TMDLS FOR CHLORIDE, SULFATE, AND TDS IN THE CROOKED CREEK WATERSHED, ARKANSAS

DRAFT
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Prepared for

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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 the entire length of Crooked Creek, which is divided into two reaches for assessment purposes (reaches 11010003-048 and 11010003-049). For reach 11010003-048 (the downstream reach), a TMDL was developed for total dissolved solids (TDS). For reach 11010003-049 (the upstream reach), TMDLs were developed for chloride, sulfate, and TDS.

Crooked Creek originates in the Ozark Mountains near Harrison, Arkansas and flows generally eastward across northern Arkansas to the White River. The drainage area of Crooked Creek at its mouth is approximately 462 square miles. The Crooked Creek watershed is in the Ozark Highlands ecoregion, with 94% of the watershed covered by forest or grass. There are three continuous point source discharges and 33 regulated stormwater discharges in the watershed. The three continuous point source discharges are the wastewater treatment plants for the City of Yellville and the City of Harrison and a small groundwater treatment system (DM Petroleum Cleanup).

These two reaches of Crooked Creek were listed as impaired on the final version of the 2008 303(d) list for Arkansas and on the draft version of the 2010 303(d) list for Arkansas. The pollutants causing the impairments were listed as TDS for reach 11010003-048, and chloride, sulfate, and TDS for reach 11010003-049. The suspected pollutant sources were listed as “resource extraction” and “unknown”.

The Arkansas Department of Environmental Quality (ADEQ) had collected historical water quality data at five locations along these two reaches of Crooked Creek. These data were tabulated and analyzed for basic statistics, seasonal patterns, and relationships between concentration and stream flow. Concentrations of chloride, sulfate, and TDS tended to be slightly

higher just downstream of Harrison than they were farther downstream near Yellville. In the seasonal analysis, a few of the data showed slightly higher concentrations in the late summer and fall. Many of the plots of concentration versus stream flow indicated that the highest concentrations tended to occur during lower flows.

The load duration curve method was used to develop all four TMDLs (one chloride, one sulfate, and two TDS) in this report. 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 a flow duration curve; 2) converting the flow duration curve to load duration curves; 3) plotting observed loads with load duration curves; and 4) calculating the TMDL, margin of safety (MOS), wasteload allocation (WLA), and load allocation (LA).

The load duration curves were plotted with units of tons/day on the vertical axis and percent exceedance (unitless) on the horizontal axis. Each TMDL was calculated as the area under the load duration curve. Five percent (5%) of each TMDL was set aside as an explicit MOS.

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 a NPDES permit. The total diffuse loading was divided between regulated stormwater and nonpoint source inflows based on drainage area. The loads from regulated stormwater were assigned to a WLA and the remaining diffuse loading was assigned to the LA.

The loading that was available for continuous point source discharges was calculated by taking each TMDL and subtracting the MOS, the WLA for regulated stormwater, and the LA for nonpoint sources.

The results of the TMDL calculations and percent reduction calculations are summarized in Tables ES.1 and ES.2.

Table ES.1 Summary of TMDL for reach 11010003-048

	Allowable loads of TDS (tons/day)
WLA for non-stormwater point source discharges	5.73
WLA for NPDES-regulated stormwater (9 facilities)	0.28
LA for nonpoint sources	232.60
MOS	12.56
TMDL	251.17

Table ES.2 Summary of TMDLs for reach 11010003-049

	Allowable loads (tons/day)		
	Chloride	**Sulfate**	**TDS**
WLA for non-stormwater point source discharges	7.70	7.57	11.23
WLA for NPDES-regulated stormwater (24 facilities)	0.02	0.02	0.70
LA for nonpoint sources	3.23	3.36	97.57
MOS	0.58	0.58	5.76
TMDL	11.53	11.53	115.26

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1.0 INTRODUCTION

This report presents total maximum daily loads (TMDLs) for the entire length of Crooked Creek, which is divided into two reaches for assessment purposes (reaches 11010003-048 and 11010003-049). For reach 11010003-048 (the downstream reach), a TMDL was developed for total dissolved solids (TDS). For reach 11010003-049 (the upstream reach), TMDLs were developed for chloride, sulfate, and TDS. These two stream reaches were listed as impaired on the final version of the 2008 303(d) list for Arkansas (United States Environmental Protection Agency (USEPA) 2008) and on the draft version of the 2010 303(d) list for Arkansas (Arkansas Department of Environmental Quality (ADEQ) 2010). Table 1.1 presents relevant information from the draft 2010 303(d) list concerning these two stream reaches. The TMDLs in this report were developed in accordance with Section 303(d) of the Federal Clean Water Act and USEPA 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 water body 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 Information from the 2010 draft 303(d) list for TMDLs in this report.

Reach Number	Stream Name	Impaired Use	Pollutants Causing Impairment	Suspected Pollutant Sources	TMDL Priority
11010003-048	Crooked Creek	Fisheries[1]	TDS	Resource extraction	Low
11010003-049	Crooked Creek	Fisheries[1]	Chloride, Sulfate, TDS	Unknown	Low

[1] Referred to as Aquatic Life Use in previous 303(d) lists

2.0 BACKGROUND INFORMATION

2.1 General Information

The study area for this report is the watershed for Crooked Creek in northern Arkansas (see Figure A.1 in Appendix A). Crooked Creek originates southwest of Harrison and flows generally eastward before emptying into the White River. Crooked Creek is divided into two reaches for ADEQ's assessments and 303(d) lists; reach 11010003-049 is the portion of Crooked Creek that is upstream of the confluence of Clear Creek and reach 11010003-048 is the portion of Crooked Creek that is downstream of the confluence of Clear Creek.

The drainage area of Crooked Creek at its mouth is approximately 462 square miles (United States Geological Survey (USGS) 1974). The Crooked Creek watershed is in the Ozark Highlands ecoregion and in ADEQ Planning Segment 4I. Most of the watershed lies within Boone and Marion counties.

2.2 Land Use

Land use data for the study area have been published by the Center for Advanced Spatial Technology (CAST) at the University of Arkansas in Fayetteville. These data were based on satellite imagery from the summer of 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 show that the primary land uses in the study area are forest and grass.

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

Land Use Category	Percentage of Study Area
Low Intensity Urban	2.3%
High Intensity Urban	0.6%
Barren Land	0.8%
Herbaceous / Woody	2.3%
Forest	54.8%
Warm Season Grass	9.5%
Cool Season Grass	29.7%
TOTAL	100.0%

2.3 Stream Flow Data

The TMDLs in this report were developed using Crooked Creek flow data from two USGS gaging stations that essentially represent one location. The original station at Yellville (07055608) was replaced by another station slightly upstream at Kelly Crossing at Yellville (07055607). Due to their proximity, their combined period of record was used for the TMDLs in this report. Selected information for these gages is summarized in Table 2.2. The locations of these gaging stations are shown on Figure A.1 in Appendix A. These are the only USGS gaging stations with continuous daily flow data for Crooked Creek.

Table 2.2 Information for USGS stream flow gaging stations (USGS 2004; USGS 2010)

Gage number	Gage name	Descriptive location	Period of record	Drainage area (square miles)
07055607	Crooked Creek at Kelly Crossing at Yellville, AR	Left bank before Kelly low water crossing on County Road 4002	December 2006 – present	398
07055608	Crooked Creek at Yellville, AR	Left bank at bridge on State Hwy 14	July 1988 – September 1994, October 2001 – September 2003	406

2.4 Water Quality Standards

Water quality standards for Arkansas waterbodies are listed in Regulation No. 2 (Arkansas Pollution Control and Ecology Commission (APCEC) 2010). Designated uses for Crooked Creek are primary and secondary contact recreation; domestic, industrial, and agricultural water supply; and perennial Ozark Highlands fishery.

Section 2.511 of Regulation No. 2 provides both a narrative criterion and numeric criteria for dissolved minerals. The general narrative criterion is: “Mineral quality shall not be altered by municipal, industrial, other waste discharges or instream activities so as to interfere with designated uses.” The regulation also includes a list of numeric criteria for dissolved minerals for specific streams. The stream-specific numeric criteria for Crooked Creek are 20 mg/L for chloride, 20 mg/L for sulfate, and 200 mg/L for TDS.

As specified in USEPA'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 2008 Integrated Report specified resource extraction and unknown sources as the suspected sources of dissolved minerals in Crooked Creek (ADEQ 2008). The discharge permit for the City of Harrison wastewater treatment plant (WWTP) states that “the elevated minerals concentrations [in Crooked Creek] are a reflection of the geology of the watershed. Crooked Creek arises in an area known as the Bloyd Shale, which is rich in chlorides and sulfates” (ADEQ 2007).

