

TMDL FOR TURBIDITY FOR LAKE FRIERSON, AR

**FINAL
JANUARY 16, 2007**

TMDL FOR TURBIDITY
FOR LAKE FRIERSON, AR

Prepared for

EPA Region VI
Water Quality Protection Division
Permits, Oversight, and TMDL Team
Dallas, TX 75202

Contract No. 68-C-02-108
Task Order #127

Prepared by

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

FINAL
January 16, 2007

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 loads (TMDLs) for those waterbodies. A TMDL is the amount of a pollutant that a waterbody can assimilate without exceeding the established water quality standards for that pollutant. Through a TMDL, pollutant loads can be allocated to point sources and nonpoint sources discharging to the waterbody.

This report presents a TMDL for siltation/turbidity for Lake Frierson (HUC 08020302) north of Jonesboro in northeast Arkansas. The watershed for this lake covers 10.2 square miles and lies entirely within Crowley's Ridge. Although Crowley's Ridge is within the Delta ecoregion, it is more hilly than the rest of the Delta ecoregion. The Lake Frierson watershed consists mostly of forest, with some cropland and pasture in the valleys. There are no point source discharges or urban areas in the Lake Frierson watershed.

Lake Frierson was included in both the draft and final versions of the 2004 303(d) list for not supporting its designated use of aquatic life due to exceedances of the numeric criteria for turbidity in the Arkansas water quality standards. The applicable numeric criteria for turbidity for Lake Frierson are 25 NTU ("primary" value) and 45 NTU ("storm-flow" value).

Water quality data for turbidity and total suspended solids (TSS) were collected in Lake Frierson by the Arkansas Department of Environmental Quality (ADEQ), the United States Geological Survey (USGS), and by FTN Associates, Ltd. (FTN). These data were plotted and analyzed for relationships between concentration and stream flow and a relationship between turbidity and TSS. These analyses showed no significant relationship between concentration and stream flow, but higher turbidity levels tended to correspond with higher TSS values.

This TMDL was expressed using TSS as a surrogate for turbidity because turbidity cannot be expressed as a mass load. A regression between TSS and turbidity was developed and was used with the numeric turbidity criteria to develop target TSS concentrations of 11 mg/L (corresponding to the primary turbidity criterion of 25 NTU) and 13 mg/L (corresponding to the storm-flow turbidity criterion of 45 NTU).

The TMDL in this report was developed using the load duration curve methodology. This method illustrates allowable loading at a wide range of stream flow conditions. The steps for applying this methodology for the TMDL in this report were:

1. Developing a flow duration curve,
2. Converting the flow duration curve to a load duration curve,
3. Plotting observed loads with the load duration curve,
4. Calculating the TMDL components, and
5. Calculating percent reductions.

The load duration curve was developed using multiple target TSS concentrations because Arkansas has different turbidity criteria for different flow conditions. The target TSS concentration corresponding to the primary turbidity criterion was applied between the 100 percent exceedance of stream flow and the 60 percent exceedance of stream flow. The target TSS concentration corresponding to the storm-flow turbidity criterion was applied between the 60 percent exceedance of stream flow and the 0 percent exceedance of stream flow.

The wasteload allocation (WLA) for point source contributions was set to zero because there are no point source discharges in the Lake Frierson watershed.

An implicit margin of safety (MOS) was incorporated through the use of conservative assumptions. The primary conservative assumption was calculating the TMDL assuming that TSS is a conservative parameter and does not settle out of the water column.

The load allocation (LA) for nonpoint sources was set equal to the TMDL because the WLA was zero and the MOS was implicit. The components of the TMDL and percent reductions needed are summarized in Table ES.1.

Table ES.1. Summary of TMDL and percent reductions.

Waterbody Name	Flow Category	Loads (lbs/day of TSS)				Percent Reduction Needed
		WLA	LA	MOS	TMDL	
Lake Frierson	Base flow	0	82.5	implicit	82.5	55%
	Storm-flow	0	939	implicit	939	82%

TABLE OF CONTENTS

1.0	INTRODUCTION	1-1
2.0	BACKGROUND INFORMATION	2-1
2.1	General Information.....	2-1
2.2	Topography and Soils	2-1
2.3	Land Use	2-2
2.4	Description of Hydrology	2-2
2.5	Water Quality Standards.....	2-3
2.6	Nonpoint Sources.....	2-4
2.7	Point Sources	2-4
2.8	Previous Studies.....	2-4
2.9	Lake Water Management Plan.....	2-5
3.0	EXISTING WATER QUALITY FOR TURBIDITY AND TSS	3-1
3.1	General Description of Data	3-1
3.2	Seasonal Patterns	3-2
3.3	Relationships Between Concentration and Flow	3-2
3.4	Relationship Between TSS and Turbidity.....	3-2
4.0	TMDL DEVELOPMENT.....	4-1
4.1	Seasonality and Critical Conditions.....	4-1
4.2	Water Quality Target	4-1
4.3	Methodology for TMDL Calculations	4-2
4.4	Flow Duration Curve	4-2
4.5	Load Duration Curves.....	4-2
4.6	Observed Loads	4-3
4.7	TMDL and MOS.....	4-3
4.8	Point Source Loads	4-4
4.9	Nonpoint Source Loads.....	4-4
4.10	Percent Reductions.....	4-4

TABLE OF CONTENTS (CONTINUED)

4.11 Future Growth..... 4-5

5.0 OTHER RELEVANT INFORMATION 5-1

6.0 PUBLIC PARTICIPATION 6-1

7.0 REFERENCES 7-1

LIST OF APPENDICES

APPENDIX A: Maps

APPENDIX B: Plots of Turbidity and TSS

APPENDIX C: Load Duration Curves and TMDL Calculations

LIST OF TABLES

Table ES.1 Summary of TMDL and percent reductions ii

Table 1.1 303(d) listing for Lake Frierson..... 1-1

Table 2.1 Land use percentages for the study area 2-2

Table 2.2 Information for USGS stream flow gaging station 2-3

Table 3.1 Summary of data for turbidity and TSS 3-1

Table 3.2 Results of regression between TSS and turbidity 3-2

Table 4.1 Summary of turbidity TMDL for Lake Frierson..... 4-5

1.0 INTRODUCTION

This report presents a total maximum daily load (TMDL) for siltation/turbidity for Lake Frierson in northeast Arkansas. This lake was included on the Arkansas Department of Environmental Quality (ADEQ) draft 2004 Arkansas 303(d) list (ADEQ 2005a) and the final 2004 Arkansas 303(d) list (EPA 2006) as not supporting the designated use of aquatic life. The sources of contamination and causes of impairment from the 2004 303(d) listing are shown in Table 1.1. The TMDL in this report was developed in accordance with Section 303(d) of the Federal Clean Water Act and EPA's regulations in 40 CFR 130.7.

The purpose of a TMDL is to determine the pollutant loading that a waterbody can assimilate without exceeding the water quality standards for that pollutant and to establish the load reduction that is necessary to meet the standard in a waterbody. The TMDL is the sum of the wasteload allocation (WLA), the 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. 303(d) listing for Lake Frierson.

HUC	Waterbody Name	Sources	Causes	Category	Priority
08020302	Lake Frierson	Unknown	Siltation/turbidity	5a	Medium

2.0 BACKGROUND INFORMATION

2.1 General Information

The study area for this report is the Lake Frierson watershed located north of Jonesboro in northeast Arkansas (see Figure A.1 in Appendix A). The Lake Frierson watershed is in the Delta ecoregion, but it lies entirely within Crowley's Ridge, which is more hilly than the rest of the Delta ecoregion. The watershed covers 10.2 square miles. Lake Frierson is in United States Geological Survey (USGS) Hydrologic Unit 08020302 and in ADEQ Planning Segment 4B. The outflow from Lake Frierson eventually drains into Bayou DeView.

Lake Frierson was built in the 1970s by the Soil Conservation Service (now the Natural Resources Conservation Service) as part of its Big Creek Watershed Flood Control Program, but it is now owned by the Arkansas Game and Fish Commission (AGFC). The AGFC controls the water level of the lake solely for the purpose of managing fisheries in the lake, although farmers downstream of the lake use the water released from the lake for agriculture. At normal water levels, the lake has an average depth of about 8 ft and a maximum depth of about 18 ft. During 2006, which was an extended dry period, the water level was about 5 ft below normal (Barkley 2006a).

2.2 Topography and Soils

As mentioned above, the Lake Frierson watershed lies entirely within Crowley's Ridge. The topography of most of the Lake Frierson watershed is characterized by "ridges with narrow winding tops; short side slopes; and narrow valleys between ridges. Slopes on the ridges dominantly range from 12 to 40 percent, and along valley drainage ways they are generally less than 1 percent" (United States Department of Agriculture (USDA) 1979). Nearly all of the soils in the Lake Frierson watershed are classified as silt loam (National Cooperative Soil Survey (NCSS) 2006).

2.3 Land Use

Land use data for the study area were obtained from the GEOSTOR database, which is maintained by the Center for Advanced Spatial Technology (CAST) at the University of Arkansas in Fayetteville. These data were based on satellite imagery from 2004. 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. These data indicate that the study area consists mostly of forest, with some cropland and pasture in the valleys. Some small parcels of land within the watershed may be misclassified in these land use data, but most of the watershed appears to be properly classified based on local knowledge of the area.

