. | 54 |
| mid-range | 43 |
| moist cond. | 27 |
| high flows | 11 |

Table of raw data for concentration and reach flow:

| Date | TSS from RED0005 (mg/L) | Flow at downstream end of reach 11140302-006 (cfs) | Hydraulic range |
|---|---|---|---|
| 9/3/2002 | 46.3 | 111.5163636 | dry cond. |
| 8/29/2000 | 55.0 | 112.1877686 | dry cond. |
| 8/17/2004 | 69.6 | 112.4694215 | dry cond. |
| 11/19/2001 | 60.0 | 113.7966942 | dry cond. |
| 7/11/2006 | 55.8 | 114.5163636 | dry cond. |
| 7/13/1993 | 37 | 114.8684298 | dry cond. |
| 9/18/1995 | 56.5 | 114.9289256 | dry cond. |
| 7/27/2004 | 91.5 | 115.5490909 | dry cond. |
| 8/7/1995 | 62.0 | 115.5867769 | dry cond. |
| 6/13/2006 | 48.9 | 115.6571901 | dry cond. |
| 8/20/1991 | 27.5 | 116.5206612 | dry cond. |
| 8/12/2008 | 75.3 | 118.2247934 | dry cond. |
| 5/6/2003 | 52.3 | 119.092562 | dry cond. |
| 9/1/2008 | 56.8 | 119.6330579 | dry cond. |
| 8/12/2003 | 49.3 | 120.4495868 | dry cond. |
| 7/15/2003 | 64.0 | 121.9801653 | dry cond. |
| 5/14/1996 | 61.0 | 123.6 | dry cond. |
| 7/1/2002 | 53.3 | 123.6842975 | dry cond. |
| 5/19/1992 | 36 | 123.6958678 | dry cond. |
| 5/25/2004 | 87.9 | 127.1438017 | dry cond. |
| 5/16/2006 | 51.5 | 132.1950413 | dry cond. |
| 5/18/1999 | 40.5 | 141.9305785 | dry cond. |
| 7/16/1996 | 44.0 | 142.3768595 | dry cond. |
| 5/5/1998 | 68.0 | 148.7785124 | dry cond. |
| 2/3/2009 | 28.5 | 152.6561983 | dry cond. |
| 4/27/2004 | 53.5 | 155.9421488 | dry cond. |
| 11/16/2004 | 80.0 | 159.0446281 | dry cond. |
| 2/12/2008 | 107 | 166.738843 | dry cond. |
| 8/10/1993 | 76 | 167.2793388 | dry cond. |
| 1/27/2004 | 51.8 | 169.5454545 | dry cond. |
| 5/15/2007 | 15.8 | 207.0677686 | dry cond. |
| 3/30/2004 | 61.9 | 216.4975207 | dry cond. |
| 12/4/2007 | 33.0 | 222.3371901 | dry cond. |
| 9/26/1994 | 53.5 | 224.1197025 | dry cond. |
| 8/21/2001 | 49.5 | 224.938843 | dry cond. |
| 8/25/1997 | 59.5 | 226.9153719 | dry cond. |
| 8/6/2002 | 60.0 | 227.0327273 | dry cond. |
| 11/9/1992 | 26 | 227.7057851 | dry cond. |
| 7/18/1995 | 55.0 | 231.5256198 | dry cond. |
| 1/15/2008 | 40.5 | 237.3586777 | dry cond. |
| 6/27/1994 | 87.0 | 238.9190083 | dry cond. |
| 12/8/2008 | 32.0 | 245.2264463 | dry cond. |
| 9/24/1996 | 55.0 | 275.6231405 | dry cond. |
| 10/16/1995 | 78.0 | 341.2112397 | mid-range |
| 8/15/1994 | 67.5 | 343.3983471 | mid-range |
| 4/11/2006 | 41.2 | 355.6033058 | mid-range |
| 4/26/2005 | 41.2 | 389.3487603 | mid-range |
| 10/15/1991 | 36 | 396.4082645 | mid-range |
| 11/14/1995 | 21.5 | 404.328595 | mid-range |

Table of raw data for concentration and reach flow:

| Date | TSS from RED0005 (mg/L) | Flow at downstream end of reach 11140302-006 (cfs) | Hydraulic range |
|---|---|---|---|
| 3/26/1991 | 39 | 429.7487603 | mid-range |
| 11/29/1994 | 23.0 | 470.338843 | mid-range |
| 2/20/2007 | 39.8 | 480.7735537 | mid-range |
| 11/28/1995 | 17.5 | 501.2112397 | mid-range |
| 10/21/2003 | 37.5 | 508.8919008 | mid-range |
| 11/13/2007 | 52.2 | 520.1123967 | mid-range |
| 10/2/1990 | 54 | 523.3143802 | mid-range |
| 2/4/2003 | 44.8 | 526.246281 | mid-range |
| 9/4/1990 | 18 | 534.4459504 | mid-range |
| 6/29/1993 | 40.0 | 539.8181818 | mid-range |
| 7/16/1991 | 38 | 544.3471074 | mid-range |
| 7/14/1997 | 64.0 | 545.2247934 | mid-range |
| 7/25/2000 | 106.5 | 545.2347107 | mid-range |
| 7/15/2008 | 48.0 | 547.7980165 | mid-range |
| 7/14/2009 | 85.3 | 548.3755372 | mid-range |
| 7/17/2001 | 68.5 | 549.2859504 | mid-range |
| 6/17/2008 | 65.0 | 556.9289256 | mid-range |
| 1/6/2009 | 33.5 | 560.8909091 | mid-range |
| 9/15/1992 | 28 | 561.0429752 | mid-range |
| 3/29/2005 | 39.2 | 567.7669421 | mid-range |
| 4/24/2007 | 48.5 | 587.3090909 | mid-range |
| 6/11/1996 | 53.0 | 596.9239669 | mid-range |
| 6/4/2002 | 51.5 | 616.1884298 | mid-range |
| 4/8/2003 | 46.0 | 652.6727273 | mid-range |
| 10/26/2004 | 43.7 | 733.9603306 | mid-range |
| 1/31/2006 | 28.0 | 739.8396694 | mid-range |
| 10/30/1990 | 28 | 1023.633058 | mid-range |
| 10/21/1997 | 49.0 | 1040.694215 | mid-range |
| 12/10/1991 | 15 | 1070.512397 | mid-range |
| 9/30/2008 | 39.0 | 1093.581818 | mid-range |
| 9/17/1991 | 43 | 1097.877686 | mid-range |
| 1/28/1997 | 36.5 | 1104.818182 | mid-range |
| 6/18/1991 | 43 | 1158.490909 | mid-range |
| 4/21/1992 | 37 | 1165.634711 | mid-range |
| 4/14/2009 | 64.0 | 1177.742149 | mid-range |
| 6/2/1998 | 26.0 | 1256.454545 | mid-range |
| 1/26/1999 | 9.5 | 1278.730579 | mid-range |
| 10/13/1992 | 34 | 1388.854215 | mid-range |
| 2/22/2005 | 31.3 | 1465.86281 | mid-range |
| 9/18/2001 | 51.5 | 1679.561983 | mid-range |
| 2/24/2004 | 19.0 | 1770.173554 | mid-range |
| 4/18/1994 | 32.5 | 1959.128926 | moist cond. |
| 10/24/1994 | 29.5 | 2037.81157 | moist cond. |
| 12/11/2001 | 19.5 | 2168.066116 | moist cond. |
| 10/22/1996 | 48.0 | 2244.239669 | moist cond. |
| 5/21/2002 | 57.5 | 2259.446281 | moist cond. |
| 2/14/1994 | 32.5 | 2307.900826 | moist cond. |
| 3/21/2000 | 31 | 2442.003306 | moist cond. |
| 7/18/1994 | 56.5 | 2549.666116 | moist cond. |

Table of raw data for concentration and reach flow:

| Date | TSS from RED0005 (mg/L) | Flow at downstream end of reach 11140302-006 (cfs) | Hydraulic range |
|---|---|---|---|
| 3/31/2009 | 45.0 | 2599.958678 | moist cond. |
| 11/27/1990 | 36 | 2631.583471 | moist cond. |
| 12/18/2000 | 5.5 | 2678.165289 | moist cond. |
| 4/7/1998 | 22.5 | 2695.272727 | moist cond. |
| 6/19/1995 | 48.5 | 2893.990083 | moist cond. |
| 5/17/1993 | 25 | 3044.370248 | moist cond. |
| 6/16/1997 | 27.0 | 3207.363636 | moist cond. |
| 8/20/1996 | 39.0 | 3227.378512 | moist cond. |
| 11/17/1998 | 28.0 | 3623.821488 | moist cond. |
| 6/12/2007 | 37.3 | 3657.796694 | moist cond. |
| 12/16/1997 | 20.0 | 3658.963636 | moist cond. |
| 10/27/1998 | 30.0 | 3697.928926 | moist cond. |
| 12/8/1992 | 22 | 3849.72562 | moist cond. |
| 4/18/2000 | 33 | 3970.667769 | moist cond. |
| 12/7/2004 | 22.2 | 3976.429752 | moist cond. |
| 7/21/1992 | 14 | 3986.755372 | moist cond. |
| 5/4/1993 | 28 | 4037.717355 | moist cond. |
| 9/29/2009 | 45.5 | 4095.553719 | moist cond. |
| 6/16/1992 | 4 | 4139.252893 | moist cond. |
| 6/29/2004 | 33.8 | 4459.785124 | moist cond. |
| 10/23/2001 | 21.8 | 5426 | moist cond. |
| 5/23/1994 | 27.0 | 5510.312397 | moist cond. |
| 2/19/1991 | 42 | 5697.652893 | moist cond. |
| 2/23/1993 | 32 | 6295.434711 | moist cond. |
| 11/5/2002 | 27.5 | 6303.980165 | moist cond. |
| 1/25/1994 | 19.5 | 6308.578512 | moist cond. |
| 11/14/2000 | 16.5 | 6497.604959 | moist cond. |
| 1/7/2003 | 17.8 | 6610.404959 | moist cond. |
| 1/25/2005 | 102 | 6656.968595 | moist cond. |
| 8/4/2009 | 57.2 | 7033.145455 | moist cond. |
| 3/23/1999 | 24.0 | 7477.53719 | moist cond. |
| 2/25/1992 | 24 | 7602.51405 | moist cond. |
| 2/13/1995 | 9 | 8084.117355 | moist cond. |
| 3/19/2002 | 14.5 | 8127.85124 | moist cond. |
| 5/23/2000 | 38.5 | 8137.404959 | moist cond. |
| 3/11/2008 | 60.0 | 8553.446281 | moist cond. |
| 11/19/1996 | 14.5 | 9083.504132 | moist cond. |
| 11/9/1993 | 6 | 9328.502149 | moist cond. |
| 8/18/1992 | 16 | 9583.337851 | moist cond. |
| 6/15/2009 | 9.0 | 9631.01157 | moist cond. |
| 11/12/1991 | 72 | 9728.806612 | moist cond. |
| 5/26/2009 | 5.8 | 9766.476033 | moist cond. |
| 6/19/2001 | 6.8 | 9803.973554 | moist cond. |
| 4/1/2008 | 6.5 | 9822.555372 | moist cond. |
| 2/19/2002 | 4.5 | 9822.793388 | moist cond. |
| 5/6/2008 | 7.5 | 9863.500826 | moist cond. |
| 2/16/1999 | 17.5 | 9923.590083 | moist cond. |
| 5/12/1997 | 15.0 | 9973.758678 | moist cond. |
| 12/21/1993 | 10.5 | 9973.81157 | moist cond. |