2.6 Point Sources

Information for point source discharges in the study area was obtained by searching USEPA’s Integrated Compliance Information System - National Pollutant Discharge Elimination System (ICIS-NPDES) and ADEQ’s online NPDES permits database. The search yielded three facilities with continuous discharges and 33 facilities with stormwater discharges. Selected information for these facilities is presented in Tables 2.3 and 2.4. Locations of the facilities are

shown on Figure A.3 in Appendix A. None of these facilities has permit limits or monitoring requirements for chloride, sulfate, or TDS.

Table 2.3 List of point source discharges for reach 11010003-048

Permit No.	Facility Name	Type of Discharge	Receiving Waterbody	Permit Expiration Date
AR0034037	City of Yellville	Domestic wastewater [1]	Crooked Crk	2/28/2015
ARR000112	Mountain Home Concrete	Stormwater	Crooked Crk	2/01/2011
ARR000120	Mountain Home Concrete	Stormwater	Crooked Crk	2/01/2011
ARR00A247	King Ready Mix	Stormwater	Crooked Crk	2/01/2011
ARR00B549	Tucker Lumber Co	Stormwater	Crooked Crk	2/01/2011
ARR00B747	APAC Arkansas	Stormwater	Elm Branch, Hug Crk, Crooked Crk	6/30/2014
ARR00B748	APAC Arkansas	Stormwater	Trib, Hog Crk, Crooked Crk	2/01/2011
ARR00B955	Marion Co Transfer Station	Stormwater	Crooked Crk.	2/01/2011
ARR00C059	McClain Forest Products	Stormwater	Ditch,Clear Crk, Crooked Crk	6/30/2014
ARR153381	Pyatt, Town of	Stormwater	Crooked Crk	10/31/2011

[1] Design flow for City of Yellville WWTP is 0.75 MGD.

Table 2.4 List of point source discharges for reach 11010003-049

Permit No.	Facility Name	Type of Discharge	Receiving Waterbody	Permit Expiration Date
AR0034321	City of Harrison	Domestic wastewater [1]	Crooked Crk	9/30/2012
ARG790092	DM Petroleum Cleanup	Treated groundwater [2]	Trib, Crooked Crk	3/31/2011
ARR000163	Yeager Auto Salvage	Stormwater	Dry Jordan Crk, Crooked Crk	6/30/2014
ARR000259	Methvin Sanitation	Stormwater	Crooked Crk	2/01/2011
ARR000388	Harmon Metal	Stormwater	Trib, Crooked Crk	2/01/2011
ARR000399	Harriscrap	Stormwater	Dry Jordan Crk, Crooked Crk	2/01/2011
ARR00A050	Tyson Foods - Bergman Feedmill	Stormwater	Sugar Orchard Crk, Crooked Crk	6/30/2014
ARR00A123	Ark Products Co.	Stormwater	Crooked Crk	6/30/2014
ARR00A265	ADC Manufacturing	Stormwater	Dry Jordan Crk, Crooked Crk	6/30/2014
ARR00A322	Tankinetics	Stormwater	Dry Jordan Crk, Crooked Crk	2/01/2011
ARR00A566	Claridge Products & Equipment	Stormwater	Crooked Crk	2/01/2011
ARR00A641	Claridge Extrusions	Stormwater	Dry Branch,Crooked Crk	2/01/2011
ARR00A804	M & M Ready Mix	Stormwater	Dry Jordan Crk, Crooked Crk	2/01/2011
ARR00A979	Pace Industries	Stormwater	Dry Jordan Crk, Crooked Crk	6/30/2014
ARR00B256	FedEx Freight	Stormwater	Dry Jordan Crk, Crooked Crk	6/30/2014
ARR00B355	Flexsteel Industries	Stormwater	Crooked Crk	6/30/2014
ARR00B386	United Parcel Service	Stormwater	Dry Jordan Crk, Crooked Crk	6/30/2014
ARR00B437	Rock-Tenn Co	Stormwater	Dry Jordan Crk, Crooked Crk	2/01/2011
ARR00B457	Harrison Auto Salvage	Stormwater	Huzzan Crk, Crooked Crk	2/01/2011
ARR00B517	Distribution Solutions	Stormwater	Crooked Crk	6/30/2014
ARR00C036	Wabash National Wood Products	Stormwater	Dry Jordan Crk, Crooked Crk	6/30/2014
ARR00C194	ABC Block	Stormwater	Dry Jordan Crk, Crooked Crk	2/01/2011
ARR00C230	Wood Creek	Stormwater	Crooked Crk	2/01/2011
ARR00C373	Harrison, City of / WWTP	Stormwater	Crooked Crk	6/30/2014
ARR00C478	Danny Hall's Quarry	Stormwater	Trib, Crooked Crk	2/01/2011
ARR151875	Harrison, City of / WWTP	Stormwater	Crooked Crk	10/31/2011

[1] Design flow for City of Harrison WWTP is 2.60 MGD.

[2] Design flow for DM Petroleum Cleanup is 0.029 MGD.

2.7 Previous Water Quality Studies

No previous water quality studies were found for Crooked Creek.

3.0 EXISTING WATER QUALITY

3.1 General Description of Data

Routine monitoring data for chloride, sulfate, and TDS have been collected by ADEQ at seven sites along Crooked Creek. Data from two of the sites (WHI0193 and WHI0048A) were combined due to their proximity and the fact that the official site description for WHI0048A indicates that it replaced WHI0193 on August 8, 2006. 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. Appendix B includes tabular listings of the individual data (Tables B.1 – B.5) and time series plots of the data (Figures B.1 – B.15).

For chloride and sulfate, WHI0066 (Crooked Creek below Harrison) was the only site with more than 10% of the values above the criteria. For TDS, though, all of the sites had more than 10% of the values above the criterion.

For all three parameters (chloride, sulfate, and TDS), the median concentrations and numbers of criterion exceedances were higher at WHI0066 than at WHI0193 and WHI0048A (the next sites downstream of WHI0066). This suggests that dissolved minerals in Crooked Creek are being diluted by inflows between Harrison and Yellville.

3.2 Seasonal Patterns

Seasonal plots of chloride, sulfate, and TDS concentrations in Crooked Creek are shown on Figures C.1 – C.15 in Appendix C. Most of the plots appeared to have little or no correlation between concentrations and time of the year. However, several plots showed generally higher concentrations and greater numbers of criterion exceedances in the late summer and fall (Figure C.3 – TDS at WHI0067, Figure C.4 – chloride at WHI0066, and Figure C.6 – TDS at WHI0066). Because the WHI0067 data are collected upstream of any point source discharges, the seasonal pattern of TDS data at that site suggest that subsurface seepage into the stream in the upper part of the watershed may have high concentrations of TDS.

Table 3.1 Summary of ADEQ dissolved mineral data for Crooked Creek

	WHI0067	WHI0066	WHI0048A/ WHI0193	WHI0048B	WHI0048C
Site Description	Crooked Creek above Harrison	Crooked Creek below Harrison	Crooked Creek at / west of Yellville	Crooked Creek 2 mi south of Flippin	Crooked Creek at Hwy 101, north of Rea Valley
Reach Number	11010003-049	11010003-049	11010003-048	11010003-048	11010003-048
Period of Record	9/25/1990 – 1/12/2010	9/25/1990 – 1/12/2010	9/25/1990 – 12/08/2009	1/13/1998 – 12/08/2009	1/13/1998 – 12/08/2009
Chloride					
Number of Values	226	226	215	68	74
Minimum (mg/L)	2.9	3.2	3.0	2.6	1.8
Maximum (mg/L)	19.4	36.2	36.1	10.1	11.8
Median (mg/L)	6.9	12.1	7.0	6.3	6.3
Number of Values > 20 mg/L	0	39	1	0	0
Percent of Values > 20 mg/L	0%	17%	< 1%	0%	0%
Sulfate					
Number of Values	228	228	216	68	74
Minimum (mg/L)	1.9	3.6	1.6	4.4	3.9
Maximum (mg/L)	16.6	37.7	19.3	8.6	36.5
Median (mg/L)	5.7	10.7	6.4	5.8	5.9
Number of Values > 20 mg/L	0	26	0	0	1
Percent of Values > 20 mg/L	0%	11%	0%	0%	1%
TDS					
Number of Values	229	229	215	65	72
Minimum (mg/L)	108	112	145	134	145
Maximum (mg/L)	250	297	343	231	281
Median (mg/L)	203	223	190	197	197
Number of Values > 200 mg/L	127	162	60	24	28
Percent of Values > 200 mg/L	55%	71%	28%	37%	39%

Several plots for the lower part of the watershed showed opposite seasonal patterns, with slightly lower concentrations during the late summer and fall. Two plots that displayed this trend were Figure C.9 (TDS at WHI0048A/WHI0193) and Figure C.11 (sulfate at WHI0048B).