Table 2.1 Land use percentages for the study area (CAST 2005).

Land Use Category	Percentage of study area
Urban	0.0%
Barren	0.3%
Water	7.1%
Forest	50.4%
Soybeans	14.8%
Rice	0.7%
Cotton	2.3%
Corn	0.6%
Other crops	7.9%
Fallow	0.0%
Pasture/grass	15.9%
TOTAL	100.0%

2.4 Description of Hydrology

Average precipitation for the study area is about 50 inches per year based on data from the National Weather Service gage for Paragould (NCDC 2006). Stream flow in the study area was characterized using USGS flow data from the L'Anguille River near Colt because there are no USGS flow gages in the study area. Information for this gage is summarized in Table 2.2.

Table 2.2. Information for USGS stream flow gaging station (USGS 2006a).

Gage name:	L'Anguille River near Colt, AR
Gage number:	07047942
Descriptive location:	3.9 miles northwest of Colt (60 miles south of Lake Frierson)
Period of record:	October 1970 – present*
Drainage area:	535 square miles
Mean daily flow:	706 cfs
Median daily flow:	351 cfs

*Note: Flows for August through October 2006 were not available for the Colt gage, so these flows were estimated using data for the L'Anguille River near Palestine (07047950) (USGS 2006b).

2.5 Water Quality Standards

Water quality standards for Arkansas waterbodies are listed by ecoregion in Regulation No. 2 (APCEC 2006). Designated uses for Lake Frierson are primary and secondary contact recreation; public, industrial, and agricultural water supply; and Delta fishery.

Section 2.503 of Regulation No. 2 provides both a narrative criterion and numeric criteria that apply to siltation/turbidity. The general narrative criterion is: “There shall be no distinctly visible increase in turbidity of receiving waters attributable to municipal, industrial, agricultural, other waste discharges, or instream activities.” The numeric turbidity criteria for lakes in the Delta ecoregion are 25 NTU (“primary” value) and 45 NTU (“storm-flow” value). The regulation also states that “the non-point source runoff shall not result in the exceedance of the in stream storm-flow values in more than 20% of the ADEQ ambient monitoring network samples taken in not less than 24 monthly samples.”

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.
- 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.

2.6 Nonpoint Sources

According to the 2004 303(d) list, the source of turbidity for Lake Frierson is listed as unknown (ADEQ 2005a). However, the 2004 Arkansas 305(b) report states that Lake Frierson has "a history of elevated turbidity values most likely due to in-lake processes of wind action on shallow waters, soil types susceptible to colloidal suspensions, and/or disturbances in the watershed" (ADEQ 2005b; p. 75).

2.7 Point Sources

No point source discharges exist in the Lake Frierson watershed, based on information in the Arkansas 305(b) report (ADEQ 2005b) and EPA's Permit Compliance System (PCS 2006).

2.8 Previous Studies

Two previous studies of this lake were identified. Every 5 years ADEQ collects data in the significant publicly owned lakes in Arkansas, including Lake Frierson (ADEQ 2000). At each lake two samples are taken, one near the surface (epilimnion) and one near the bottom (hypolimnion), and each sample is analyzed for turbidity, total suspended solids (TSS), and other water quality parameters. Data were collected in 1989, 1994, 1999, and 2004 for these field studies, but the most recent report from these studies was published in 2000.

The USGS published a report titled *Water Quality of Eleven Lakes in Eastern and Southern Arkansas from August 2004 - July 2005*. Lake Frierson was one of the eleven lakes included in the study. The USGS collected six samples from Lake Frierson and analyzed them for various water quality parameters. The report concluded that Lake Frierson had high turbidity caused by clay particles and that the highest turbidities measured in any of the lakes were measured in Lake Frierson. The turbidities measured in Lake Frierson for this study ranged from 32 NTU to 120 NTU (USGS 2006c).

2.9 Lake Water Management Plan

As discussed in Section 2.1, Lake Frierson is managed for fishing. The high turbidities have greatly affected the fishing in this lake. The AGFC has tried several things to reduce the turbidity in the lake. From 1986 to 1996, the lake was drawn down every 3 years. In each drawdown, the water level of the lake was dropped about 10 ft for a short time and grasses were planted in the exposed areas of land. As the lake filled back up, this produced some reduction in turbidity (by causing suspended solids to bind to the decomposing grasses and then settle to the bottom), but the effect lasted less than a year. A new approach was taken from 1996 to 2006. In these years the AGFC annually drew the lake down 6 ft but over a period of 6 months and let volunteer grasses grow (as opposed to planting any grasses). According to Sam Barkley at AGFC, “This was done to enhance predation, as opposed to trying to combat the siltation. Drawdowns were effective in producing big bass but bass recruitment (fish moving into intermediate size groups) was nil. There was not a reduction in biomass of large gizzard shad nor an increase in their reproduction as hoped for and expected” (Barkley 2006b). The AGFC has now decided on another strategy to increase the bass recruitment (unlike from 1986-1996 where the focus was on reducing turbidity). Beginning in 2007 the AGFC will cease all drawdowns and, for the next 2-3 years, water willow will be planted. This plant will serve as a food source and will increase spawning habitat. Although the willow may decompose and cause sediment to settle, its main purpose is for fish food rather than reducing turbidity.

3.0 EXISTING WATER QUALITY FOR TURBIDITY AND TSS

3.1 General Description of Data

Turbidity and TSS data have been collected in Lake Frierson by USGS, ADEQ, and FTN. The location of the USGS sampling site is shown on Figure A.1 (located in Appendix A). TSS data are discussed here because TSS is needed as a surrogate parameter for expressing this siltation/turbidity TMDL. These historical turbidity and TSS data were obtained from the USGS study of eleven lakes (USGS 2006c), the report for ADEQ data collected from 1989–1999 (ADEQ 2000), and unpublished ADEQ data collected in 2004 (ADEQ 2006). The historical data are summarized in Table 3.1 along with data collected by FTN during the fall of 2006. The individual data are listed in Table B.1 and shown graphically as time series plots on Figures B.1 and B.2 (located in Appendix B).

Table 3.1. Summary of data for turbidity and TSS.

Organization	Parameter	Count	Minimum	Median	Average	Maximum
USGS	Turbidity	6	32	61	72	120
	TSS	6	8	17	17	28
ADEQ	Turbidity	6	9.7	12	16	28
	TSS	6	13	17	17	23
FTN	Turbidity	8	200	235	228	240
	TSS	8	19	78	68	99

Table B.1 includes a comparison between the observed turbidity data and the numeric water quality criteria. This comparison required the observed data to be separated into base flow data (to be compared with the “primary” criterion) and storm-flow data (to be compared with the “storm-flow” criterion). It was assumed here that the lowest 40% of stream flow values represent flow conditions without significant influence from storm runoff and that stream flow values above the 40th percentile would have some influence from storm runoff. The turbidity data were considered to be base flow data when the flow on the sampling day at the USGS gage on

L'Anguille River was 224 cfs or less (the 40th percentile flow, or the flow that was exceeded 60% of the time). The turbidity data were considered to be storm-flow data when the flow on the sampling day at the USGS gage on L'Anguille River was 225 cfs or more. Table B.1 shows that, for the entire period of record, the turbidity data in Lake Frierson exceeded the applicable criteria 70% of the time during base flow conditions and 60% of the time during storm-flow conditions.

3.2 Seasonal Patterns

Seasonal patterns for turbidity and TSS could not be evaluated due to the lack of data.

3.3 Relationships Between Concentration and Flow

Plots of turbidity and TSS versus stream flow were developed to examine any correlation between these two parameters (Figures B.3 and B.4, located in Appendix B). These plots showed no noticeable relationship between concentration and flow. The highest turbidity values were from the samples collected by FTN during the fall of 2006, none of which occurred during very high flows.

3.4 Relationship Between TSS and Turbidity

A plot and regression analysis were used to examine the relationship between TSS and turbidity. The regression was performed using the natural logarithms of the TSS data (rather than the raw data values) because the data fit a semi-lognormal distribution better than several other distributions. The results of the linear regression analysis are summarized in Table 3.2 and the data are plotted on Figure B.5.

Table 3.2. Results of regression between TSS and turbidity.

Regression Equation	Number of Data	R ²	Significance Level (P value)
Turbidity = 101.31 × Ln(TSS) – 217.24	20	0.69	5.7 × 10 ⁻⁶

The strength of the linear relationship is measured by the coefficient of determination (R²) calculated during the regression analysis (Zar 1996). The R² value is the percentage of the

total variation in turbidity that is explained or accounted for by the fitted regression (Ln TSS). For example, in the regression above, 69% of the variation in turbidity is accounted for by TSS and the remaining 31% of variation in turbidity is unexplained. The unexplained portion is attributed to factors other than the measured value of TSS.

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

1. Velocity of the water at the time of sampling;
2. Carbonaceous biochemical oxygen demand (CBOD) concentration;
3. Ammonia concentration;
4. Nitrate concentration;
5. Phosphorus concentration;
6. Algal mass in the water column;
7. Bacteria mass in the water;
8. Measured color of the water;
9. Mass of the organic component of the TSS;
10. Mass of the material passing through the filter during the TSS analysis;
11. Grain size distribution of the inorganic portion of the TSS;
12. Specific gravity of the different sizes of inorganic solids particles;
13. Hydrograph for the inflowing stream;
14. Position on the hydrograph (i.e., rising limb, falling limb) at the time of sampling;
15. Number of overlapping rainfall events represented by this sample day;
16. Magnitude of each of the rainfall events represented by this sample day; and
17. Lags of the overlapping rainfall events represented by this sample day.