Table of raw data for concentration and reach flow:

| Date | TSS from RED0005 (mg/L) | Flow at downstream end of reach 11140302-006 (cfs) | Hydraulic range |
|---|---|---|---|
| 5/22/1995 | 10.5 | 10016.89917 | moist cond. |
| 1/21/1992 | 22 | 10045.40331 | moist cond. |
| 12/21/1998 | 11.5 | 10075.52397 | moist cond. |
| 12/17/1996 | 6.5 | 10103.47769 | moist cond. |
| 1/27/1998 | 6.0 | 10125.52066 | high flows |
| 4/14/1997 | 4.5 | 10161.83471 | high flows |
| 11/17/2009 | 7.5 | 10204.92397 | high flows |
| 12/8/2009 | 8.0 | 10205.08264 | high flows |
| 4/24/1995 | 15.5 | 10244.09917 | high flows |
| 3/3/2003 | 13.5 | 10269.66942 | high flows |
| 1/26/1993 | 16 | 10280.19835 | high flows |
| 5/21/1991 | 12 | 10316.8595 | high flows |
| 1/29/2001 | 16.0 | 10359.2314 | high flows |
| 3/14/1994 | 12.0 | 10398.43802 | high flows |
| 3/23/1993 | 26 | 10401.07438 | high flows |
| 3/17/1992 | 16 | 10420.13223 | high flows |
| 4/16/2002 | 13.5 | 10481.41322 | high flows |
| 3/3/1998 | 9.0 | 10485.07438 | high flows |
| 1/2/2002 | 13.0 | 10489.30413 | high flows |
| 1/26/2010 | 3.0 | 10543.59504 | high flows |
| 1/22/1991 | 23 | 10599.10744 | high flows |
| 7/17/2007 | 0.5 | 10602.24132 | high flows |
| 2/25/1997 | 18.5 | 10643.10744 | high flows |
| 2/26/2001 | 6.0 | 10701.09091 | high flows |
| 2/9/2010 | 3.0 | 10722.55372 | high flows |
| 1/23/2007 | 12.5 | 10789.36364 | high flows |
| 4/16/2001 | 7.0 | 10862.24793 | high flows |
| 12/20/1994 | 9.5 | 10933.24793 | high flows |
| 3/27/2001 | 2.2 | 10990.47107 | high flows |

FILE: R:\PROJECTS\3013-380\TECH\ADEQ_WQ_DATA\RED RIVER\RED0005 SULPHUR RIVER REVISED TMDL METHOD.XLSX

## TABLE E.7 COMPONENTS OF TMDL FOR TSS/TURBIDITY FOR SULPHUR RIVER REACH 11140302-008

Calculations for diffuse loads:

Existing diffuse load = (Ambient flow at d/s end of reach for min. flow w/in hydrol. zone) × (Average existing conc.)

Allowable diffuse load = (Ambient flow at d/s end of reach for min. flow w/in hydrol. zone) × MIN (Average existing conc., Criterion)

Calculations for dividing regulated and non-regulated diffuse loads:

Tot. drain. area for regul. stormwater = 7 facilities × 40 ac each = 280 ac

Tot. drain. area for reach 11140302-008 = 3,479 sq. mi. = 2,226,560 ac

Drainage area for regul. stormwater as percent of total drainage area = 0.01%

--> WLA for regulated stormwater = 0.01% of allowable load from diffuse sources

--> LA for non-regulated diffuse sources = 99.99% of allowable load from diffuse sources

Calculations for non-storm point sources:

Sum of design flows for non-storm point sources for this reach (cfs) = 0 MGD = 0.00 cfs

Effluent concentration is set manually so that allocated loads (Σ WLA + LA) do not exceed TMDL

WLA for non-storm point sources = Sum of design flows × effluent concentration × converstion factor

Load reserved for future growth = TMDL – LA for non-regulated diffuse sources – WLA for regulated stormwater – WLA for non-storm point sources

| | High flows | Moist cond. | Mid-range | Dry cond. | Low flows |
|---|---|---|---|---|---|
| Ambient (includ. upstream) ambient flow at d/s end of reach from Table E.1 for minimum flow within each hydrologic range (cfs) = | 11019 | 2767 | 488 | 174 | 11 |

**TMDL COMPONENTS**

| | High flows | Moist cond. | Mid-range | Dry cond. | Low flows |
|---|---|---|---|---|---|
| Average existing concentration from Table E.6 (mg/L) = | 11 | 27 | 43 | 54 | 51 |
| Existing load from diffuse sources (tons/day) = | 326.89 | 201.49 | 56.60 | 25.37 | 1.49 |
| Allowable load from diffuse sources (tons/day) = | 326.89 | 201.49 | 44.76 | 11.27 | 0.70 |
| | | | | | |
| LA for non-regulated diffuse sources (tons/day) = | 326.85 | 201.46 | 44.75 | 11.26 | 0.69 |
| WLA for regulated stormwater (tons/day) = | 0.04 | 0.03 | 0.01 | 0.01 | 0.01 |
| | | | | | |
| Effluent conc. for non-storm point sources (mg/L) = | 0 | 0 | 0 | 0 | 0 |
| WLA for non-storm point sources (tons/day) = | 0 | 0 | 0 | 0 | 0 |
| | | | | | |
| Load reserved for future growth (tons/day) = | 683.49 | 52.24 | 0 | 0 | 0 |
| TMDL from Table E.1 (tons/day) | 1010.38 | 253.73 | 44.76 | 11.27 | 0.70 |
| Error check: Sum of WLAs + LA + FG ≤ TMDL? | ok | ok | ok | ok | ok |

FILE: R:\PROJECTS\3013-380\TECH\ADEQ_WQ_DATA\RED RIVER\RED0005 SULPHUR RIVER REVISED TMDL METHOD.XLSX

TABLE E.8 COMPONENTS OF TMDL FOR TSS/TURBIDITY FOR SULPHUR RIVER REACH 11140302-006

Calculations for diffuse loads:

Existing diffuse load = (Ambient flow at d/s end of reach for min. flow w/in hydrol. zone) × (Average existing conc.)

Allowable diffuse load = (Ambient flow at d/s end of reach for min. flow w/in hydrol. zone) × MIN (Average existing conc., Criterion)

Calculations for dividing regulated and non-regulated diffuse loads:

| | | | | |
|---|---|---|---|---|
| Tot. drain. area for regul. stormwater = 4 facilities × 40 ac each = | | | 160 | ac |
| Tot. drain. area for reach 11140302-006 = | 3,542 | sq. mi. = | 2,266,880 | ac |
| Drainage area for regul. stormwater as percent of total drainage area = | | | 0.01% | |

--> WLA for regulated stormwater = 0.01% of allowable load from diffuse sources

--> LA for non-regulated diffuse sources = 99.99% of allowable load from diffuse sources

Calculations for non-storm point sources:

Sum of design flows for non-storm point sources for this reach (cfs) = 0 MGD = 0.00 cfs

Effluent concentration is set manually so that allocated loads (Σ WLA + LA) do not exceed TMDL

WLA for non-storm point sources = Sum of design flows × effluent concentration × converstion factor

Load reserved for future growth = TMDL – LA for non-regulated diffuse sources – WLA for regulated stormwater – WLA for non-storm point sources

| | High flows | Moist cond. | Mid-range | Dry cond. | Low flows |
|---|---|---|---|---|---|
| Ambient (includ. upstream) ambient flow at d/s end of reach from Table E.2 for minimum flow within each hydrologic range (cfs) = | 11119 | 2819 | 524 | 175 | 12 |