3.3 Relationships between Concentration and Flow

Concentrations of chloride, sulfate, and TDS were plotted versus stream flow to examine any visual correlation between concentration and flow (see Figures D.1 – D.15 located in Appendix D). For many of the plots, the highest concentrations tended to occur during lower flows. The site where this pattern was the strongest was WHI0066.

4.0 TMDL DEVELOPMENT

4.1 Seasonality and Critical Conditions

USEPA 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 would be considered as critical conditions.

The TMDLs in this report were not developed for individual seasons because 1) the water quality data did not show consistent seasonal patterns throughout the watershed, and 2) neither point source discharge has seasonal permit limits for chloride, sulfate, or TDS. Critical flow conditions were addressed by using the load duration curve to develop these TMDLs. The load duration curve calculates allowable loading at a wide range of flows.

4.2 Water Quality Targets

The water quality targets for the TMDLs in this report were simply the criteria for Crooked Creek from the water quality standards as discussed in Section 2.4 (20 mg/L chloride, 20 mg/L sulfate, and 200 mg/L TDS). Chloride, sulfate, and TDS can easily be expressed as mass, so there was no need to use surrogate parameters.

4.3 Methodology for TMDL Calculations

The methodology used for all of the 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 just a fixed load for one flow condition. This methodology is described in a USEPA guidance document titled “An Approach for Using Load Duration Curves in the Development of TMDLs” (USEPA 2007). The steps for how this methodology is applied for the TMDLs 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 curve (Section 4.5);
3. Plot observed loads with the load duration curves (Section 4.6); and
4. Calculate the TMDL, MOS, WLA, and LA (Sections 4.7 - 4.9).

4.4 Flow Duration Curves

A flow duration curve was developed using the long term daily flow data for Crooked Creek discussed in Section 2.3 (the combined data set from gages 07055607 and 07055608). Daily flow data were sorted in increasing order and the percentile ranking of each flow was calculated. Flows at the downstream end of each impaired reach were estimated by multiplying the flows at the gage times the ratio of drainage area for the reach and for the gage.

Each flow duration curve was then plotted as daily flow (cfs) versus percent exceedance (100% minus percentile ranking). The flow duration curves are shown on Figure E.1 (located in Appendix E) for reach 11010003-048 and on Figure F.1 (located in Appendix F) for reach 11010003-049.

4.5 Load Duration Curves

For each TMDL, the flow values from the flow duration curves were multiplied by the appropriate target concentration of chloride, sulfate, or TDS (from Section 4.2) to make a duration curve of allowable loads. Each load duration curve is a plot of tons per day of chloride, sulfate, or TDS versus the percent exceedances from the flow duration curve. The calculations for the load duration curves are presented in Table E.1 for reach 11010003-048 and in Table F.1 for reach 11010003-049. Load duration curves for chloride and sulfate were not developed for reach 11010003-048 because that reach is not impaired for either chloride or sulfate. The load duration curves are plotted in the appendices as follows:

Figure E.2:	TDS curve for reach 11010003-048
Figures F.2 – F.4:	chloride, sulfate, and TDS curves for reach 11010003-049

The load duration curve shows the calculation of the TMDL at any flow rather than at a single critical flow. The official TMDL number is reported as a single number, but the curve is

provided to demonstrate the value of the acceptable load at any flow. This will allow analysis of load cases in the future for different flow regimes.

4.6 Observed Loads

The plots of the load duration curves also show observed loads on sampling days. The observed loads were calculated using sampling data from the water quality monitoring station that was farthest downstream in each reach (WHI0048C for reach 11010003-048 and WHI0066 for reach 11010003-049).

For each of these two monitoring stations, observed loads were calculated by multiplying each observed concentration of chloride, sulfate, or TDS 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 on Figure E.2 (reach 11010003-048) and Figures F.2 – F.4 (reach 11010003-049).

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 water quality standards. Observed loads below the load duration curve represent conditions where observed loads were less than loads corresponding to the numeric criterion (i.e., not violating the 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. Assumptions of the probable source or sources of the impairment can sometimes be made from the plotted data.

4.7 TMDL and MOS

Each TMDL was calculated as the area under the load duration curve. The area on these plots represents a load because the vertical axis is tons/day and the horizontal axis is unitless (percentage).

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 explicit MOS was established as 5% of each TMDL.

4.8 Loads from Diffuse Sources

Loads from diffuse sources consist of 1) industrial or municipal stormwater that is regulated by a NPDES permit, and 2) nonpoint source runoff or baseflow from all other areas that are not regulated by a NPDES permit. The total existing loads from diffuse sources were calculated using load duration curves with the same methodology as described for calculating the TMDLs, except that each flow value on the flow duration curve was multiplied by an estimated existing concentration rather than the criterion from the water quality standards. The existing concentrations at different flow rates were estimated from ADEQ historical water quality data for the upper most monitoring location within each reach (WHI0048A / WHI0193 for reach 1101003-048 and WHI0067 for reach 1101003-049). The ADEQ water quality data were sorted by stream flow rates on the sampling day so that existing concentrations could be interpolated for each flow value on the flow duration curve. The existing load for each parameter was then calculated as the area under the load duration curve. These calculations are shown in Table E.2 (reach 11010003-048) and Table F.2 (reach 11010003-049).

After the existing loads from all diffuse sources were calculated, these loads were then divided into WLAs for stormwater regulated by a NPDES permit and LAs for all other diffuse loading. Dividing the diffuse loading was necessary because USEPA requires loads from stormwater regulated by a NPDES permit to be classified as a WLA rather than a LA (USEPA 2002). The total diffuse loading was divided based on drainage area. Because information concerning drainage area was not available for most of the stormwater facilities, each facility was assumed to cover 40 acres. With this assumption, the 9 stormwater facilities draining to reach 11010003-048 comprised 0.12% of the total drainage area for that reach.

Likewise, the 24 stormwater facilities draining to reach 11010003-049 comprised 0.71% of the total drainage area for that reach. Therefore, the WLAs for regulated stormwater were set equal to 0.12% of the total diffuse loading in reach 11010003-048 and 0.71% of the total diffuse loading in reach 11010003-049. The remainder of the diffuse loading in each reach was assigned to the LA for nonpoint sources. The results of these calculations are shown at the bottom of Tables E.1 and F.1.

The WLAs for regulated stormwater were not specified for individual facilities because there was not sufficient information available. USEPA'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 ..." (USEPA 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 Crooked Creek watershed.

4.9 Continuous Point Source Discharges

The loading that was available for continuous (i.e., non-stormwater) point source discharges was calculated by taking each TMDL and subtracting the MOS, the WLA for regulated stormwater, and the LA for nonpoint sources. The results of these calculations are shown at the bottom of Tables E.1 and F.1. The components of the TMDLs are summarized in Tables 4.1 and 4.2.

Table 4.1 Summary of TMDL for reach 11010003-048

	Allowable loads of TDS (tons/day)
WLA for non-stormwater point source discharges	5.73
WLA for NPDES-regulated stormwater (9 facilities)	0.28
LA for nonpoint sources	232.60
MOS	12.56
TMDL	251.17

Table 4.2 Summary of TMDLs for reach 11010003-049

	Allowable loads (tons/day)		
	Chloride	**Sulfate**	**TDS**
WLA for non-stormwater point source discharges	7.70	7.57	11.23
WLA for NPDES-regulated stormwater (24 facilities)	0.02	0.02	0.70
LA for nonpoint sources	3.23	3.36	97.57
MOS	0.58	0.58	5.76
TMDL	11.53	11.53	115.26

4.10 Implementation in NPDES Permits

This TMDL report provides allowable loadings but does not specify numeric permit limits because the permitting authority (ADEQ) will calculate limits where applicable when permits are issued, modified, or renewed. ADEQ 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. USEPA 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.

USEPA 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 Crooked Creek watershed do not currently contain numeric limits for chloride, sulfate, or TDS. USEPA'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 [best management practices], and that numeric limits will be used only in rare instances" (USEPA 2002). Since that time, USEPA 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" (USEPA 2010).