The collection of the above data would not change the fact that inorganic particles represented in the TSS measurements is the major contributor to the turbidity reading and is the major constituent 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 regression presented above between TSS and turbidity is adequate for the preparation of this TMDL. A stakeholder group of

knowledgeable persons from the watershed may need additional information to set a plan of action for this TMDL.

The statistical significance of the regression was evaluated by computing the “P value” for the slope of the regression line. 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 value for this regression is quite small and is considered good.

4.0 TMDL DEVELOPMENT

4.1 Seasonality and Critical Conditions

EPA's 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. No seasonal patterns could be evaluated due to the small amount of turbidity and TSS data for Lake Frierson. There is no evidence of a critical season for turbidity in Lake Frierson. The methodology used to develop this TMDL (load duration curve) addresses allowable loading for a wide range of flow conditions.

4.2 Water Quality Target

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, 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, "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 relationship between turbidity and TSS presented in Table 3.2 was used to develop target TSS concentrations (i.e., numeric endpoints) for this TMDL. The target TSS concentration developed for base flow conditions was 11 mg/L (using the primary turbidity criterion of 25 NTU). The target TSS concentration developed for storm-flow conditions was 13 mg/L (using the storm-flow turbidity criterion of 45 NTU). The discussion in Section 3.1 associating the primary turbidity standard with the base flow portion of the duration curve is the basis for using

the descriptor “base flow” in this document for the conditions when the “primary” turbidity standard should apply.

4.3 Methodology for TMDL Calculations

The methodology used for the TMDL in this report is the load duration curve. This TMDL represents a continuum of desired loads over all flow conditions (rather than fixed at a single value) because loading capacity varies as a function of the flow present in the stream. The basic elements of this procedure are documented on the Kansas Department of Health and Environment web site (KDHE 2005). This method was used to illustrate allowable loading at a wide range of flows. The steps for how this methodology was applied for the TMDL in this report can be summarized as follows:

1. Develop a flow duration curve (Section 4.4);
2. Convert the flow duration curve to load duration curves (Section 4.5);
3. Plot observed loads with load duration curves (Section 4.6);
4. Calculate TMDL, MOS, WLA, and LA (Sections 4.7-4.9); and
5. Calculate percent reductions (Section 4.10).

4.4 Flow Duration Curve

A flow duration curve was developed for the study area (see Table C.1 in Appendix C for details). Daily streamflow measurements from the L'Anguille River near Colt (USGS Gage No. 07047942) were sorted in increasing order and the percent exceedance of each flow was calculated. Then each L'Anguille River flow value was divided by the ratio of the Lake Frierson drainage area to the L'Anguille River at Colt drainage area. The duration curve of these estimated flows for Lake Frierson is shown on Figure C.1 in Appendix C.

4.5 Load Duration Curves

Each flow from the flow duration curve was multiplied by the appropriate TSS target concentration to develop plots of allowable load versus flow exceedance (load duration curves). The water quality standards for Arkansas (APCEC 2006) do not specify a range of flows or flow exceedances for which each of the turbidity criteria (primary and storm-flow) is applicable. As

discussed in Section 3.1, it was assumed here that the lowest 40% of stream flow values represent flow conditions without significant influence from storm runoff and that stream flow values above the 40th percentile would have some influence from storm runoff. The TSS target corresponding to the primary turbidity criterion was applied to the lowest 40% of flows (from 100 percent exceedance of stream flow to 60 percent exceedance of stream flow). The TSS target corresponding to the storm-flow turbidity criterion was applied from 60 percent exceedance of stream flow to 0 percent exceedance of stream flow. The load duration curves for storm-flow conditions and base flow conditions are shown on Figures C.2 and C.3 (in Appendix C).

4.6 Observed Loads

The observed TSS loads for Lake Frierson were calculated for each sampling day. Each observed load was calculated by simply multiplying the observed TSS concentration times the estimated flow on the sampling day (with a conversion factor incorporated).

The load duration plots (Figures C.2 and C.3) provide visual comparisons between observed and allowable loads under different flow conditions. Observed loads that are plotted above the load duration curve represent conditions where observed water quality concentrations exceed the target concentrations. Observed loads below the load duration curve represent conditions where observed water quality concentrations were less than target concentrations (i.e., not exceeding water quality criteria).

4.7 TMDL and MOS

The allowable load for storm-flow conditions was calculated as the TSS target for storm-flow conditions (13 mg/L) multiplied times the estimated Lake Frierson flow at the 30% flow exceedance. The 30% flow exceedance was used because it is considered to represent a typical flow value for storm-flow conditions (it is the midpoint along the flow duration curve between 0% and 60%). The allowable load for base flow conditions was calculated as the TSS target for base flow conditions (11 mg/L) multiplied times the estimated Lake Frierson flow at the 80% flow exceedance. The 80% flow exceedance was used because it is considered to

represent a typical flow value for base flow conditions (it is the midpoint along the flow duration curve between 60% and 100%). These calculations are shown at the bottom of Table C.1.

Both Section 303(d) of the Clean Water Act and regulations at 40 CFR 130.7 require TMDLs to include a MOS to account for uncertainty in available data or in the actual effect that controls will have on the loading reductions and receiving water quality. The MOS may be expressed explicitly as unallocated assimilative capacity or implicitly through conservative assumptions used in establishing the TMDL. For this TMDL, an implicit MOS was incorporated through the use of conservative assumptions. The primary conservative assumption was calculating the TMDL assuming that TSS is a conservative parameter and does not settle out of the water column.

4.8 Point Source Loads

The WLA was set to zero because there are no point source discharges that drain into Lake Frierson.

4.9 Nonpoint Source Loads

The LA for nonpoint sources, including natural background, results in being equal to the TMDL because the WLA was zero and the MOS was implicit.

4.10 Percent Reductions

In addition to calculating allowable loads, estimates were made for percent reductions of nonpoint source loads that are needed. For each observed TSS load that exceeded the allowable load at that flow (i.e., each observed TSS load above the allowable load curve in Figures C.2 and C.3), a uniform percent reduction was applied until the number of TSS loads exceeding the allowable loads was less than or equal to an acceptable number. For storm-flow conditions, the acceptable number of exceedances was 20% of the number of storm-flow data. This percentage (20%) was based on the Arkansas water quality standards, which state that “the non-point source runoff shall not result in the exceedance of the in stream storm-flow values in more than 20% of the ADEQ ambient monitoring network samples taken in not less than 24 monthly samples”

(APCEC 2006). For base flow conditions, the acceptable number of exceedances was 25% of the number of base flow data. This percentage (25%) was based on the ADEQ assessment methodology for turbidity for base flow conditions (ADEQ 2005b; p. 42). For both storm-flow and base flow conditions, whenever the appropriate percentage multiplied by the number of observed values yielded a fractional number (e.g., $25\% \times 9 = 2.25$), the allowable number of exceedances was rounded up to the next whole number (e.g., 2.25 rounded up to 3) in accordance with the ADEQ assessment methodology (ADEQ 2005b; p. 42). The calculations for percent reductions are shown in Tables C.2 and C.3 (in Appendix C) and are summarized in Table 4.1.

Table 4.1. Summary of turbidity TMDL for Lake Frierson.

Waterbody Name	Flow Category	Loads (lbs/day of TSS)				Percent Reduction Needed
		WLA	LA	MOS	TMDL	
Lake Frierson	Base flow	0	82.5	implicit	82.5	55%
	Storm-flow	0	939	implicit	939	82%

4.11 Future Growth

For this turbidity TMDL, typical point source discharges that might occur in the future would not need a WLA 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 most point sources are assumed to consist primarily of organic solids rather than inorganic solids. Discharges of organic suspended solids from point sources are already addressed by ADEQ through their permitting of point sources to maintain water quality standards for dissolved oxygen. Therefore, future growth for typical new point source discharges would not be restricted by this turbidity TMDL.

5.0 OTHER RELEVANT INFORMATION

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.

6.0 PUBLIC PARTICIPATION

When EPA establishes a TMDL, federal regulations require EPA to publicly notice and seek comment concerning the TMDL. Pursuant to a May 2000 consent decree, this TMDL was prepared under contract to EPA. After development of the draft version of this TMDL, EPA prepared a notice seeking comments, information, and data from the general public and affected public. No comments, data, or information were submitted during the public comment period. EPA has transmitted the final TMDL to ADEQ for implementation and for incorporation into ADEQ's current water quality management plan.