**TMDL COMPONENTS**

| | High flows | Moist cond. | Mid-range | Dry cond. | Low flows |
|---|---|---|---|---|---|
| Average existing concentration from Table E.6 (mg/L) = | 11 | 27 | 43 | 54 | 51 |
| Existing load from diffuse sources (tons/day) = | 329.85 | 205.30 | 60.76 | 25.51 | 1.58 |
| Allowable load from diffuse sources (tons/day) = | 329.85 | 205.30 | 48.04 | 11.34 | 0.75 |
| LA for non-regulated diffuse sources (tons/day) = | 329.81 | 205.27 | 48.03 | 11.33 | 0.74 |
| WLA for regulated stormwater (tons/day) = | 0.04 | 0.03 | 0.01 | 0.01 | 0.01 |
| Effluent conc. for non-storm point sources (mg/L) = | 0 | 0 | 0 | 0 | 0 |
| WLA for non-storm point sources (tons/day) = | 0 | 0 | 0 | 0 | 0 |
| Load reserved for future growth (tons/day) = | 689.69 | 53.23 | 0 | 0 | 0 |
| TMDL from Table E.2 (tons/day) | 1019.54 | 258.53 | 48.04 | 11.34 | 0.75 |
| Error check: Sum of WLAs + LA + FG ≤ TMDL? | ok | ok | ok | ok | ok |

FILE: R:\PROJECTS\3013-380\TECH\ADEQ_WQ_DATA\RED RIVER\RED0005 SULPHUR RIVER REVISED TMDL METHOD.XLSX

TABLE E.9 COMPONENTS OF TMDL FOR TSS/TURBIDITY FOR SULPHUR RIVER REACH 11140302-004

Calculations for diffuse loads:

Existing diffuse load = (Ambient flow at d/s end of reach for min. flow w/in hydrol. zone) × (Average existing conc.)

Allowable diffuse load = (Ambient flow at d/s end of reach for min. flow w/in hydrol. zone) × MIN (Average existing conc., Criterion)

Calculations for dividing regulated and non-regulated diffuse loads:

Tot. drain. area for regul. stormwater = 0 facilities × 40 ac each = 0 ac

Tot. drain. area for reach 11140302-004 = 3,563 sq. mi. = 2,280,320 ac

Drainage area for regul. stormwater as percent of total drainage area = 0.00%

--> WLA for regulated stormwater = 0.00% of allowable load from diffuse sources

--> LA for non-regulated diffuse sources = 100.00% of allowable load from diffuse sources

Calculations for non-storm point sources:

Sum of design flows for non-storm point sources for this reach (cfs) = 0 MGD = 0.00 cfs

Effluent concentration is set manually so that allocated loads (Σ WLA + LA) do not exceed TMDL

WLA for non-storm point sources = Sum of design flows × effluent concentration × converstion factor

Load reserved for future growth = TMDL – LA for non-regulated diffuse sources – WLA for regulated stormwater – WLA for non-storm point sources

| | High flows | Moist cond. | Mid-range | Dry cond. | Low flows |
|---|---|---|---|---|---|
| Ambient (includ. upstream) ambient flow at d/s end of reach from Table E.3 for minimum flow within each hydrologic range (cfs) = | 11156 | 2850 | 541 | 175 | 12 |

**TMDL COMPONENTS**

| | High flows | Moist cond. | Mid-range | Dry cond. | Low flows |
|---|---|---|---|---|---|
| Average existing concentration from Table E.6 (mg/L) = | 11 | 27 | 43 | 54 | 51 |
| Existing load from diffuse sources (tons/day) = | 330.96 | 207.51 | 62.73 | 25.53 | 1.60 |
| Allowable load from diffuse sources (tons/day) = | 330.96 | 207.51 | 49.60 | 11.35 | 0.75 |
| LA for non-regulated diffuse sources (tons/day) = | 330.96 | 207.51 | 49.60 | 11.35 | 0.75 |
| WLA for regulated stormwater (tons/day) = | 0 | 0 | 0 | 0 | 0 |
| Effluent conc. for non-storm point sources (mg/L) = | 0 | 0 | 0 | 0 | 0 |
| WLA for non-storm point sources (tons/day) = | 0 | 0 | 0 | 0 | 0 |
| Load reserved for future growth (tons/day) = | 692.00 | 53.80 | 0 | 0 | 0 |
| TMDL from Table E.3 (tons/day) | 1022.96 | 261.31 | 49.60 | 11.35 | 0.75 |
| Error check: Sum of WLAs + LA + FG ≤ TMDL? | ok | ok | ok | ok | ok |

FILE: R:\PROJECTS\3013-380\TECH\ADEQ_WQ_DATA\RED RIVER\RED0005 SULPHUR RIVER REVISED TMDL METHOD.XLSX

TABLE E.10 COMPONENTS OF TMDL FOR TSS/TURBIDITY FOR SULPHUR RIVER REACH 11140302-002

Calculations for diffuse loads:

Existing diffuse load = (Ambient flow at d/s end of reach for min. flow w/in hydrol. zone) × (Average existing conc.)

Allowable diffuse load = (Ambient flow at d/s end of reach for min. flow w/in hydrol. zone) × MIN (Average existing conc., Criterion)

Calculations for dividing regulated and non-regulated diffuse loads:

Tot. drain. area for regul. stormwater = 1 facilities × 40 ac each = 40 ac

Tot. drain. area for reach 11140302-002 = 3,742 sq. mi. = 2,394,880 ac

Drainage area for regul. stormwater as percent of total drainage area = 0.002%

--> WLA for regulated stormwater = 0.002% of allowable load from diffuse sources

--> LA for non-regulated diffuse sources = 99.998% of allowable load from diffuse sources

Calculations for non-storm point sources:

Sum of design flows for non-storm point sources for this reach (cfs) = 0 MGD = 0.00 cfs

Effluent concentration is set manually so that allocated loads (Σ WLA + LA) do not exceed TMDL

WLA for non-storm point sources = Sum of design flows × effluent concentration × converstion factor

Load reserved for future growth = TMDL – LA for non-regulated diffuse sources – WLA for regulated stormwater – WLA for non-storm point sources

| | High flows | Moist cond. | Mid-range | Dry cond. | Low flows |
|---|---|---|---|---|---|
| Ambient (includ. upstream) ambient flow at d/s end of reach from Table E.4 for minimum flow within each hydrologic range (cfs) = | 11467 | 3040 | 642 | 203 | 35 |

**TMDL COMPONENTS**

| | High flows | Moist cond. | Mid-range | Dry cond. | Low flows |
|---|---|---|---|---|---|
| Average existing concentration from Table E.6 (mg/L) = | 11 | 27 | 43 | 54 | 51 |
| Existing load from diffuse sources (tons/day) = | 340.18 | 221.34 | 74.43 | 29.62 | 4.80 |
| Allowable load from diffuse sources (tons/day) = | 340.18 | 221.34 | 58.85 | 13.17 | 2.26 |
| LA for non-regulated diffuse sources (tons/day) = | 340.17 | 221.33 | 58.84 | 13.16 | 2.25 |
| WLA for regulated stormwater (tons/day) = | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| Effluent conc. for non-storm point sources (mg/L) = | 0 | 0 | 0 | 0 | 0 |
| WLA for non-storm point sources (tons/day) = | 0 | 0 | 0 | 0 | 0 |
| Load reserved for future growth (tons/day) = | 711.28 | 57.38 | 0 | 0 | 0 |
| TMDL from Table E.4 (tons/day) | 1051.46 | 278.72 | 58.85 | 13.17 | 2.26 |
| Error check: Sum of WLAs + LA + FG ≤ TMDL? | ok | ok | ok | ok | ok |

FILE: R:\PROJECTS\3013-380\TECH\ADEQ_WQ_DATA\RED RIVER\RED0005 SULPHUR RIVER REVISED TMDL METHOD.XLSX

## TABLE E.11 COMPONENTS OF TMDL FOR TSS/TURBIDITY FOR SULPHUR RIVER REACH 11140302-001

Calculations for diffuse loads:

Existing diffuse load = (Ambient flow at d/s end of reach for min. flow w/in hydrol. zone) × (Average existing conc.)

Allowable diffuse load = (Ambient flow at d/s end of reach for min. flow w/in hydrol. zone) × MIN (Average existing conc., Criterion)

Calculations for dividing regulated and non-regulated diffuse loads:

Tot. drain. area for regul. stormwater = 0 facilities × 40 ac each = 0 ac

Tot. drain. area for reach 11140302-001 = 3,748 sq. mi. = 2,398,720 ac

Drainage area for regul. stormwater as percent of total drainage area = 0.00%

--> WLA for regulated stormwater = 0.00% of allowable load from diffuse sources

--> LA for non-regulated diffuse sources = 100.00% of allowable load from diffuse sources

Calculations for non-storm point sources:

Sum of design flows for non-storm point sources for this reach (cfs) = 0 MGD = 0.00 cfs

Effluent concentration is set manually so that allocated loads (Σ WLA + LA) do not exceed TMDL

WLA for non-storm point sources = Sum of design flows × effluent concentration × converstion factor

Load reserved for future growth = TMDL – LA for non-regulated diffuse sources – WLA for regulated stormwater – WLA for non-storm point sources

| | High flows | Moist cond. | Mid-range | Dry cond. | Low flows |
|---|---|---|---|---|---|
| Ambient (includ. upstream) ambient flow at d/s end of reach from Table E.5 for minimum flow within each hydrologic range (cfs) = | 11479 | 3045 | 646 | 204 | 35 |