The use of BMPs to control the discharge of pollutants from stormwater is consistent with USEPA regulations at 40 CFR 122.44(k). In the Crooked Creek watershed, regulated stormwater is not a suspected source of high concentrations of chloride, sulfate, or TDS. Rainfall is expected to have low concentrations of dissolved minerals, and unless the runoff comes in contact with highly soluble materials on the ground, the stormwater from regulated facilities should have relatively low concentrations of chloride, sulfate, and TDS. For many of the plots of concentration versus flow for Crooked Creek (discussed in Section 3.3), the highest concentrations tended to occur during lower flows.

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 chloride, sulfate, or TDS.

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

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 will conduct a public review period to seek comments and relevant information from the public concerning the draft TMDLs in this report. This report will be available on ADEQ's web site throughout the public review period. If ADEQ receives public comments or information concerning these TMDLs during the public review period, the TMDLs will be revised accordingly and a response to comments will be included in the revised TMDL document.

7.0 REFERENCES

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APPENDIX A

Maps of Watershed, Land Use, and Point Sources

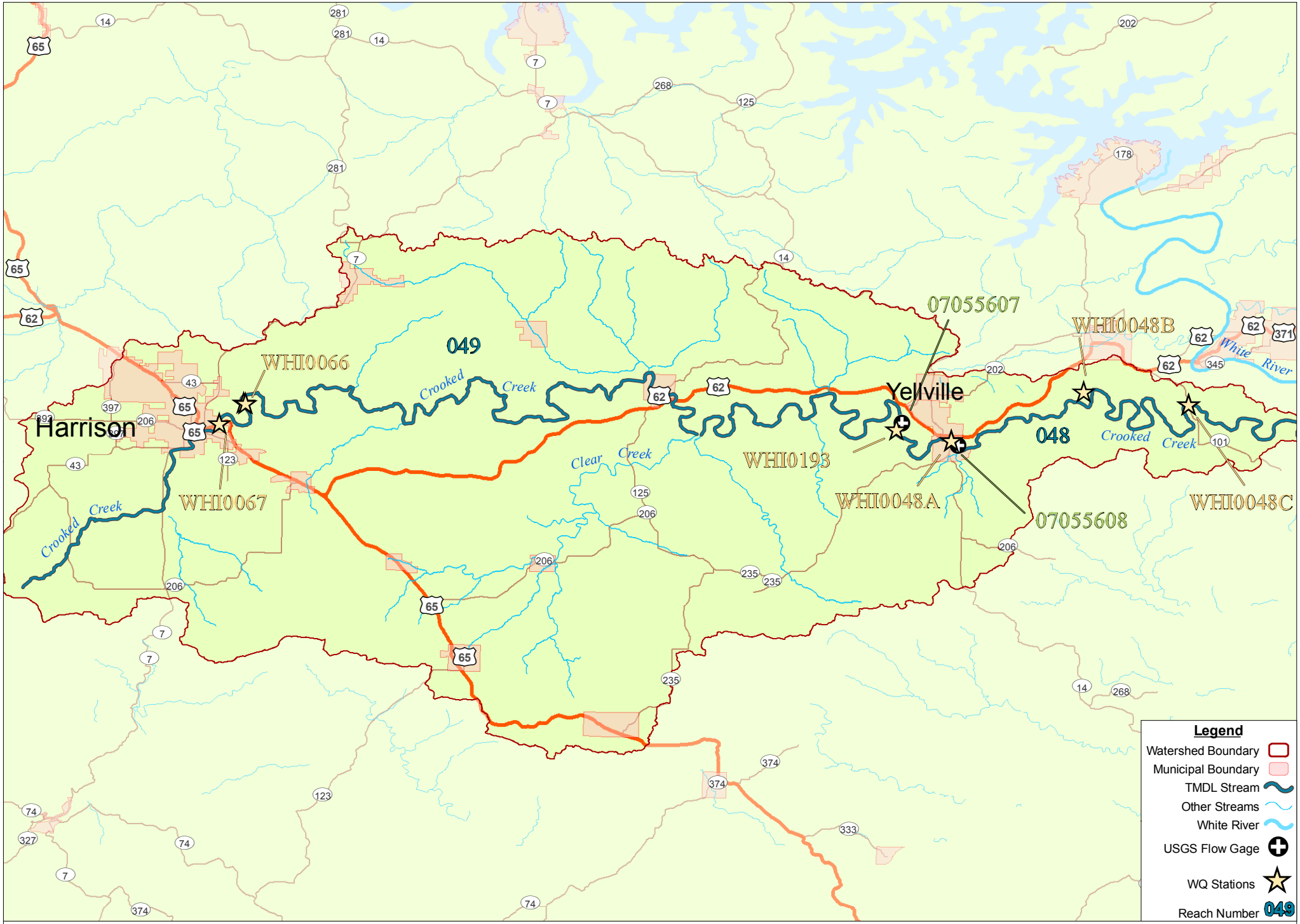

Figure A.1 Watershed Map for Crooked Creek

R:\projects\3013-380\gis\mapdoc\CrookedCreek.mxd

Roads: ESRI Other Water Features: USGS

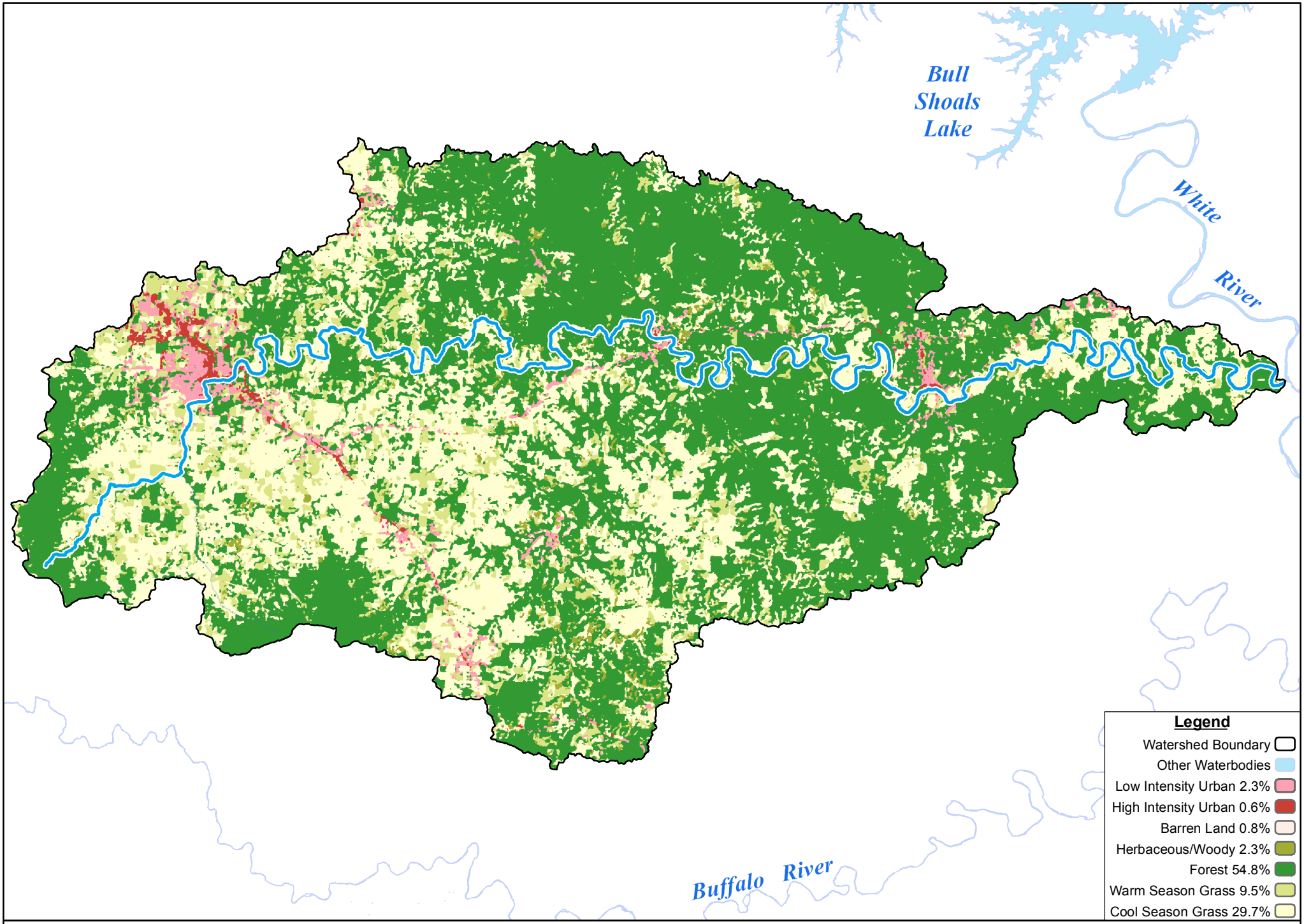

Figure A.2 Land Use Map for Crooked Creek

R:\projects\3013-380\gis\mapdoc\CrookedCreeklulc.mxd

Other Water Features: USGS

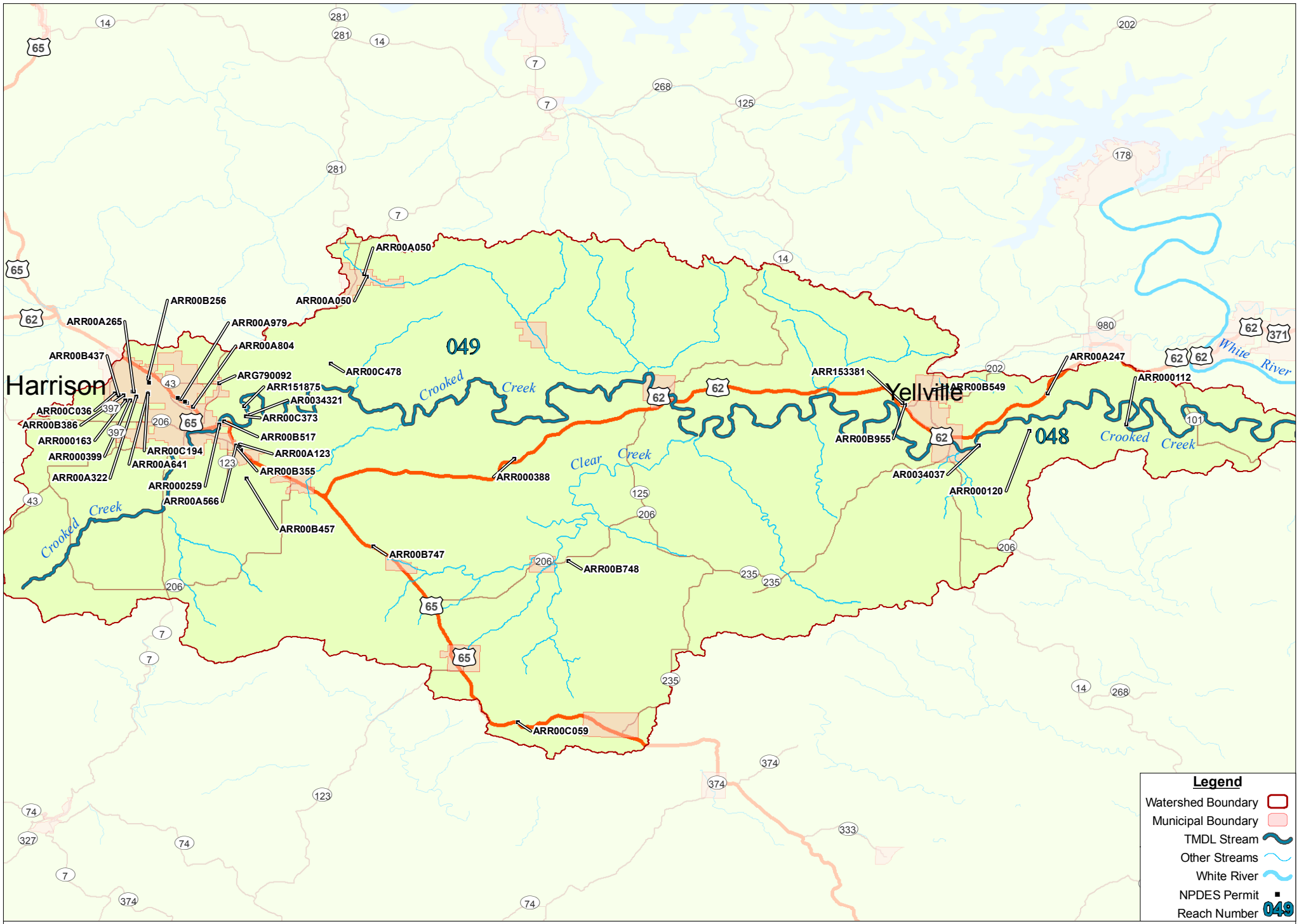

Figure A.3 Map of NPDES Permits for Crooked Creek

R:\projects\3013-380\gis\mapdoc\CrookedCreek.mxd Roads: ESRI Other Water Features: USGS

APPENDIX B

Tabular Listings and Time Series Plots of Water Quality Data

Table B.1 Historical Water Quality Data for Crooked Creek above Harrison, AR

Site ID	Date Collected	Chloride (mg/L)	Sulfate (mg/L)	TDS (mg/L)
WHI0067	9/25/1990	6.9	3.0	212
WHI0067	10/9/1990	3.9	5.0	135
WHI0067	10/23/1990	5.8	5.0	211
WHI0067	11/19/1990	8.0	6.0	211
WHI0067	12/18/1990	5.6	6.0	179