7.0 REFERENCES

- ADEQ. 2000. Water Quality Assessment of Arkansas' Significant Publicly-Owned Lakes, Summer 1999. Prepared by Arkansas Department of Environmental Quality. Downloaded from ADEQ web site (www.adeq.state.ar.us/water/branch_planning/pdfs/WQ00-06-1.pdf)
- ADEQ. 2005a. Arkansas Draft 2004 List of Impaired Waterbodies. Prepared by Arkansas Department of Environmental Quality, February 2005. Downloaded from ADEQ web site (www.adeq.state.ar.us/water/branch_planning/pdfs/303d_list_public_notice.pdf)
- ADEQ. 2005b. 2004 Integrated Water Quality Monitoring and Assessment Report. Prepared pursuant to Section 305(b) 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/WQ05-07-01.pdf)
- ADEQ. 2006. Unpublished data from ADEQ 2004 lake assessment. Obtained from ADEQ via e-mail, September 2006.
- APCEC. 2006. Regulation No. 2, As Amended. Regulation Establishing Water Quality Standards for Surface Waters of the State of Arkansas. Arkansas Pollution Control and Ecology Commission. Dated April 23, 2004 and amended April 28, 2006. Downloaded from ADEQ web site (www.adeq.state.ar.us/regs/files/reg02_final_060623.pdf)
- Barkley, Sam. 2006a. Personal communication with Sam Barkley, Arkansas Game & Fish Commission, October 23, 2006.
- Barkley, Sam. 2006b. Lake Frierson Greene County 2006 Annual Fish Population Sampling Report. Published August 2006.
- CAST. 2005. Land Use / Land Cover Summer 2004. Dataset developed by Center for Advanced Spatial Technologies, University of Arkansas, Fayetteville. Downloaded from CAST web site (www.geostor.arkansas.gov/Portal/index.jsp)
- EPA. 1991. Monitoring Guidelines to Evaluate Effects of Forestry Activities on Streams in Pacific Northwest. EPA 910/9-91/001. Region 10, U.S. Environmental Protection Agency, Seattle, WA.
- EPA. 2006. EPA's Record of Decision on the 2004 Arkansas §303(d) List. Downloaded from EPA web site (www.epa.gov/region6/water/npdes/tmdl/2006/arkansas/rod_final.pdf)
- KDHE. 2005. "Kansas TMDL Curve Methodology". Web site maintained by Kansas Department of Health and Environment (www.kdheks.gov/tmdl/basic.htm#data)
- NCDC. 2006. National Climactic Data Center web site. Maintained by National Oceanic and Atmospheric Administration. <http://www.ncdc.noaa.gov/oa/ncdc.html>
- NCSS. 2006. National Cooperative Soil Survey. Web site maintained by Natural Resource Conservation Service (NRCS). <http://websoilsurvey.nrcs.usda.gov/app/>
-

- PCS. 2006. Permit Compliance System web site. Maintained by U.S. Environmental Protection Agency. www.epa.gov/enviro/html/pcs/adhoc.html
- 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.
- Standard Methods. 1999. Standard Methods for the Examination of Water and Wastewater. 20th Edition. Published by American Public Health Association, American Water Works Association, and Water Environment Federation.
- USDA. 1979. Soil Survey for Craighead County, Arkansas. Published by Soil Conservation Service, U.S. Department of Agriculture in cooperation with Arkansas Agricultural Experiment Station. December 1979.
- USGS. 2006a. National Water Information System web site. Maintained by United States Geological Survey. <http://waterdata.usgs.gov/ar/nwis/nwis>
- USGS. 2006b. United States Geological Survey, Little Rock District Office. Daily flow data sent to FTN on October 24, 2006 via e-mail.
- USGS. 2006c. Water Quality of Eleven Lakes in Eastern and Southern Arkansas from August 2004 - July 2005. Scientific Investigations Report 2006-5047. Published by United States Geological Survey, Little Rock District. Downloaded from USGS web site (<http://pubs.usgs.gov/sir/2006/5047/pdf/SIR2006-5047.pdf>)
- Zar, J.H., 1996. Biostatistical Analysis (3rd ed.). New Jersey: Prentice Hall.