**TMDL COMPONENTS**

| | High flows | Moist cond. | Mid-range | Dry cond. | Low flows |
|---|---|---|---|---|---|
| Average existing concentration from Table E.6 (mg/L) = | 11 | 27 | 43 | 54 | 51 |
| Existing load from diffuse sources (tons/day) = | 340.52 | 221.75 | 74.87 | 29.64 | 4.81 |
| Allowable load from diffuse sources (tons/day) = | 340.52 | 221.75 | 59.20 | 13.18 | 2.26 |
| LA for non-regulated diffuse sources (tons/day) = | 340.52 | 221.75 | 59.20 | 13.18 | 2.26 |
| WLA for regulated stormwater (tons/day) = | 0 | 0 | 0 | 0 | 0 |
| Effluent conc. for non-storm point sources (mg/L) = | 0 | 0 | 0 | 0 | 0 |
| WLA for non-storm point sources (tons/day) = | 0 | 0 | 0 | 0 | 0 |
| Load reserved for future growth (tons/day) = | 712.00 | 57.49 | 0 | 0 | 0 |
| TMDL from Table E.5 (tons/day) | 1052.52 | 279.24 | 59.20 | 13.18 | 2.26 |
| Error check: Sum of WLAs + LA + FG ≤ TMDL? | ok | ok | ok | ok | ok |