WHI0067	1/29/1991	5.4	4.0	170
WHI0067	2/26/1991	6.6	7.0	194
WHI0067	4/2/1991	5.3	5.0	163
WHI0067	4/23/1991	4.8	7.0	170
WHI0067	5/7/1991	3.8	4.0	173
WHI0067	6/25/1991	5.4	3.0	207
WHI0067	7/23/1991	6.1	3.0	203
WHI0067	8/27/1991			212
WHI0067	9/24/1991			201
WHI0067	10/22/1991			224
WHI0067	11/19/1991	4.0	5.8	154
WHI0067	12/17/1991	4.8	5.9	185
WHI0067	1/28/1992	5.4	7.0	190
WHI0067	2/18/1992	5.5	8.5	167
WHI0067	3/17/1992	5.2	7.9	180
WHI0067	4/21/1992	5.6	4.8	188
WHI0067	6/2/1992	4.9	7.1	147
WHI0067	6/23/1992	4.8	4.7	182
WHI0067	7/21/1992	5.3	4.7	199
WHI0067	8/18/1992	6.2	2.0	212
WHI0067	9/15/1992	6.6	4.1	210
WHI0067	10/13/1992	6.5	8.1	211
WHI0067	11/3/1992	4.8	6.2	183
WHI0067	12/8/1992	5.7	6.4	196
WHI0067	1/12/1993	4.7	7.4	162
WHI0067	2/9/1993	5.2	5.0	187
WHI0067	3/9/1993	5.3	5.0	168
WHI0067	4/20/1993	5.1	8.5	162
WHI0067	5/11/1993	3.7	5.4	150
WHI0067	6/15/1993	4.9	4.8	190
WHI0067	7/6/1993	5.1	6.1	203
WHI0067	8/3/1993	6.2	4.9	221
WHI0067	8/31/1993	6.7	5.8	220
WHI0067	10/5/1993	6.3	7.2	201
WHI0067	11/9/1993	6.4	3.6	222

Site ID	Date Collected	Chloride (mg/L)	Sulfate (mg/L)	TDS (mg/L)
WHI0067	12/14/1993	4.4	8.9	142
WHI0067	1/11/1994	6.1	4.5	200
WHI0067	2/15/1994		7.5	177
WHI0067	3/15/1994	4.7	6.0	160
WHI0067	4/5/1994	5.4	1.9	167
WHI0067	5/10/1994	4.8	4.7	190
WHI0067	6/7/1994	6.1	4.9	214
WHI0067	7/12/1994	5.9	4.0	210
WHI0067	8/9/1994	6.5	4.8	123
WHI0067	9/6/1994	6.7	6.3	219
WHI0067	10/11/1994	7.5	6.6	216
WHI0067	11/8/1994	7.4	9.3	200
WHI0067	12/6/1994	6.3	8.1	189
WHI0067	1/10/1995	7.8		
WHI0067	2/27/1995	6.6	5.4	184
WHI0067	3/21/1995	5.1	6.1	177
WHI0067	4/11/1995	4.6	8.8	147
WHI0067	5/9/1995	3.7	6.4	138
WHI0067	6/6/1995	6.2	5.7	201
WHI0067	8/1/1995	6.2	4.1	209
WHI0067	8/29/1995	7.0	5.1	212
WHI0067	9/26/1995	7.334*	7.2	223
WHI0067	10/24/1995	7.0	5.2	220
WHI0067	11/14/1995	7.7	7.6	213
WHI0067	12/5/1995	7.0	5.6	208
WHI0067	1/23/1996	10.7	6.5	174
WHI0067	2/27/1996	6.9	4.7	188
WHI0067	3/19/1996	9.4	8.3	195
WHI0067	4/16/1996	5.7	7.2	166
WHI0067	5/14/1996	5.6	6.1	190
WHI0067	6/4/1996	6.4	8.0	202
WHI0067	7/2/1996	6.6	8.2	201*
WHI0067	8/20/1996	7.3	9.2	209
WHI0067	9/10/1996	7.8	7.8	221
WHI0067	10/22/1996	7.6	8.2	210
WHI0067	11/12/1996	6.1	9.1	195
WHI0067	12/3/1996	5.7	4.1	178
WHI0067	1/7/1997	5.9	6.4	198
WHI0067	2/11/1997	6.0	6.8	178
WHI0067	3/4/1997	5.6	6.6	160
WHI0067	4/8/1997	5.4	6.1	171
WHI0067	5/6/1997	6.3	6.8	202