APPENDIX A

Maps

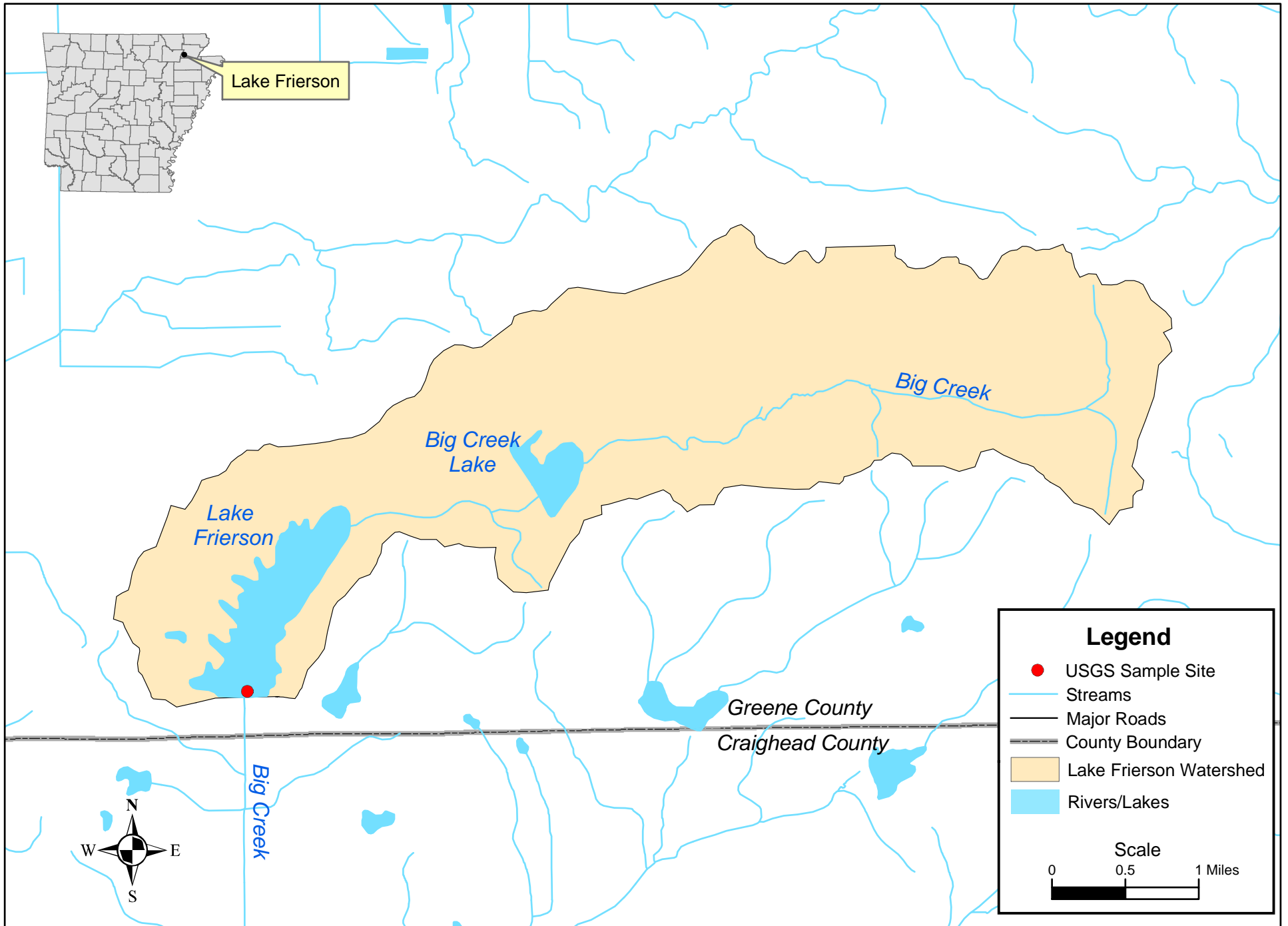


Figure A.1. Watershed Map for Lake Frierson

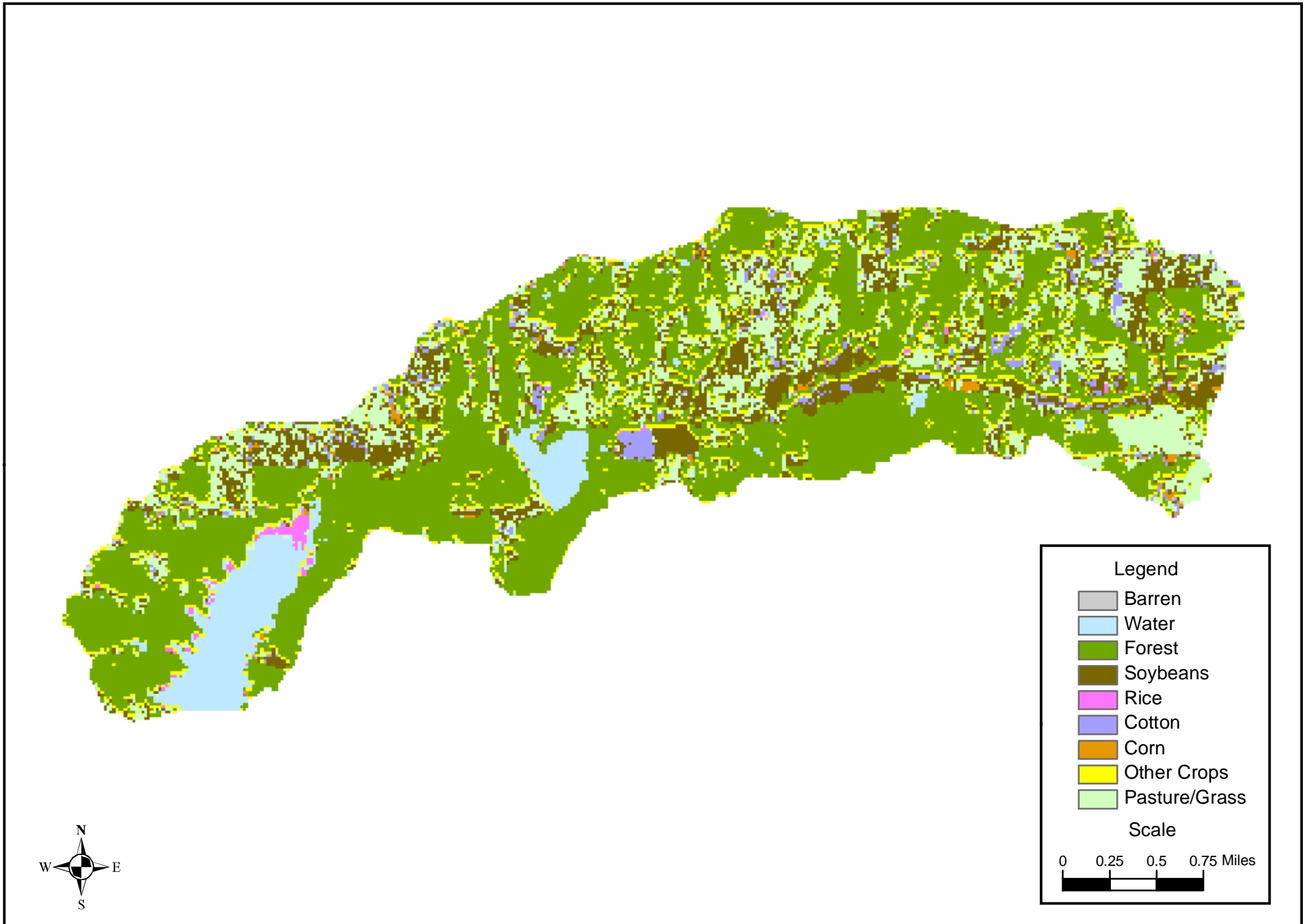


Figure A.2. Land Use Map for Lake Frierson

APPENDIX B

Plots of Turbidity and TSS

Table B.1. Summary of turbidity values and standard violations for Lake Frierson.

Source	Date	Turbidity (NTU)	Est. Flow for Lake Frierson (cfs)	Category	Base flow crit. Violation?	Storm-flow crit. Violation?
USGS	8/24/2004	120	15	Storm-Flow		yes
	10/20/2004	120	12	Storm-Flow		yes
	12/6/2004	78	40	Storm-Flow		yes
	2/9/2005	39	18	Storm-Flow		no
	4/27/2005	32	10	Storm-Flow		no
	6/8/2005	44	1	Base flow	yes	
ADEQ	8/4/1994	10	10	Storm-Flow		no
	7/28/1999	11	2	Base flow	no	
	7/26/2004	23.4	3	Base flow	no	
	8/4/1994	9.7	10	Storm-Flow		no
	7/28/1999	13	2	Base flow	no	
	7/26/2004	28.1	3	Base flow	yes	
FTN	9/11/2006	200	1	Base flow	yes	
	9/14/2006	210	1	Base flow	yes	
	9/18/2006	240	3	Base flow	yes	
	9/21/2006	240	8	Storm-Flow		yes
	9/26/2006	240	8	Storm-Flow		yes
	9/28/2006	230	6	Storm-Flow		yes
	10/2/2006	240	3	Base flow	yes	
	10/5/2006	220	2	Base flow	yes	
No. of violations =					7	6
No. of values =					10	10
% of violations =					70%	60%