FILE: R:\PROJECTS\3013-380\TECH\ADEQ_WQ_DATA\RED RIVER\RED0005 SULPHUR RIVER REVISED TMDL METHOD.XLSX

**Figure E.1 Flow Duration Curve for Sulphur River Reach 11140302-001**

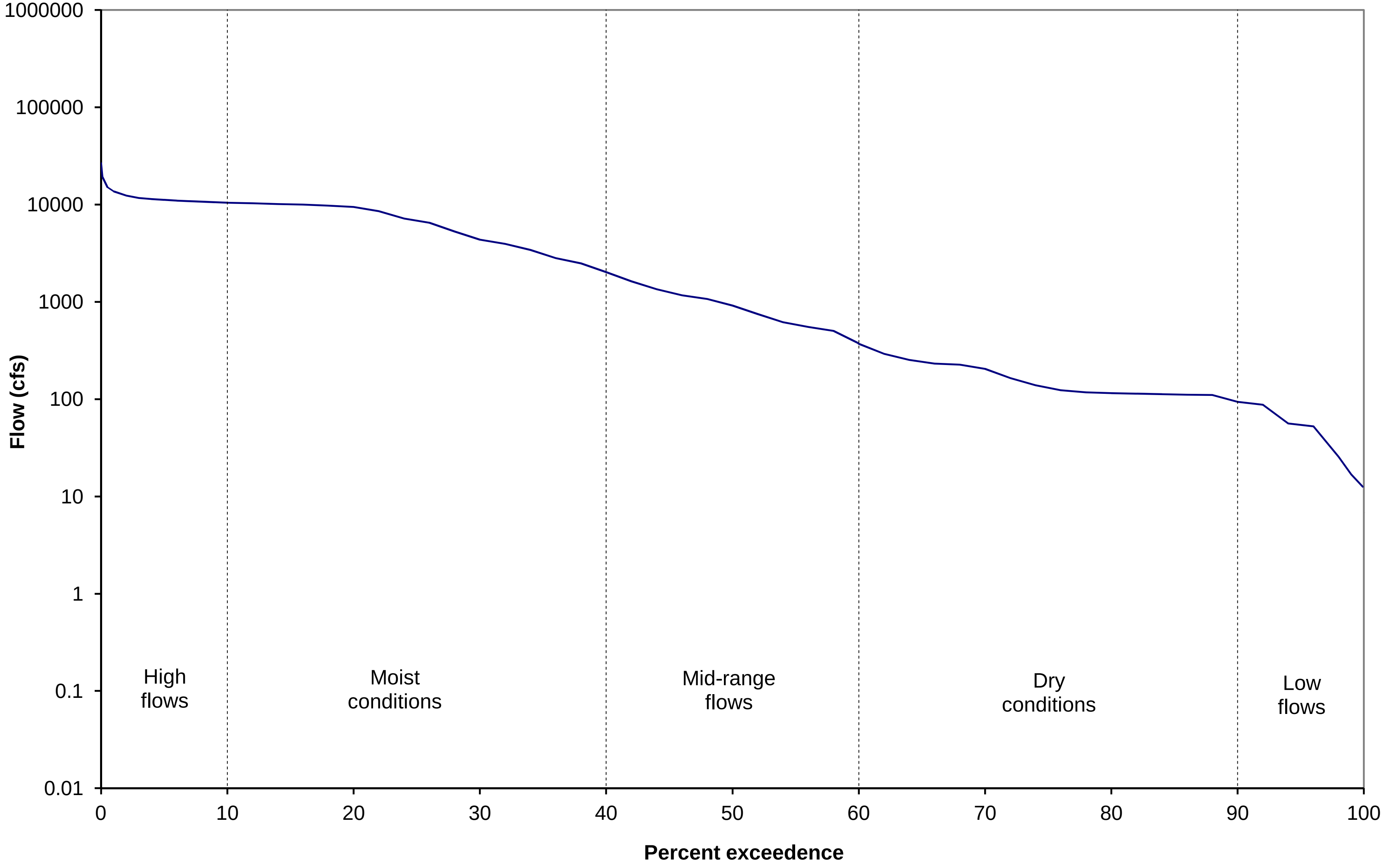


**Figure E.2 TSS Load Duration Curve for Sulphur River Reach 11140302-008**

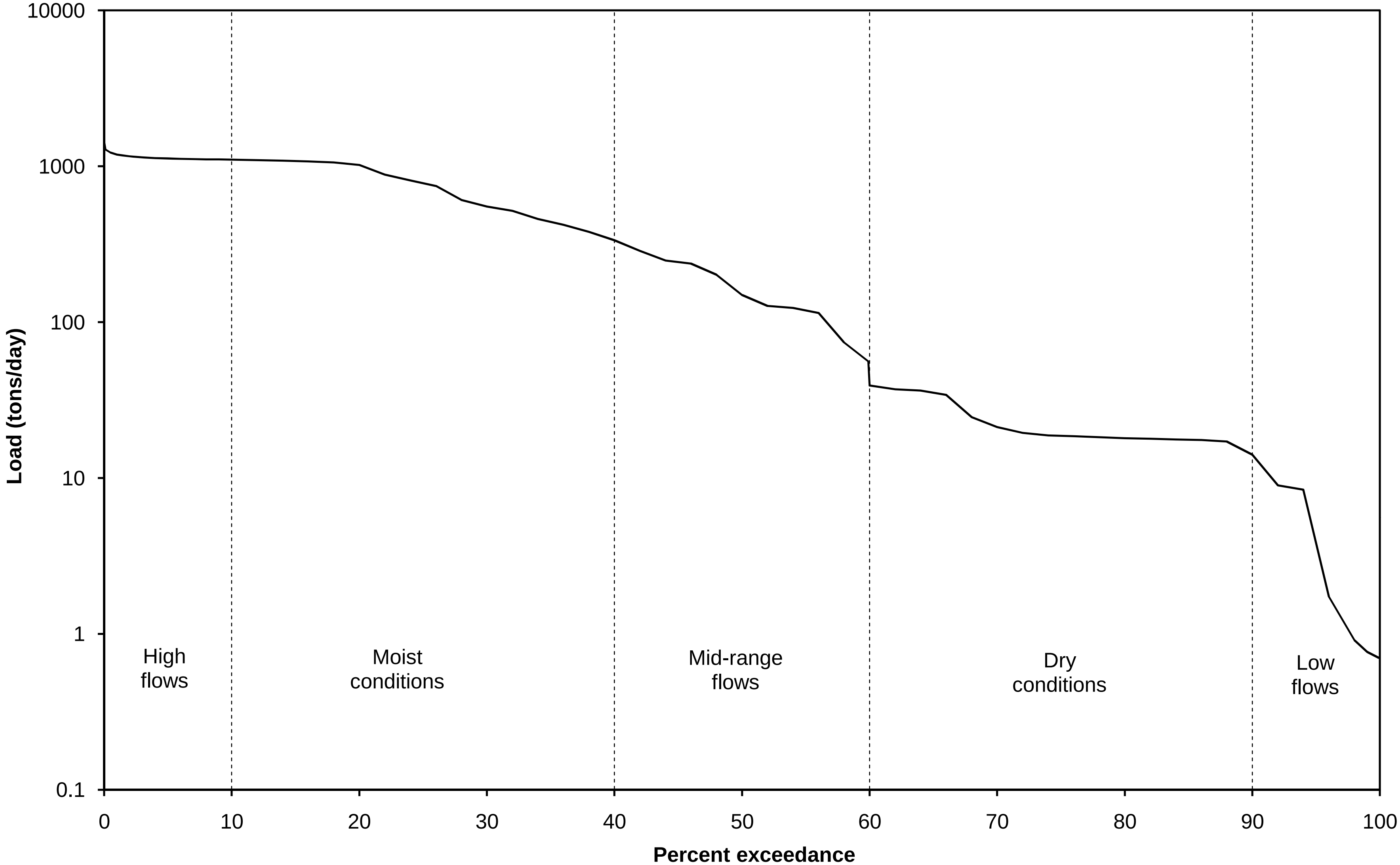


**Figure E.3 TSS Load Duration Curve for Sulphur River Reach 11140302-006**

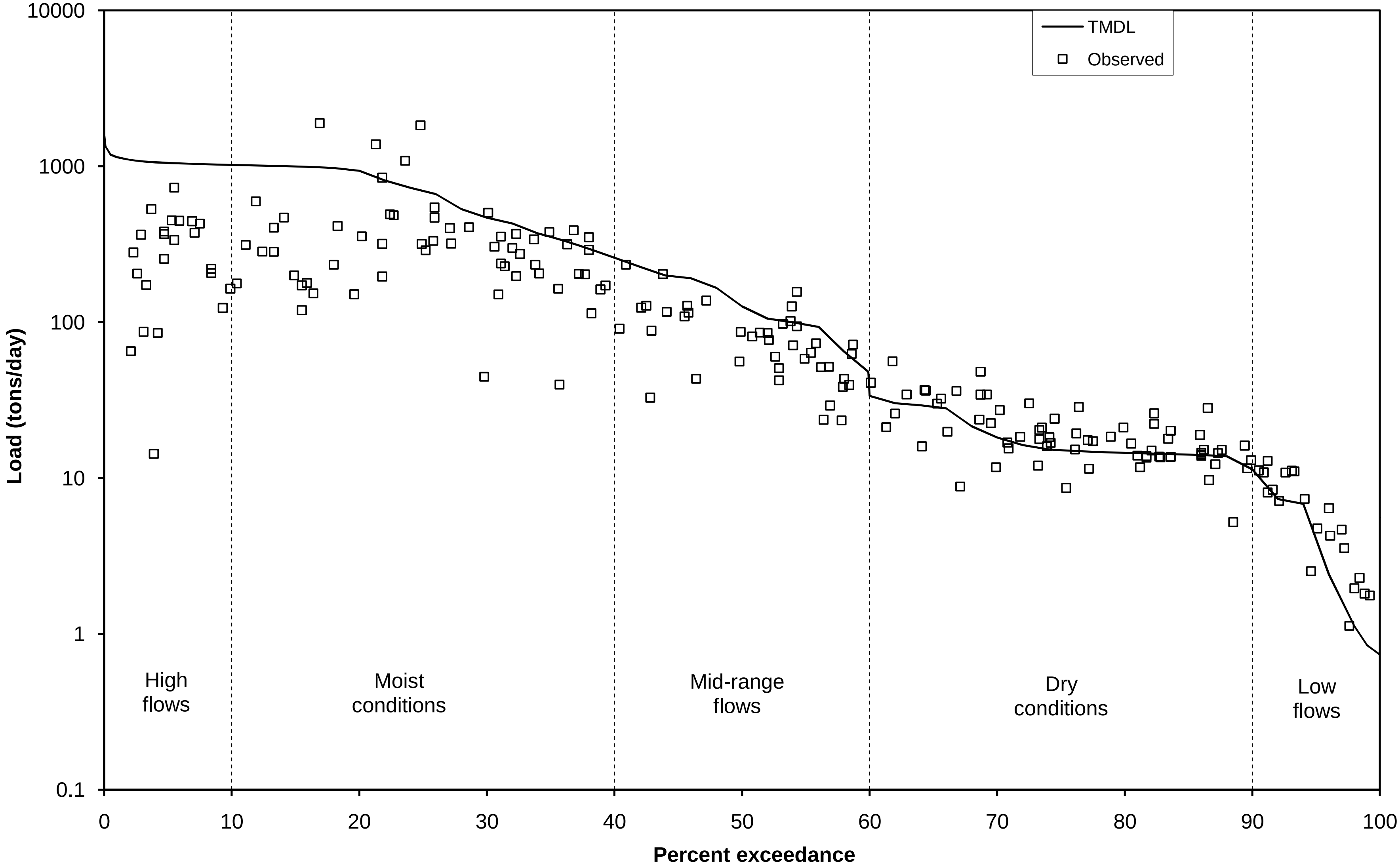
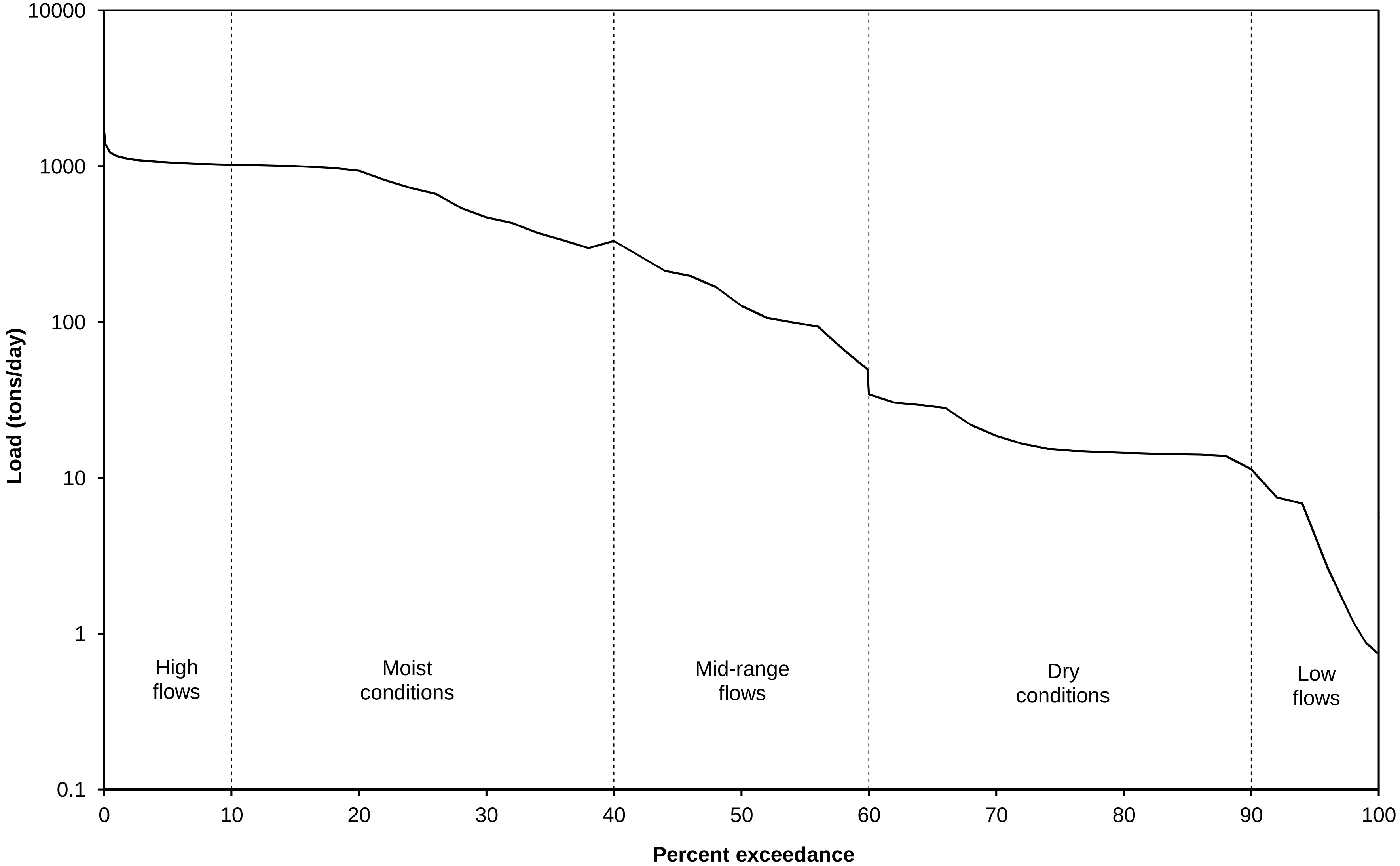