Site ID	Date Collected	Chloride (mg/L)	Sulfate (mg/L)	TDS (mg/L)
WHI0067	6/24/1997	6.5	10.8	208
WHI0067	7/8/1997	6.3	11.0	202
WHI0067	8/5/1997	8.1	8.1	202
WHI0067	9/9/1997	6.67*	4.9	211
WHI0067	10/7/1997	7.0	5.7	225
WHI0067	11/4/1997	7.6	5.8	221
WHI0067	12/2/1997	7.6	6.3	214
WHI0067	1/6/1998	5.3	5.9	131
WHI0067	2/3/1998	7.6	7.3	207
WHI0067	3/3/1998	4.9	4.6	173
WHI0067	3/31/1998	4.3	6.0	144
WHI0067	5/5/1998	5.2	5.1	189
WHI0067	6/2/1998	5.9	4.8	209
WHI0067	6/30/1998	7.1	4.5	206
WHI0067	8/4/1998	5.9	4.6	128
WHI0067	9/15/1998	5.0	5.0	180
WHI0067	10/13/1998	6.7	7.2	210
WHI0067	11/3/1998	5.7	5.6	183
WHI0067	12/1/1998	5.8	5.3	202
WHI0067	1/11/1999	6.5	6.4	176
WHI0067	2/9/1999	5.4	5.8	168
WHI0067	3/9/1999	4.8	8.2	166
WHI0067	4/20/1999	5.4	5.7	175
WHI0067	5/4/1999	4.6	4.9	163
WHI0067	6/8/1999	6.1	5.9	206
WHI0067	7/13/1999	7.2	5.6	214
WHI0067	8/10/1999	6.6	5.1	210
WHI0067	9/14/1999	6.7	5.5	218
WHI0067	10/12/1999	7.4	6.2	226
WHI0067	11/22/1999	7.6	5.2	224
WHI0067	12/7/1999	7.8	5.8	218
WHI0067	1/4/2000	6.6	5.5	196
WHI0067	2/8/2000	10.7	6.9	230
WHI0067	3/7/2000	9.2	8.3	215
WHI0067	4/4/2000	8.0	7.3	198
WHI0067	5/16/2000	7.7	5.8	203
WHI0067	6/13/2000	7.3	5.8	197
WHI0067	7/18/2000	8.2	5.8	199
WHI0067	8/15/2000	7.5	5.1	222
WHI0067	9/12/2000	6.1	4.8	184
WHI0067	10/10/2000	7.1	5.3	228
WHI0067	11/7/2000	5.0	6.5	194

Site ID	Date Collected	Chloride (mg/L)	Sulfate (mg/L)	TDS (mg/L)
WHI0067	12/5/2000	7.8	6.4	213
WHI0067	1/23/2001	9.1	6.9	183
WHI0067	2/27/2001	6.3	5.6	154
WHI0067	3/27/2001	7.1	5.6	185
WHI0067	4/24/2001	7.4	6.1	194
WHI0067	5/29/2001	8.1	4.8	213
WHI0067	6/26/2001	8.2	5.5	213
WHI0067	7/24/2001	8.9	5.4	208
WHI0067	8/28/2001	8.0	5.0	227
WHI0067	9/11/2001	6.9	5.3	201
WHI0067	10/16/2001	8.2	6.0	214
WHI0067	11/19/2001	9.6	6.3	223
WHI0067	12/4/2001	9.3	8.0	210
WHI0067	1/29/2002	6.8	6.1	180
WHI0067	2/26/2002	6.5	5.6	184
WHI0067	3/12/2002	6.4	7.0	166
WHI0067	4/9/2002	4.8	5.5	144
WHI0067	5/14/2002	4.9	5.4	153
WHI0067	6/11/2002	4.7	5.4	162
WHI0067	7/23/2002	6.7	4.1	221
WHI0067	8/20/2002	7.3	4.2	231
WHI0067	9/17/2002	4.3	16.6	118
WHI0067	10/22/2002	7.5	5.3	221
WHI0067	11/19/2002	7.4	5.3	226
WHI0067	12/10/2002	11.2	6.2	217
WHI0067	1/14/2003	8.3	6.9	207
WHI0067	2/11/2003	19.4	5.8	228
WHI0067	3/4/2003	9.7	8.2	221
WHI0067	4/8/2003	8.7	6.1	196
WHI0067	5/13/2003	10.3	5.9	215
WHI0067	6/17/2003	4.5	4.5	134
WHI0067	7/8/2003	8.9	5.1	217
WHI0067	8/5/2003	8.3	5.3	222
WHI0067	9/9/2003	9.5	5.4	237
WHI0067	10/21/2003	10.1	6.2	246
WHI0067	11/18/2003	7.2	4.4	206
WHI0067	12/16/2003	10.1	7.9	215
WHI0067	1/27/2004	9.2	8.6	206
WHI0067	2/24/2004	8.9	7.1	200
WHI0067	3/30/2004	7.4	8.8	213
WHI0067	4/27/2004	7.4	6.1	194
WHI0067	5/25/2004	7.3	4.5	217

Site ID	Date Collected	Chloride (mg/L)	Sulfate (mg/L)	TDS (mg/L)
WHI0067	6/22/2004	11.4	8.3	235
WHI0067	7/27/2004	8.1	5.1	224
WHI0067	8/24/2004	8.4	4.8	217
WHI0067	9/28/2004	8.3	4.9	230
WHI0067	10/19/2004	9.1	7.3	223
WHI0067	11/16/2004	8.2	6.9	205
WHI0067	12/14/2004	7.7	5.6	206
WHI0067	1/11/2005	8.2	5.7	192
WHI0067	2/8/2005	8.0	6.7	194
WHI0067	3/15/2005	8.1	6.0	215
WHI0067	4/12/2005	5.6	6.3	158
WHI0067	5/17/2005	7.8	4.8	209
WHI0067	6/14/2005	7.7	4.6	215
WHI0067	7/26/2005	8.3	4.4	215
WHI0067	8/16/2005	7.5	4.5	211
WHI0067	9/13/2005	8.5	4.7	228
WHI0067	10/18/2005	8.8	5.4	219
WHI0067	11/15/2005	6.6	3.8	194
WHI0067	12/13/2005	8.3	5.7	225
WHI0067	1/3/2006	8.8	5.5	218
WHI0067	1/31/2006	8.9	5.5	213
WHI0067	3/7/2006	11.3	7.1	208
WHI0067	4/18/2006	9.1	8.3	207
WHI0067	5/16/2006	7.2	5.5	199
WHI0067	6/20/2006	7.9	4.7	216
WHI0067	7/18/2006	8.6	5.0	222
WHI0067	8/15/2006	9.3	5.2	226
WHI0067	9/12/2006	7.9	5.9	224
WHI0067	10/10/2006	9.0	6.1	233
WHI0067	10/31/2006	8.7	6.0	234
WHI0067	12/12/2006	10.2	7.9	
WHI0067	1/16/2007	6.6	5.8	161
WHI0067	2/27/2007	8.2	6.1	189
WHI0067	3/27/2007	7.9	5.3	211
WHI0067	4/10/2007	7.8	5.2	206
WHI0067	5/15/2007	7.2	6.5	186
WHI0067	6/19/2007	7.6	4.9	203
WHI0067	7/17/2007	7.7	5.8	199
WHI0067	9/5/2007	8.6	4.7	216
WHI0067	10/2/2007	7.7	4.7	203
WHI0067	11/13/2007	8.7	5.2	226
WHI0067	12/4/2007	8.3	5.1	217