FILE: R:\PROJECTS\2110-621\TECH\FRIERSON_TMDL\LAKE FRIERSON TMDL.XLS

Figure B.1. Time Series Plot of Turbidity for Lake Frierson

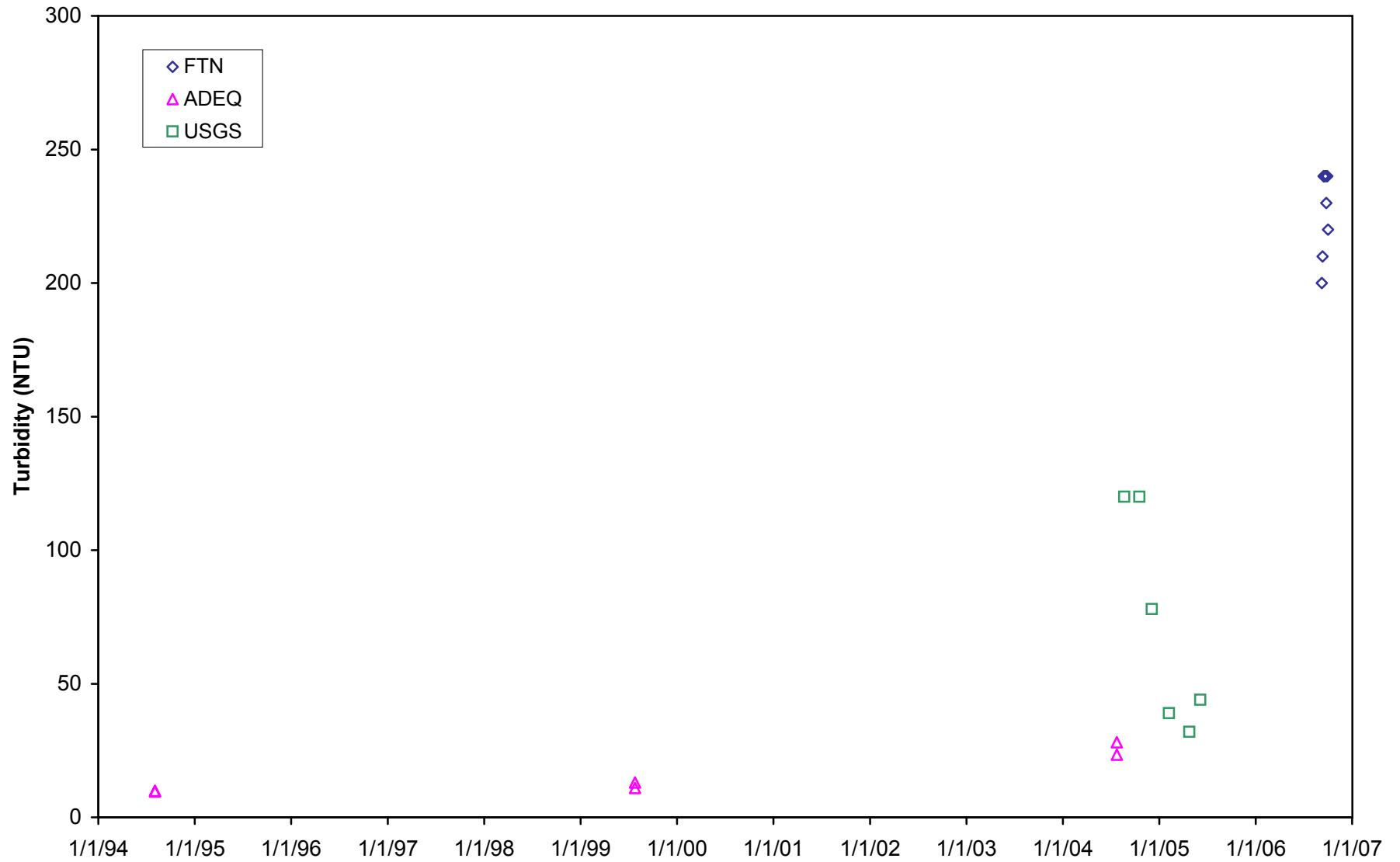


Figure B.2. Time Series Plot of TSS for Lake Frierson

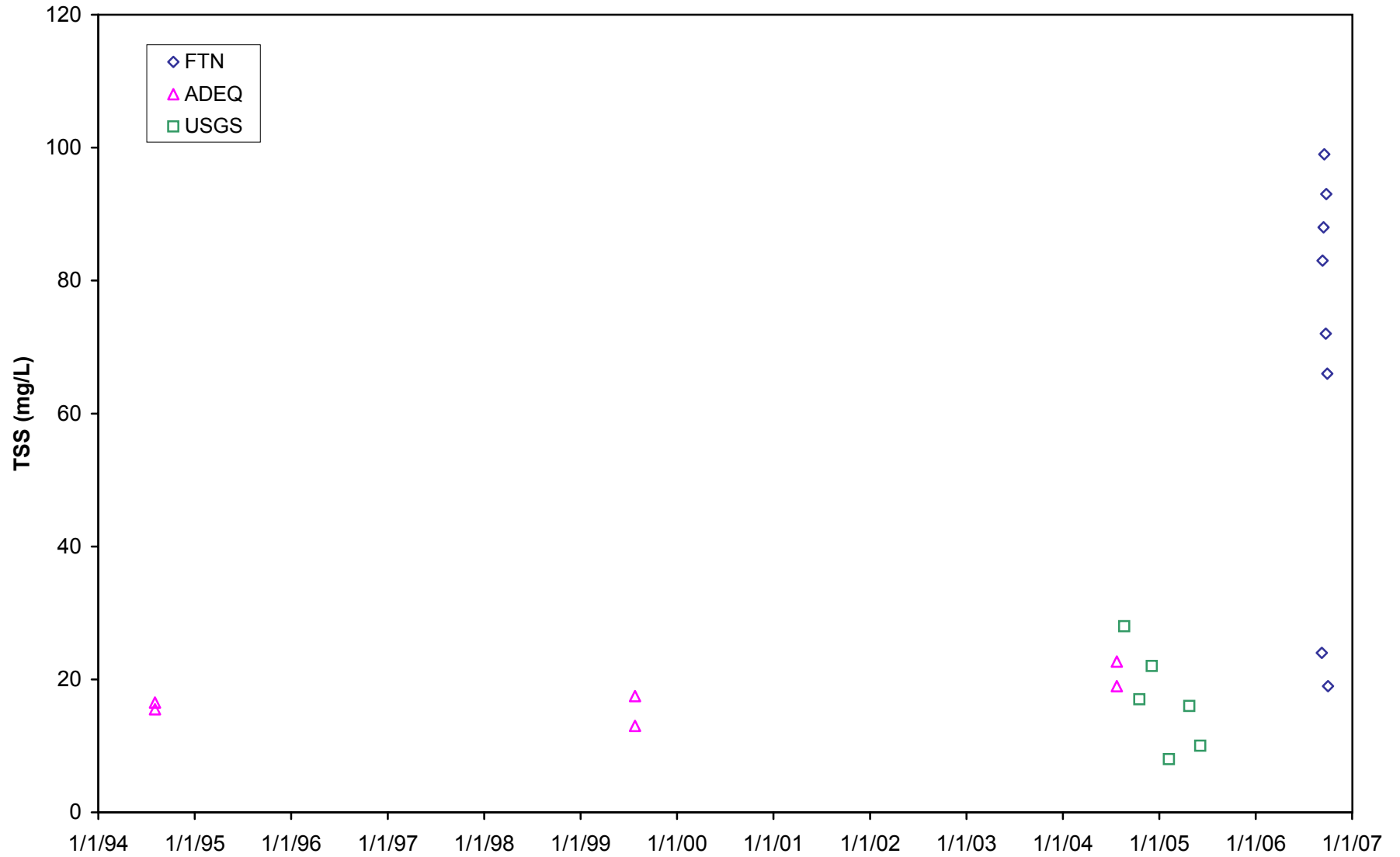


Figure B.3. Turbidity vs flow for Lake Frierson

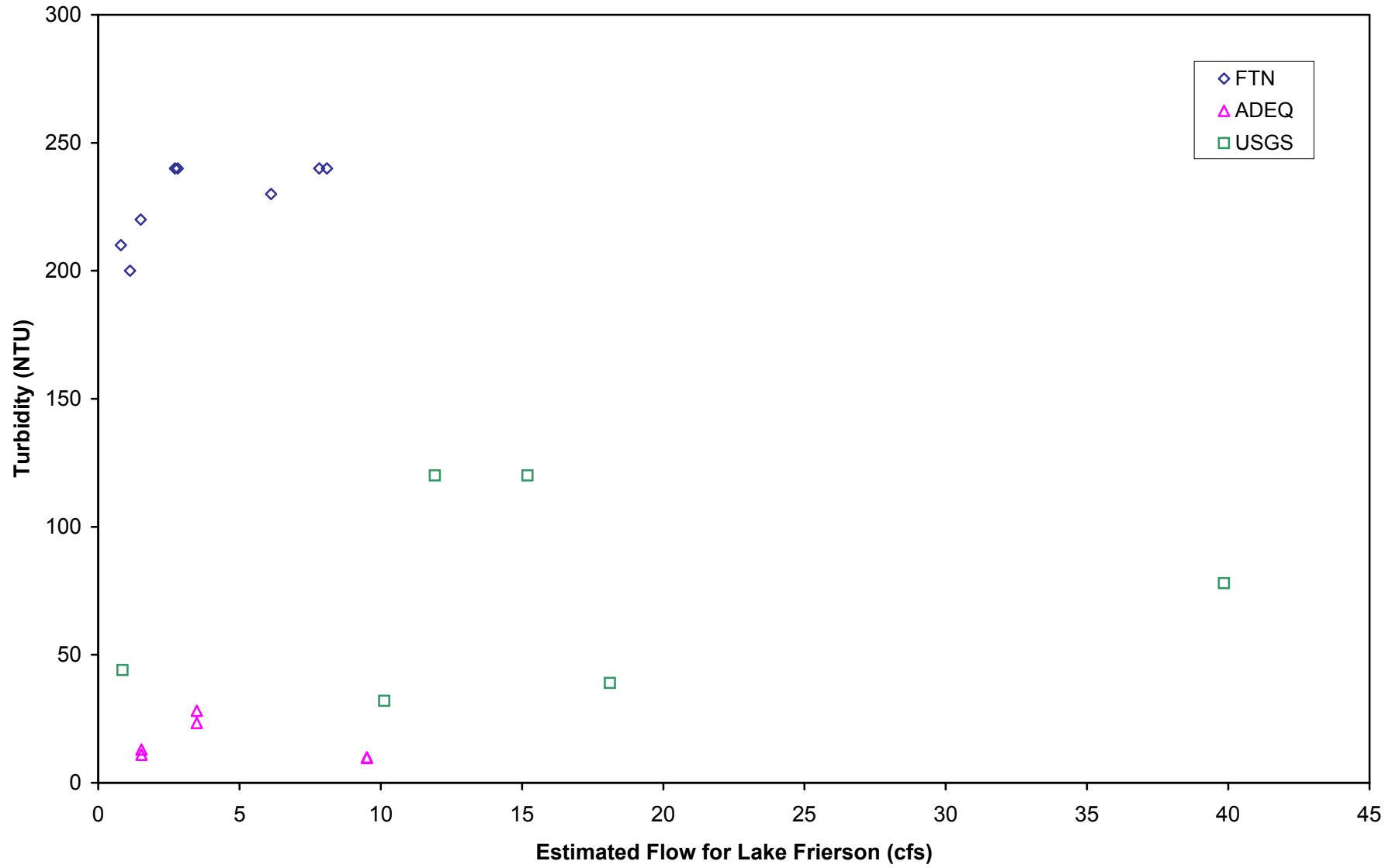


Figure B.4. TSS vs flow for Lake Frierson

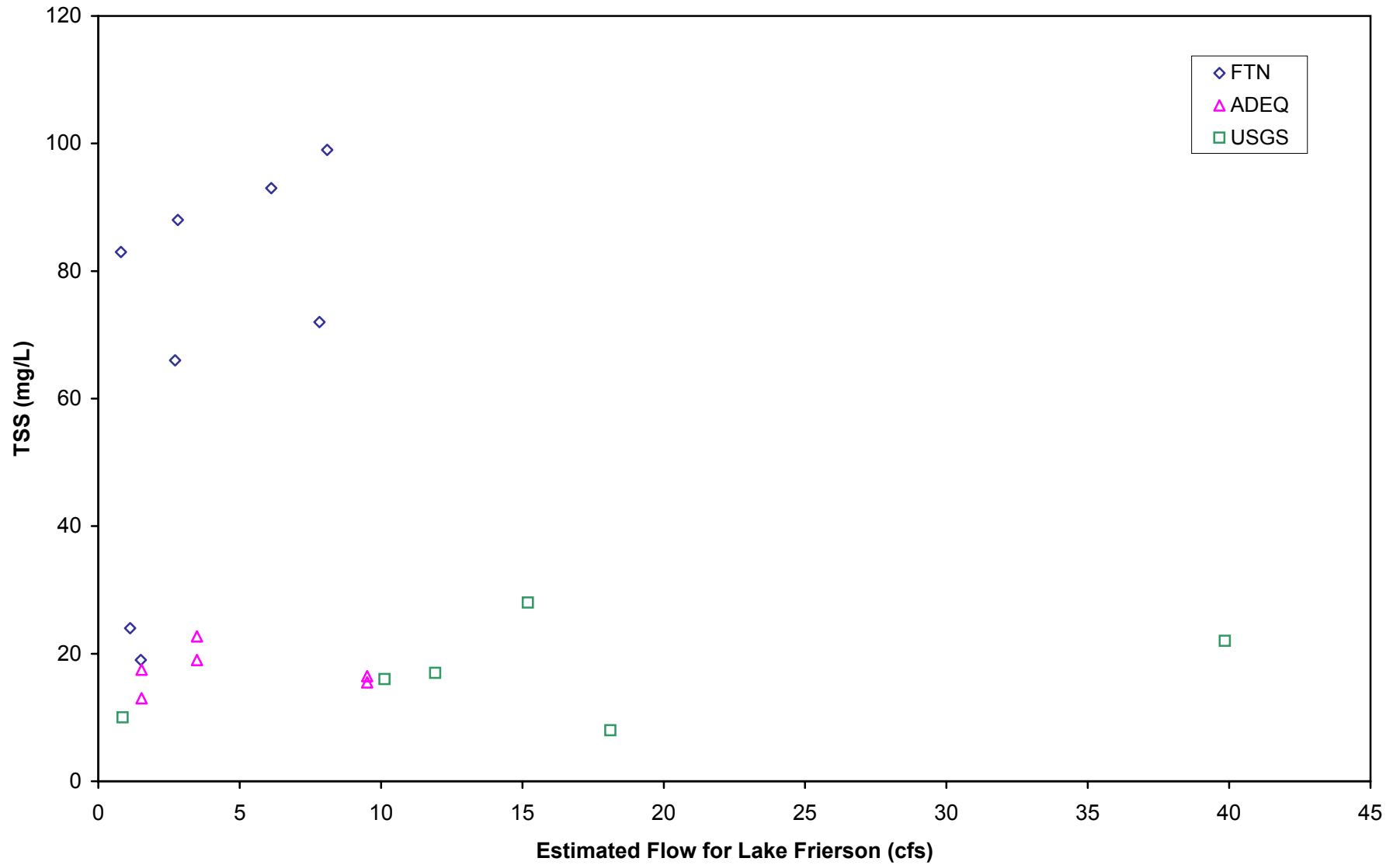
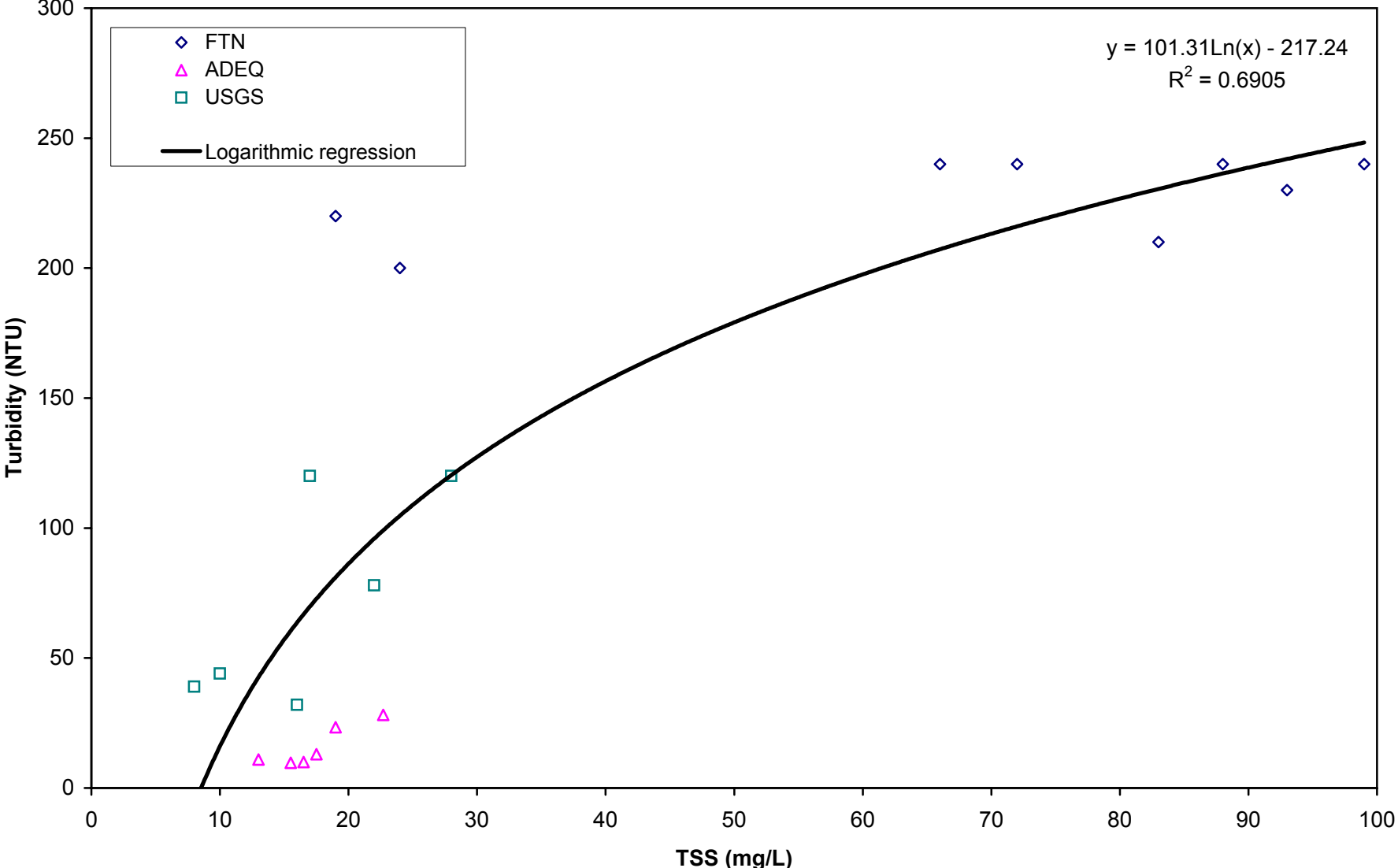


Figure B.5. Turbidity vs TSS for Lake Frierson



APPENDIX C

Load Duration Curves and TMDL Calculations

TABLE C.1. CALCULATIONS FOR ALLOWABLE LOAD FOR LAKE FRIERSON.

Flow for L'Anguille near Colt (cfs)	Est. Flow for Lake Frierson (cfs)	Percent of days flow exceeded	WQ Standard category	Turbidity Criterion (NTU)	Target TSS conc. (mg/L)	Allowable TSS load (lbs/day)
1.0	0.019	99.977	Base flow	25	11	1.13E+00
1.1	0.021	99.943	Base flow	25	11	1.24E+00
1.2	0.023	99.924	Base flow	25	11	1.36E+00

The rows between 99.924% and 80.018% percent exceedance have been hidden for the sake of brevity.

73	1.39	80.018	Base flow	25	11	8.25E+01
----	------	--------	-----------	----	----	----------

The rows between 80.018% and 60.181% percent exceedance have been hidden for the sake of brevity.

223	4.25	60.181	Base flow	25	11	2.52E+02
223	4.25	60.124	Base flow	25	11	2.52E+02
224	4.27	60.082	Base flow	25	11	2.53E+02
225	4.29	59.980	Storm-flow	45	13	3.01E+02
226	4.31	59.862	Storm-flow	45	13	3.02E+02
227	4.32	59.805	Storm-flow	45	13	3.03E+02

The rows between 59.805% and 30.011% percent exceedance have been hidden for the sake of brevity.

704	13.4	30.011	Storm-flow	45	13	9.39E+02
-----	------	--------	------------	----	----	----------

The rows between 30.011% and 0.027% percent exceedance have been hidden for the sake of brevity.

13000	248	0.027	Storm-flow	45	13	1.74E+04
14300	273	0.019	Storm-flow	45	13	1.91E+04
15000	286	0.008	Storm-flow	45	13	2.00E+04

Flow in middle of base flow range (80% exceedance) = 1.39 cfs