**Figure E.4 TSS Load Duration Curve for Sulphur River Reach 11140302-004**



## Figure E.5 TSS Load Duration Curve for Sulphur River Reach 11140302-002

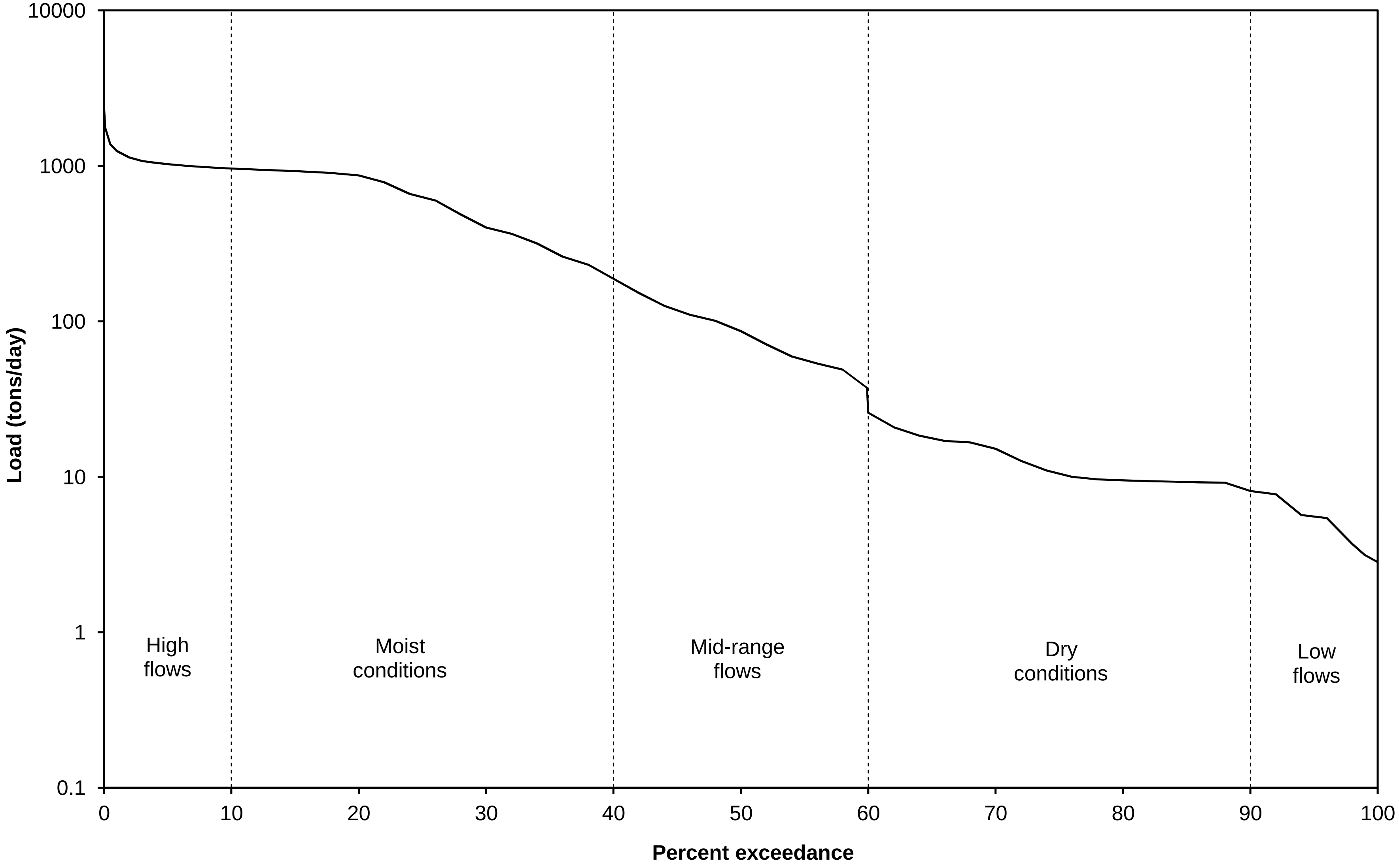
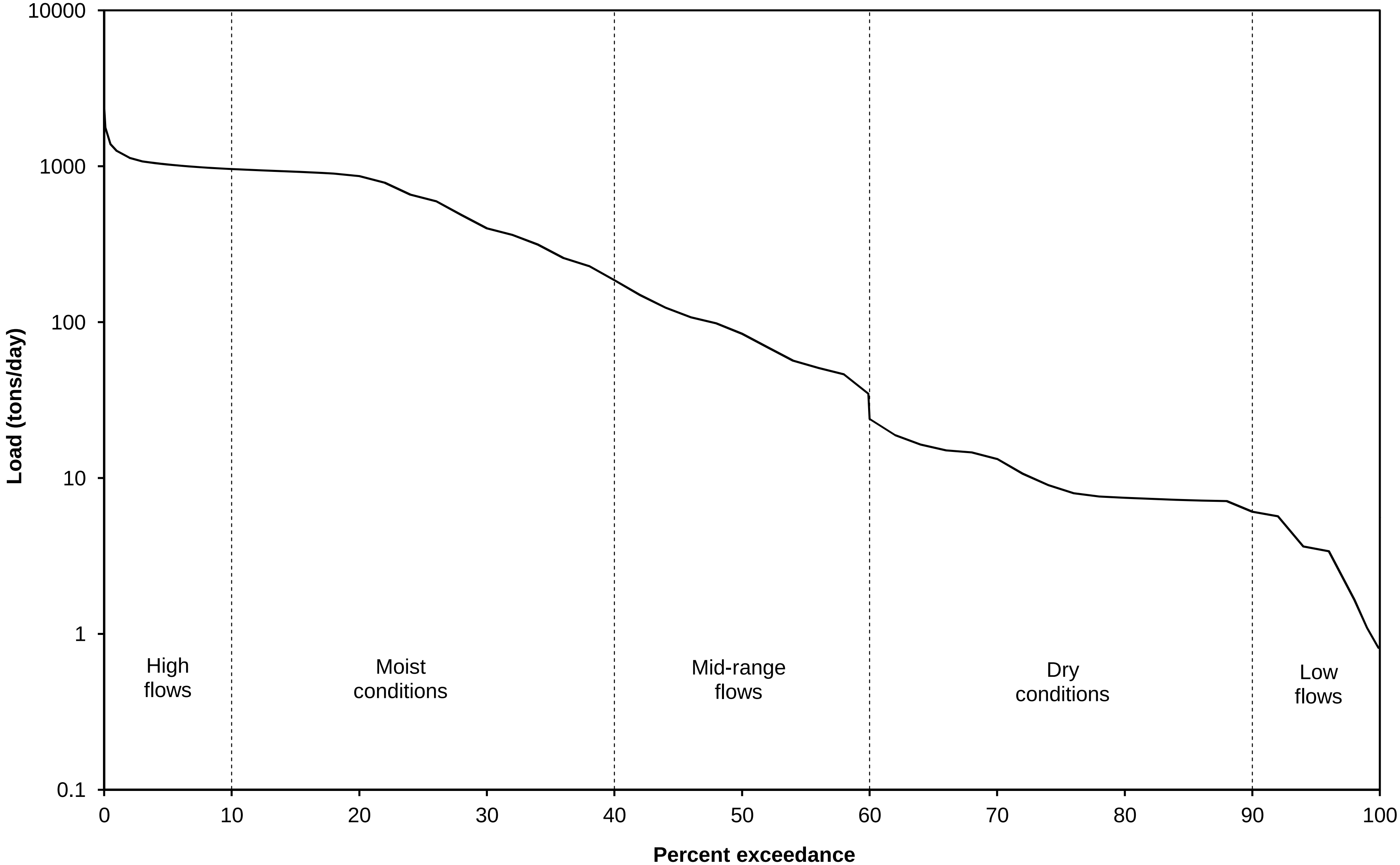


**Figure E.6 TSS Load Duration Curve for Sulphur River Reach 11140302-001**



# APPENDIX F

## Turbidity TMDLs for the Red River

TABLE F.1 ALLOWABLE LOAD OF TSS FOR RED RIVER REACH 11140201-003

Drainage area at flow gage (Red River at Spring Bank, AR) = 50,973 square miles
Drainage area at downstream end of reach 11140201-003 = 50,984 square miles

No continuous point sources in study area discharge to this reach.

| Percent exceedance for flow | Flow Category | Flow in Red River at flow gage at Spring Bank, AR (cfs) | Ambient flow at downstream end of reach 11140201-003 (cfs) | Target TSS (mg/L) | Total allowable load (i.e., TMDL) for TSS (tons/day) |
|---|---|---|---|---|---|
| 99.9 | Base | 1,192.3 | 1,192.6 | 53 | 170.5 |
| 99 | Base | 1,410.0 | 1,410.3 | 53 | 201.6 |
| 98 | Base | 1,580.0 | 1,580.3 | 53 | 225.9 |
| 96 | Base | 2,030.0 | 2,030.4 | 53 | 290.2 |
| 94 | Base | 2,270.0 | 2,270.5 | 53 | 324.5 |
| 92 | Base | 2,472.8 | 2,473.3 | 53 | 353.5 |
| 90 | Base | 2,716.0 | 2,716.6 | 53 | 388.3 |
| 88 | Base | 2,920.0 | 2,920.6 | 53 | 417.5 |
| 86 | Base | 3,120.0 | 3,120.7 | 53 | 446.1 |
| 84 | Base | 3,370.0 | 3,370.7 | 53 | 481.8 |
| 82 | Base | 3,590.0 | 3,590.8 | 53 | 513.2 |
| 80 | Base | 3,800.0 | 3,800.8 | 53 | 543.3 |
| 78 | Base | 4,010.0 | 4,010.9 | 53 | 573.3 |
| 76 | Base | 4,258.4 | 4,259.3 | 53 | 608.8 |
| 74 | Base | 4,441.6 | 4,442.6 | 53 | 635.0 |
| 72 | Base | 4,674.8 | 4,675.8 | 53 | 668.3 |
| 70 | Base | 4,968.0 | 4,969.1 | 53 | 710.3 |
| 68 | Base | 5,200.0 | 5,201.1 | 53 | 743.4 |
| 66 | Base | 5,484.4 | 5,485.6 | 53 | 784.1 |
| 64 | Base | 5,777.6 | 5,778.8 | 53 | 826.0 |
| 62 | Base | 6,080.0 | 6,081.3 | 53 | 869.2 |
| 60 | Base | 6,434.0 | 6,435.4 | 53 | 919.8 |
| 59.9 | Storm | 6,450.0 | 6,451.4 | 252 | 4,384.5 |
| 58 | Storm | 6,800.0 | 6,801.5 | 252 | 4,622.4 |
| 56 | Storm | 7,210.4 | 7,212.0 | 252 | 4,901.4 |
| 54 | Storm | 7,610.0 | 7,611.6 | 252 | 5,173.0 |
| 52 | Storm | 8,140.0 | 8,141.8 | 252 | 5,533.3 |
| 50 | Storm | 8,700.0 | 8,701.9 | 252 | 5,913.9 |
| 48 | Storm | 9,433.2 | 9,435.2 | 252 | 6,412.3 |
| 46 | Storm | 10,200.0 | 10,202.2 | 252 | 6,933.6 |
| 44 | Storm | 11,400.0 | 11,402.5 | 252 | 7,749.3 |
| 42 | Storm | 12,400.0 | 12,402.7 | 252 | 8,429.1 |
| 40 | Storm | 13,400.0 | 13,402.9 | 252 | 9,108.8 |
| 38 | Storm | 14,400.0 | 14,403.1 | 252 | 9,788.6 |
| 36 | Storm | 15,824.0 | 15,827.4 | 252 | 10,756.6 |
| 34 | Storm | 17,300.0 | 17,303.7 | 252 | 11,759.9 |
| 32 | Storm | 18,788.0 | 18,792.1 | 252 | 12,771.4 |
| 30 | Storm | 20,300.0 | 20,304.4 | 252 | 13,799.2 |
| 28 | Storm | 22,100.0 | 22,104.8 | 252 | 15,022.8 |
| 26 | Storm | 24,100.0 | 24,105.2 | 252 | 16,382.3 |
| 24 | Storm | 26,400.0 | 26,405.7 | 252 | 17,945.7 |
| 22 | Storm | 28,548.0 | 28,554.2 | 252 | 19,405.9 |
| 20 | Storm | 31,000.0 | 31,006.7 | 252 | 21,072.6 |