Site ID	Date Collected	Chloride (mg/L)	Sulfate (mg/L)	TDS (mg/L)
WHI0067	1/15/2008	8.9	6.9	222
WHI0067	2/19/2008	8.0	7.8	168
WHI0067	3/3/2008	2.9	6.5	108
WHI0067	3/17/2008	7.7	5.5	206
WHI0067	4/1/2008	3.9	5.4	124
WHI0067	5/13/2008	6.0	5.6	169
WHI0067	6/17/2008	11.8	9.4	217
WHI0067	7/15/2008	6.6	4.8	190
WHI0067	8/19/2008	7.0	5.1	215
WHI0067	9/16/2008	5.7	4.6	196
WHI0067	10/21/2008	6.5	3.8	227
WHI0067	11/24/2008	7.0	4.3	225
WHI0067	12/9/2008	6.6	4.1	205
WHI0067	1/13/2009	10.3	9.4	217
WHI0067	2/17/2009	7.6	6.0	194
WHI0067	4/7/2009	6.5	6.3	195
WHI0067	6/23/2009	6.8	4.9	205
WHI0067	7/21/2009	4.8	3.6	166
WHI0067	8/10/2009	11.6	14.0	250
WHI0067	9/15/2009	4.3	3.6	166
WHI0067	10/13/2009	4.6	4.4	162
WHI0067	11/3/2009	6.8	5.1	187
WHI0067	12/1/2009	6.4	5.1	212
WHI0067	1/12/2010	7.1	5.7	212

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

Summary:

Period of Record	9/25/90 - 1/12/10		
No. of Values	226	228	229
Minimum (mg/L)	2.9	1.9	108
Maximum (mg/L)	19.4	16.6	250
Median (mg/L)	6.9	5.7	203
Criterion from standards (mg/L)	20	20	200
No. Value > criterion	0	0	127
% Values > criterion	0%	0%	55%

FILE: R:\PROJECTS\3013-380\TECH\ADEQ_WQ_DATA\CROOKED_CREEK\WHI0067 CROOKED CREEK.XLSX

Table B.2 Historical Water Quality Data for Crooked Creek below Harrison, AR

Site ID	Date Collected	Chloride (mg/L)	Sulfate (mg/L)	TDS (mg/L)
WHI0066	9/25/1990	13.3	17.0	236
WHI0066	10/23/1990	14.8	12.0	249
WHI0066	11/19/1990	17.2	31.0	269
WHI0066	12/18/1990	10.1	11.0	205
WHI0066	1/29/1991	7.9	7.0	184
WHI0066	2/26/1991	11.4	18.0	225
WHI0066	4/2/1991	8.0	8.0	186
WHI0066	4/23/1991	5.7	8.0	178
WHI0066	5/7/1991	4.8	6.0	175
WHI0066	6/25/1991	12.8	8.0	231
WHI0066	7/23/1991	14.0	18.0	236
WHI0066	8/27/1991			236
WHI0066	9/24/1991			240
WHI0066	10/22/1991			297
WHI0066	11/19/1991	4.8	7.3	158
WHI0066	12/17/1991	6.6	9.5	196
WHI0066	1/28/1992	8.5	13.5	213
WHI0066	2/18/1992	7.4	14.1	180
WHI0066	3/17/1992	9.6	11.4	201
WHI0066	4/21/1992	11.1	18.7	219
WHI0066	6/2/1992	6.7	10.7	165
WHI0066	6/23/1992	6.4	7.3	187
WHI0066	7/21/1992	9.6	12.4	219
WHI0066	8/18/1992	13.1	10.1	236
WHI0066	9/15/1992	13.0	14.7	232
WHI0066	10/13/1992	19.6	16.5	247
WHI0066	11/3/1992	8.9	11.3	206
WHI0066	12/8/1992	10.9	11.5	223
WHI0066	1/12/1993	5.9	7.4	170
WHI0066	2/9/1993	9.4	10.0	207
WHI0066	3/9/1993	4.4	7.7	116
WHI0066	4/20/1993	6.4	10.7	175
WHI0066	5/11/1993	4.4	6.6	159
WHI0066	6/15/1993	6.2	6.1	193
WHI0066	7/6/1993	8.4	8.8	220
WHI0066	8/3/1993	13.6	12.9	239
WHI0066	8/31/1993	17.0	18.1	251
WHI0066	10/5/1993	13.4	12.3	226
WHI0066	11/9/1993	15.2	15.2	256
WHI0066	12/14/1993	5.5	10.0	152
WHI0066	1/11/1994	10.8	8.2	217
WHI0066	2/15/1994		11.2	199

Site ID	Date Collected	Chloride (mg/L)	Sulfate (mg/L)	TDS (mg/L)
WHI0066	3/15/1994	5.4	7.0	166
WHI0066	4/5/1994	7.1	3.6	173
WHI0066	5/10/1994	6.1	7.1	196
WHI0066	6/7/1994	11.4	10.5	234
WHI0066	7/12/1994	17.5	11.4	242
WHI0066	8/9/1994	15.0	14.1	242
WHI0066	9/6/1994	17.1	16.0	251
WHI0066	10/11/1994	23.0	25.7	264
WHI0066	11/8/1994	8.5	9.3	195
WHI0066	12/6/1994	14.4	16.0	219
WHI0066	1/10/1995	13.2		
WHI0066	2/27/1995	11.1	10.7	200
WHI0066	3/21/1995	8.1	8.5	190
WHI0066	4/11/1995	6.3	10.0	158
WHI0066	5/9/1995	4.1	6.4	144
WHI0066	6/6/1995	10.9	6.7	212
WHI0066	8/1/1995	10.7	7.8	226
WHI0066	8/29/1995	24.6	24.4	258
WHI0066	9/26/1995	18.26*	19.1	258
WHI0066	10/24/1995	19.7	25.2	270
WHI0066	11/14/1995	15.4	16.2	234
WHI0066	12/5/1995	23.8	23.2	258
WHI0066	1/23/1996	11.5	11.0	193
WHI0066	2/27/1996	17.6	12.1	218
WHI0066	3/19/1996	15.9	16.1	223
WHI0066	4/16/1996	6.8	8.1	168
WHI0066	5/14/1996	8.1	10.8	205
WHI0066	6/4/1996	13.1	17.6	230
WHI0066	7/2/1996	14.4	17.2	232*
WHI0066	8/20/1996	22.5	25.6	266
WHI0066	9/10/1996	21.4	29.0	277
WHI0066	10/22/1996	11.4	10.4	212
WHI0066	11/12/1996	6.7	7.2	196
WHI0066	12/3/1996	6.8	5.3	185
WHI0066	1/7/1997	10.4	9.5	216
WHI0066	2/11/1997	8.4	8.8	187
WHI0066	3/4/1997	6.6	6.6	165
WHI0066	4/8/1997	5.7	6.1	172
WHI0066	5/6/1997	10.8	11.7	214
WHI0066	6/24/1997	14.3	18.3	231
WHI0066	7/8/1997	17.0	23.0	238
WHI0066	8/5/1997	19.4	16.8	241
WHI0066	9/9/1997	19.7*	12.3	242
WHI0066	10/7/1997	21.5	12.8	259

Site ID	Date Collected	Chloride (mg/L)	Sulfate (mg/L)	TDS (mg/L)
WHI0066	11/4/1997	20.6	16.1	258
WHI0066	12/2/1997	19.3	12.0	243
WHI0066	1/6/1998	5.0	6.1	137
WHI0066	2/3/1998	8.5	7.5	195
WHI0066	3/3/1998	6.8	6.4	181
WHI0066	3/31/1998	4.8	5.8	141
WHI0066	5/5/1998	9.1	9.0	208
WHI0066	6/2/1998	12.3	13.3	234
WHI0066	6/30/1998	14.7	10.0	230
WHI0066	8/4/1998	20.9	21.7	167
WHI0066	9/15/1998	10.9	11.5	166
WHI0066	10/13/1998	18.3	13.9	244
WHI0066	11/3/1998	11.7	13.3	201
WHI0066	12/1/1998	15.9	11.3	229
WHI0066	1/11/1999	10.2	8.4	190
WHI0066	2/9/1999	6.8	6.5	177
WHI0066	3/9/1999	7.6	10.3	175
WHI0066	4/20/1999	8.1	7.6	182
WHI0066	5/4/1999	6.9	6.0	163
WHI0066	6/8/1999	13.0	10.4	233
WHI0066	7/13/1999	12.9	6.5	231
WHI0066	8/10/1999	12.5	10.2	228
WHI0066	9/14/1999	12.3	9.5	233
WHI0066	10/12/1999	20.7	11.7	250
WHI0066	11/22/1999	20.9	20.6	256
WHI0066	12/7/1999	15.1	15.6	236
WHI0066	1/4/2000	14.6	9.9	215
WHI0066	2/8/2000	25.7	21.3	259
WHI0066	3/7/2000	17.9	17.2	224
WHI0066	4/4/2000	22.0	21.7	258
WHI0066	5/16/2000	29.0	21.3	269
WHI0066	6/13/2000	22.2	19.0	250
WHI0066	7/18/2000	20.2	20.4	251
WHI0066	8/15/2000	20.6	12.6	252
WHI0066	9/12/2000	15.4	16.2	225
WHI0066	10/10/2000	25.0	12.3	262
WHI0066	11/7/2000	8.0	7.5	197
WHI0066	12/5/2000	14.4	11.4	231
WHI0066	1/23/2001	14.2	8.9	205
WHI0066	2/27/2001	7.3	6.2	164
WHI0066	3/27/2001	12.4	8.5	209
WHI0066	4/24/2001	15.6	11.2	217
WHI0066	5/29/2001	20.0	10.9	240
WHI0066	6/26/2001	20.6	14.9	247