 Target TSS for base flow conditions for Lake Frierson = 11 mg/L
 Allowable TSS load for base flow conditions for Lake Frierson = 82.5 lbs/day

Flow in middle of stormwater range (30% exceedance) = 13.4 cfs
 Target TSS for stormwater conditions for Lake Frierson = 13 mg/L
 Allowable TSS load for stormwater conditions for Lake Frierson = 939 lbs/day

FILE: R:\PROJECTS\2110-621\TECH\FRIERSON_TMDL\LAKE FRIERSON TMDL.XLS

TABLE C.2. CALCULATIONS FOR PERCENT REDUCTION FOR STORM-FLOW CONDITIONS FOR LAKE FRIERSON

Storm-flow target TSS conc. = 13 mg/L Error check for reduction is / is not needed: OK
 Percent reduction needed = 82% Error check for less or more reduction needed: OK

<u>Category</u>	<u>Date</u>	<u>Observed TSS (mg/L)</u>	<u>Est. flow on sampling day (cfs)</u>	<u>Percent exceedance for flow on sampling day</u>	<u>Current TSS load (lbs/day)</u>	<u>Reduced TSS load (lbs/day)</u>	<u>Allowable TSS load (lbs/day)</u>	<u>Reduced load less than or equal to allow. load?</u>
Storm-flow	8/24/2004	28	15	26.2%	2294.5	413.0	1065.3	Yes
Storm-flow	10/20/2004	17	12	33.7%	1092.5	196.6	835.4	Yes
Storm-flow	12/6/2004	22	40	7.9%	4727.7	851.0	2793.6	Yes
Storm-flow	2/9/2005	8	18	21.5%	781.4	140.7	1269.8	Yes
Storm-flow	4/27/2005	16	10	38.7%	873.6	157.2	709.8	Yes
Storm-flow	8/4/1994	16.5	10	40.5%	846.6	152.4	667.0	Yes
Storm-flow	8/4/1994	15.5	10	40.5%	795.3	143.1	667.0	Yes
Storm-flow	9/21/2006	99	8	45.1%	4321.5	777.9	567.5	No
Storm-flow	9/26/2006	72	8	45.9%	3037.4	546.7	548.4	Yes
Storm-flow	9/28/2006	93	6	52.0%	3069.9	552.6	429.1	No

Total number of values = 10
 Allowable % of exceedances = 20%
 Allowable no. of exceedances = 2
 No. of exceedances before reductions = 9
 No. of exceedances after reductions = 2

FILE: R:\PROJECTS\2110-621\TECH\FRIERSON_TMDL\LAKE FRIERSON TMDL.XLS

TABLE C.3. CALCULATIONS FOR PERCENT REDUCTION FOR BASE FLOW CONDITIONS FOR LAKE FRIERSON

Base flow target TSS conc. = 11 mg/L Error check for reduction is / is not needed: OK
 Percent reduction needed = 55% Error check for less or more reduction needed: OK