| Percent exceedance for flow | Flow Category | Flow in Red River at flow gage at Spring Bank, AR (cfs) | Ambient flow at downstream end of reach 11140201-003 (cfs) | Target TSS (mg/L) | Total allowable load (i.e., TMDL) for TSS (tons/day) |
|---|---|---|---|---|---|
| 18 | Storm | 34,600.0 | 34,607.5 | 252 | 23,519.8 |
| 16 | Storm | 38,000.0 | 38,008.2 | 252 | 25,831.0 |
| 14 | Storm | 41,700.0 | 41,709.0 | 252 | 28,346.1 |
| 12 | Storm | 46,108.0 | 46,118.0 | 252 | 31,342.5 |
| 10 | Storm | 52,100.0 | 52,111.2 | 252 | 35,415.6 |
| 9 | Storm | 55,400.0 | 55,412.0 | 252 | 37,658.8 |
| 8 | Storm | 58,572.0 | 58,584.6 | 252 | 39,815.1 |
| 7 | Storm | 63,600.0 | 63,613.7 | 252 | 43,232.9 |
| 6 | Storm | 70,104.0 | 70,119.1 | 252 | 47,654.1 |
| 5 | Storm | 76,500.0 | 76,516.5 | 252 | 52,001.8 |
| 4 | Storm | 82,300.0 | 82,317.8 | 252 | 55,944.5 |
| 3 | Storm | 89,752.0 | 89,771.4 | 252 | 61,010.1 |
| 2 | Storm | 97,936.0 | 97,957.1 | 252 | 66,573.2 |
| 1 | Storm | 112,000.0 | 112,024.2 | 252 | 76,133.4 |
| 0.5 | Storm | 120,420.0 | 120,446.0 | 252 | 81,857.0 |
| 0.1 | Storm | 131,884.0 | 131,912.5 | 252 | 89,649.8 |
| 0.01 | Storm | 135,442.0 | 135,471.2 | 252 | 92,068.4 |

FILE: R:\PROJECTS\3013-380\TECH\ADEQ_WQ_DATA\RED RIVER\RED0009 RED RIVER REVISED TMDL METHOD.XLSX

TABLE F.2  EXISTING NPS LOAD OF TSS FOR RED RIVER REACH 11140201-003

Table of raw data for concentration and USGS flow:

| Date | TSS from RED0009 (mg/L) | Flow in Red River at flow gage at Spring Bank, AR (cfs) | Hydraulic range |
|---|---|---|---|
| 1/10/2006 | 19.5 | 1150 | low flows |
| 11/15/2005 | 31.8 | 1320 | low flows |
| 10/3/2006 | 26.0 | 1440 | low flows |
| 12/13/2005 | 26.2 | 1450 | low flows |
| 7/11/2006 | 27.2 | 1590 | low flows |
| 9/5/2006 | 23.5 | 1710 | low flows |
| 11/16/1999 | 29 | 2000 | low flows |
| 10/24/2000 | 32.0 | 2130 | low flows |
| 11/4/2008 | 37.0 | 2350 | low flows |
| 10/12/1999 | 38.0 | 2410 | low flows |
| 12/3/2002 | 21.2 | 2410 | low flows |
| 8/1/2006 | 27.8 | 2410 | low flows |
| 6/28/2005 | 25.8 | 2450 | low flows |
| 12/8/2008 | 26.2 | 2630 | low flows |
| 10/18/2005 | 29.5 | 2710 | low flows |
| 3/14/2006 | 50.5 | 2760 | low flows |
| 9/21/2004 | 52.1 | 2770 | low flows |
| 7/26/2005 | 32.8 | 2830 | low flows |
| 8/30/2005 | 25.7 | 2860 | low flows |
| 9/28/1999 | 26.0 | 2880 | low flows |
| 10/21/2003 | 54.5 | 2880 | low flows |
| 10/1/2002 | 28.2 | 3100 | low flows |
| 7/21/1998 | 44.5 | 3150 | low flows |
| 9/23/2003 | 36.0 | 3380 | low flows |
| 12/16/2003 | 29.0 | 3440 | low flows |
| 11/18/2003 | 41.5 | 3480 | low flows |
| 5/6/2003 | 33.5 | 3580 | low flows |
| 6/13/2006 | 35.0 | 3800 | low flows |
| 3/27/2007 | 37.0 | 3850 | low flows |
| 11/19/2001 | 24.5 | 3920 | low flows |
| 9/26/2000 | 31.0 | 3950 | low flows |
| 10/26/2004 | 73.3 | 3960 | low flows |
| 1/31/2006 | 82.8 | 3960 | low flows |
| 9/27/2005 | 24.2 | 4020 | low flows |
| 5/25/2004 | 29.0 | 4180 | low flows |
| 8/29/2000 | 71.5 | 4300 | low flows |
| 1/18/2000 | 46.5 | 4310 | low flows |
| 5/17/2005 | 3.2 | 4320 | low flows |
| 8/12/2008 | 31.8 | 4560 | low flows |
| 8/31/1999 | 37.0 | 4690 | low flows |
| 11/13/2007 | 30.8 | 4750 | low flows |
| 8/11/1998 | 35.0 | 4780 | low flows |
| 8/21/2001 | 26.0 | 4820 | low flows |
| 7/1/2002 | 61.8 | 4940 | low flows |
| 12/14/1999 | 51 | 5070 | low flows |
| 9/3/2002 | 42.8 | 5070 | low flows |

| Average TSS conc. w/in each zone (mg/L) | |
|---|---|
| low flows | 38 |
| dry cond. | 41 |
| mid-range | 55 |
| moist cond. | 76 |
| high flows | 82 |

| Date | TSS from RED0009 (mg/L) | Flow in Red River at flow gage at Spring Bank, AR (cfs) | Hydraulic range |
|---|---|---|---|
| 4/27/2004 | 59.0 | 5130 | low flows |
| 10/21/1997 | 47.5 | 5260 | low flows |
| 3/30/2004 | 39.4 | 5330 | low flows |
| 6/10/2003 | 44.5 | 5480 | low flows |
| 4/8/2003 | 39.2 | 5820 | low flows |
| 10/31/2006 | 46.5 | 5840 | low flows |
| 1/15/2008 | 37.0 | 6040 | low flows |
| 2/15/2000 | 46 | 6160 | low flows |
| 7/15/2008 | 42.5 | 6210 | low flows |
| 9/1/2008 | 55.0 | 6210 | low flows |
| 4/26/2005 | 42.2 | 6370 | dry cond. |
| 9/30/2008 | 35.5 | 6380 | dry cond. |
| 7/15/2003 | 55.2 | 6410 | dry cond. |
| 7/14/2009 | 32.0 | 6420 | dry cond. |
| 4/14/2009 | 59.3 | 6570 | mid-range |
| 10/15/2007 | 44.0 | 6980 | mid-range |
| 7/27/1999 | 39.0 | 7200 | mid-range |
| 8/12/2003 | 75.6 | 7260 | mid-range |
| 9/18/2001 | 50.5 | 7310 | mid-range |
| 7/25/2000 | 37.5 | 7570 | mid-range |
| 2/4/2003 | 36.0 | 7720 | mid-range |
| 2/12/2008 | 59.5 | 7760 | mid-range |
| 12/4/2007 | 37.0 | 7790 | mid-range |
| 7/27/2004 | 66.0 | 7900 | mid-range |
| 4/11/2006 | 69.0 | 7950 | mid-range |
| 8/6/2002 | 31.5 | 8070 | mid-range |
| 7/17/2001 | 21.0 | 8630 | mid-range |
| 2/3/2009 | 24.8 | 8680 | mid-range |
| 1/6/2009 | 32.3 | 8910 | mid-range |
| 8/17/2004 | 76.2 | 9370 | mid-range |
| 3/21/2000 | 124 | 9770 | mid-range |
| 6/4/2002 | 33.5 | 10100 | mid-range |
| 10/27/1998 | 73.0 | 10200 | mid-range |
| 4/24/2007 | 68.5 | 10800 | mid-range |
| 6/17/2008 | 44.5 | 10900 | mid-range |
| 12/11/2001 | 45.8 | 11300 | mid-range |
| 11/5/2002 | 114 | 11800 | mid-range |
| 1/26/1999 | 94.0 | 12200 | mid-range |
| 5/5/1998 | 46.0 | 13200 | mid-range |
| 12/19/2006 | 38.0 | 13300 | mid-range |
| 6/2/1998 | 2.5 | 13700 | moist cond. |
| 9/22/1998 | 44.0 | 13800 | moist cond. |
| 11/17/1998 | 55.5 | 13800 | moist cond. |
| 11/16/2004 | 84.6 | 13800 | moist cond. |
| 2/20/2007 | 53.2 | 14200 | moist cond. |
| 3/31/2009 | 74.0 | 14900 | moist cond. |
| 1/27/2004 | 101 | 15200 | moist cond. |
| 2/24/2004 | 56.5 | 15700 | moist cond. |
| 12/16/1997 | 39.5 | 15800 | moist cond. |
| 3/29/2005 | 138 | 17700 | moist cond. |

| Date | TSS from RED0009 (mg/L) | Flow in Red River at flow gage at Spring Bank, AR (cfs) | Hydraulic range |
|---|---|---|---|
| 8/4/2009 | 50.0 | 18900 | moist cond. |
| 2/22/2005 | 64.3 | 19100 | moist cond. |
| 2/16/1999 | 72.5 | 20600 | moist cond. |
| 5/21/2002 | 56.5 | 23100 | moist cond. |
| 6/19/2001 | 37.8 | 24600 | moist cond. |
| 4/18/2000 | 218 | 25200 | moist cond. |
| 12/18/2000 | 38.5 | 26200 | moist cond. |
| 10/23/2001 | 62.7 | 26400 | moist cond. |
| 12/21/1998 | 112.5 | 27300 | moist cond. |
| 12/8/2009 | 35.0 | 27400 | moist cond. |
| 5/16/2006 | 96.0 | 28900 | moist cond. |
| 5/23/2000 | 132.5 | 29000 | moist cond. |
| 2/19/2002 | 37.5 | 31800 | moist cond. |
| 3/23/1999 | 66.0 | 32300 | moist cond. |
| 9/29/2009 | 53.0 | 32500 | moist cond. |
| 3/19/2002 | 48.8 | 33700 | moist cond. |
| 1/29/2001 | 64.3 | 33900 | moist cond. |
| 9/11/2007 | 107 | 34300 | moist cond. |
| 5/18/1999 | 149.0 | 37600 | moist cond. |
| 1/26/2010 | 19.0 | 38400 | moist cond. |
| 6/12/2007 | 167 | 40600 | moist cond. |
| 1/7/2003 | 44.8 | 41700 | moist cond. |
| 4/16/2001 | 101.0 | 43100 | moist cond. |
| 6/29/2004 | 59.8 | 43100 | moist cond. |
| 11/17/2009 | 45.0 | 43400 | moist cond. |
| 11/14/2000 | 156.8 | 45900 | moist cond. |
| 3/3/2003 | 76.5 | 46500 | moist cond. |
| 5/15/2007 | 109 | 52400 | high flows |
| 1/25/2005 | 16.8 | 53000 | high flows |
| 6/15/2009 | 70.3 | 53700 | high flows |
| 3/3/1998 | 118.0 | 54600 | high flows |
| 1/2/2002 | 37.8 | 56900 | high flows |
| 12/7/2004 | 173 | 58000 | high flows |
| 5/6/2008 | 47.5 | 59100 | high flows |
| 4/7/1998 | 248.0 | 59900 | high flows |
| 2/9/2010 | 16.0 | 62000 | high flows |
| 1/23/2007 | 57.8 | 65200 | high flows |
| 3/11/2008 | 4.0 | 66400 | high flows |
| 3/27/2001 | 77.8 | 69200 | high flows |
| 4/1/2008 | 32.0 | 71200 | high flows |
| 2/26/2001 | 61.8 | 74100 | high flows |
| 1/27/1998 | 185.5 | 79700 | high flows |
| 10/27/2009 | 37.0 | 94300 | high flows |
| 7/17/2007 | 66.6 | 103000 | high flows |
| 5/26/2009 | 42.5 | 112000 | high flows |
| 4/16/2002 | 152.7 | 115000 | high flows |

FILE: R:\PROJECTS\3013-380\TECH\ADEQ_WQ_DATA\RED RIVER\RED0009 RED RIVER REVISED TMDL METHOD.XLSX

TABLE F.3 COMPONENTS OF TMDL FOR TURBIDITY FOR RED RIVER REACH 11140201-003

Calculations for diffuse loads:

Existing diffuse load = (Ambient flow at d/s end of reach for min. flow w/in hydrol. zone) × (Average existing conc.)

Allowable diffuse load = (Ambient flow at d/s end of reach for min. flow w/in hydrol. zone) × MIN (Average existing conc., Criterion)

Calculations for dividing regulated and non-regulated diffuse loads:

Tot. drain. area for regul. stormwater = 0 facilities × 40 ac each = 0 ac

Tot. drain. area for reach 11140201-003 = 50,984 sq. mi. = 32,629,760 ac

Drainage area for regul. stormwater as percent of total drainage area = 0.0000%

--> WLA for regulated stormwater = 0.00% of allowable load from diffuse sources

--> LA for non-regulated diffuse sources = 100.00% of allowable load from diffuse sources

Calculations for non-storm point sources:

Sum of design flows for non-storm point sources for this reach (cfs) = 0 MGD = 0.00 cfs

Effluent concentration is set manually so that allocated loads (Σ WLA + LA) do not exceed TMDL

WLA for non-storm point sources = Sum of design flows × effluent concentration × converstion factor

Load reserved for future growth = TMDL – LA for non-regulated diffuse sources – WLA for regulated stormwater – WLA for non-storm point sources

| | High flows | Moist cond. | Mid-range | Dry cond. | Low flows |
|---|---|---|---|---|---|
| Ambient flow at downstream end of reach from Table F.1 for minimum flow within each hydrologic range (cfs) = | 52111 | 13403 | 6451 | 2717 | 1410 |

**LOADS OF TSS:**

| | High flows | Moist cond. | Mid-range | Dry cond. | Low flows |
|---|---|---|---|---|---|
| Average existing concentration from Table F.2 (mg/L) = | 82 | 76 | 55 | 41 | 38 |
| Existing load from diffuse sources (tons/day) = | 11524 | 2747 | 957 | 300.4 | 144.5 |
| Allowable load from diffuse sources (tons/day) = | 11524 | 2747 | 957 | 300.4 | 144.5 |
| LA for non-regulated diffuse sources (tons/day) = | 11524 | 2747 | 957 | 300.4 | 144.5 |
| WLA for regulated stormwater (tons/day) = | 0 | 0 | 0 | 0 | 0 |
| Effluent conc. for non-storm point sources (mg/L) = | 0 | 0 | 0 | 0 | 0 |
| WLA for non-storm point sources (tons/day) = | 0 | 0 | 0 | 0 | 0 |
| Load reserved for future growth (tons/day) = | 23892 | 6362 | 3427 | 87.9 | 57.1 |
| TMDL from Table F.1 (tons/day) | 35416 | 9109 | 4384 | 388.3 | 201.6 |
| Error check: Sum of WLAs + LA + FG ≤ TMDL? | ok | ok | ok | ok | ok |

FILE: R:\PROJECTS\3013-380\TECH\ADEQ_WQ_DATA\RED RIVER\RED0009 RED RIVER REVISED TMDL METHOD.XLSX

**Figure F.1 Flow Duration Curve for Red River Reach 11140201-003**

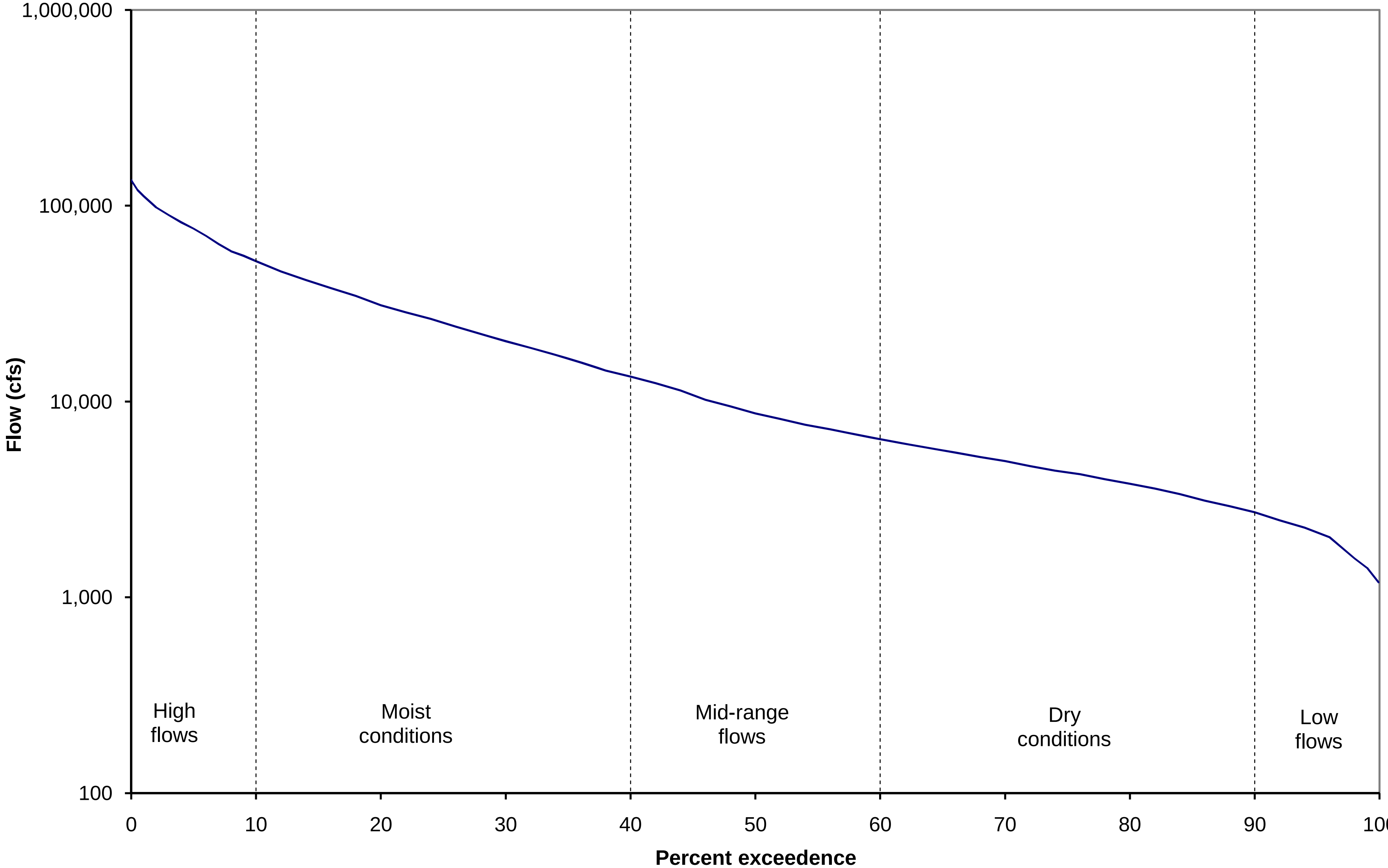


**Figure F.2 TSS Load Duration Curve for Red River Reach 11140201-003**