<u>Category</u>	<u>Date</u>	<u>Observed TSS (mg/L)</u>	<u>Est. flow on sampling day (cfs)</u>	<u>Percent exceedance for flow on sampling day</u>	<u>Current TSS load (lbs/day)</u>	<u>Reduced TSS load (lbs/day)</u>	<u>Allowable TSS load (lbs/day)</u>	<u>Reduced load less than or equal to allow. load?</u>
Base flow	6/8/2005	10	1	85.8%	46.27	20.82	50.90	Yes
Base flow	7/28/1999	13	2	78.8%	106.93	48.12	90.48	Yes
Base flow	7/26/2004	19	3	64.5%	357.50	160.88	206.98	Yes
Base flow	7/28/1999	17.5	2	78.8%	143.95	64.78	90.48	Yes
Base flow	7/26/2004	22.7	3	64.5%	427.12	192.21	206.98	Yes
Base flow	9/11/2006	24	1	82.8%	145.30	65.38	66.59	Yes
Base flow	9/14/2006	83	1	86.3%	359.62	161.83	47.66	No
Base flow	9/18/2006	88	3	69.3%	1334.60	600.57	166.83	No
Base flow	10/2/2006	66	3	69.9%	967.36	435.31	161.23	No
Base flow	10/5/2006	19	2	79.1%	153.77	69.19	89.02	Yes

Total number of values = 10
 Allowable % of exceedances = 25%
 Allowable no. of exceedances = 3
 No. of exceedances before reductions = 9
 No. of exceedances after reductions = 3

FILE: R:\PROJECTS\2110-621\TECH\FRIERSON_TMDL\LAKE FRIERSON TMDL.XLS

Figure C.1. Flow Duration for Lake Frierson

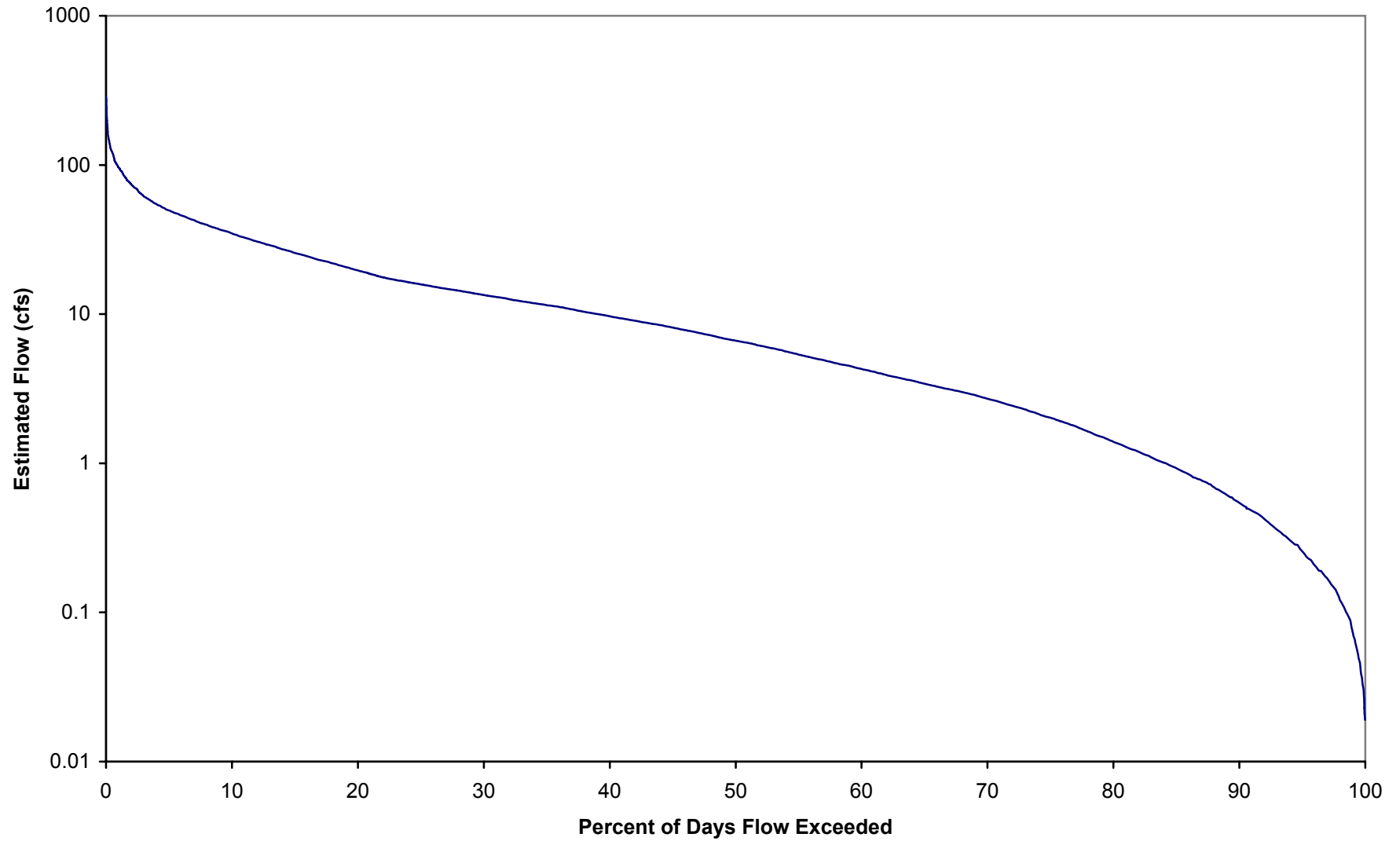


Figure C.2. Storm Flow Load Duration Curve for Lake Frierson

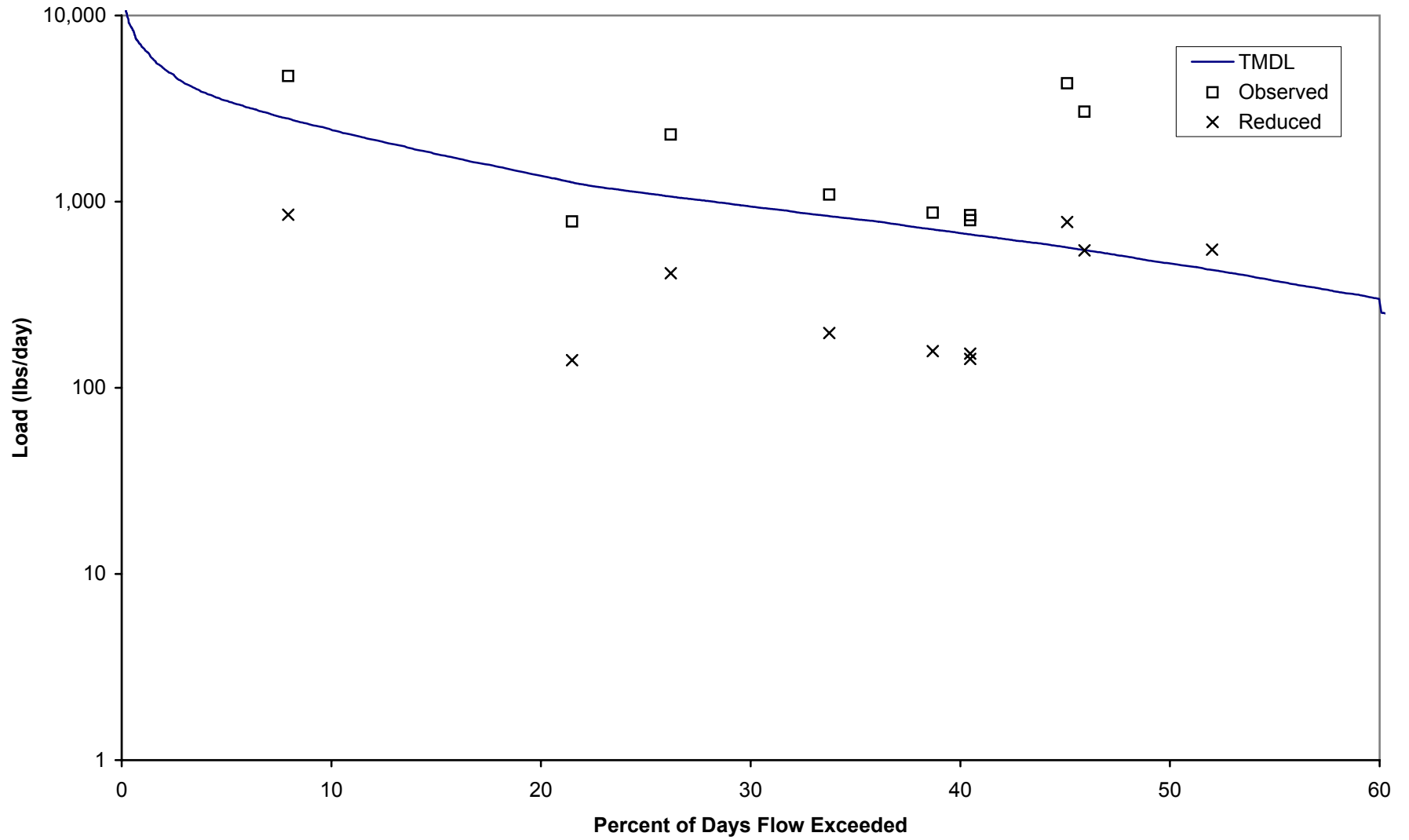


Figure C.3. Base Flow Load Duration Curve For Lake Frierson