Site ID	Date Collected	Chloride (mg/L)	Sulfate (mg/L)	TDS (mg/L)
WHI0066	7/24/2001	24.1	19.1	245
WHI0066	8/28/2001	26.6	19.5	266
WHI0066	9/11/2001	16.7	14.9	230
WHI0066	10/16/2001	19.7	12.4	242
WHI0066	11/19/2001	19.9	14.3	244
WHI0066	12/4/2001	11.9	10.0	217
WHI0066	1/29/2002	9.5	8.8	190
WHI0066	2/26/2002	9.4	7.7	201
WHI0066	3/12/2002	7.9	7.9	175
WHI0066	4/9/2002	5.0	5.8	149
WHI0066	5/14/2002	5.6	6.2	161
WHI0066	6/11/2002	5.2	6.2	169
WHI0066	7/23/2002	11.4	10.0	239
WHI0066	8/20/2002	12.3	7.3	239
WHI0066	9/17/2002	7.5	4.9	214
WHI0066	10/22/2002	21.3	8.7	253
WHI0066	11/19/2002	20.5	10.9	256
WHI0066	12/10/2002	23.8	12.4	245
WHI0066	1/14/2003	15.9	11.0	228
WHI0066	2/11/2003	36.2	18.0	263
WHI0066	3/4/2003	13.3	9.6	230
WHI0066	4/8/2003	13.3	9.6	215
WHI0066	5/13/2003	22.0	12.8	249
WHI0066	6/17/2003	6.2	6.3	133
WHI0066	7/8/2003	16.4	12.0	238
WHI0066	8/5/2003	16.2	10.0	239
WHI0066	9/9/2003	20.0	14.5	265
WHI0066	10/21/2003	22.6	13.3	270
WHI0066	11/18/2003	11.3	6.8	212
WHI0066	12/16/2003	17.4	10.4	234
WHI0066	1/27/2004	12.8	10.0	217
WHI0066	2/24/2004	14.9	11.3	216
WHI0066	3/30/2004	12.2	9.6	230
WHI0066	4/27/2004	8.2	6.6	204
WHI0066	5/25/2004	10.7	5.9	226
WHI0066	6/22/2004	7.2	4.3	229
WHI0066	7/27/2004	14.0	13.5	234
WHI0066	8/24/2004	18.2	14.5	247
WHI0066	9/28/2004	21.9	21.9	274
WHI0066	10/19/2004	16.7	13.3	244
WHI0066	11/16/2004	11.4	10.0	213
WHI0066	12/14/2004	10.5	8.2	219
WHI0066	1/11/2005	9.9	6.7	200
WHI0066	2/8/2005	10.8	8.6	210

Site ID	Date Collected	Chloride (mg/L)	Sulfate (mg/L)	TDS (mg/L)
WHI0066	3/15/2005	11.8	10.1	228
WHI0066	4/12/2005	6.5	7.1	164
WHI0066	5/17/2005	12.3	10.2	225
WHI0066	6/14/2005	17.2	15.2	239
WHI0066	7/26/2005	21.5	29.1	265
WHI0066	8/16/2005	17.3	28.8	260
WHI0066	9/13/2005	25.2	18.2	267
WHI0066	10/18/2005	21.5	19.8	269
WHI0066	11/15/2005	10.6	10.0	204
WHI0066	12/13/2005	21.1	17.1	257
WHI0066	1/3/2006	21.3	31.1	274
WHI0066	1/31/2006	15.9	13.3	230
WHI0066	3/7/2006	23.2	24.2	256
WHI0066	4/18/2006	16.9	20.7	228
WHI0066	5/16/2006	9.4	7.2	213
WHI0066	6/20/2006	17.1	29.6	261
WHI0066	7/18/2006	21.7	27.7	272
WHI0066	8/15/2006	26.6	37.7	288
WHI0066	9/12/2006	12.9	14.8	219
WHI0066	10/10/2006	22.4	23.9	287
WHI0066	10/31/2006	15.4	11.7	250
WHI0066	12/12/2006	8.9	5.8	
WHI0066	1/16/2007	7.4	6.3	168
WHI0066	2/27/2007	10.1	9.5	194
WHI0066	3/27/2007	11.2	9.6	218
WHI0066	4/10/2007	13.8	16.6	227
WHI0066	5/15/2007	11.0	15.3	210
WHI0066	6/19/2007	14.6	21.3	235
WHI0066	7/17/2007	11.1	11.2	213
WHI0066	9/5/2007	20.6	20.9	258
WHI0066	10/2/2007	19.3	17.2	257
WHI0066	11/13/2007	23.2	15.3	261
WHI0066	12/4/2007	25.6	19.5	266
WHI0066	1/15/2008	19.3	13.7	244
WHI0066	2/19/2008	11.2	10.0	178
WHI0066	3/3/2008	3.2	8.3	112
WHI0066	3/17/2008	10.6	11.0	221
WHI0066	4/1/2008	4.3	6.1	138
WHI0066	5/13/2008	7.6	7.6	176
WHI0066	6/17/2008	7.4	5.0	208
WHI0066	7/15/2008	8.5	7.9	199
WHI0066	8/19/2008	9.6	8.6	226
WHI0066	9/16/2008	6.6	5.6	204
WHI0066	10/21/2008	6.0	7.6	189

Site ID	Date Collected	Chloride (mg/L)	Sulfate (mg/L)	TDS (mg/L)
WHI0066	11/24/2008	12.0	10.0	240
WHI0066	12/9/2008	13.1	11.4	202
WHI0066	1/13/2009	7.1	5.9	209
WHI0066	2/17/2009	8.8	8.5	196
WHI0066	4/7/2009	7.8	7.3	194
WHI0066	5/19/2009	8.6	6.2	197
WHI0066	6/23/2009	8.6	7.9	204
WHI0066	7/21/2009	5.3	4.7	151
WHI0066	8/10/2009	7.1	4.3	232
WHI0066	9/15/2009	7.4	6.8	199
WHI0066	10/13/2009	4.6	4.8	165
WHI0066	11/3/2009	6.6	6.1	192
WHI0066	12/1/2009	8.1	6.2	213
WHI0066	1/12/2010	9.8	7.1	220

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

Summary:

Period of Record	9/25/90 - 1/12/10		
No. of Values	226	228	229
Minimum (mg/L)	3.2	3.6	112
Maximum (mg/L)	36.2	37.7	297
Median (mg/L)	12.1	10.7	223
Criterion from standards (mg/L)	20	20	200
No. Value > criterion	39	26	162
% Values > criterion	17%	11%	71%

FILE: R:\PROJECTS\3013-380\TECH\ADEQ_WQ_DATA\CROOKED_CREEK\WHI0066 CROOKED CREEK WITH TMDL CALCS.XLSX

Table B.3 Historical Water Quality data for Crooked Creek at Yellville (WHI0048A)
(replaced 8/08/06 by WHI0193: Crooked Creek west of Yellville at Kelly's Slab)

Site ID	Date Collected	Chloride (mg/L)	Sulfate (mg/L)	TDS (mg/L)
WHI0048A	9/25/1990	7.2	5.0	158
WHI0048A	10/23/1990	5.4	6.0	194
WHI0048A	11/19/1990	8.6	6.0	196
WHI0048A	12/18/1990	4.8	7.0	205
WHI0048A	1/29/1991	5.1	6.0	201
WHI0048A	2/26/1991	5.6	6.0	187
WHI0048A	3/19/1991	5.9	7.0	189
WHI0048A	4/23/1991	4.0	5.0	196
WHI0048A	5/14/1991	4.3	5.0	151
WHI0048A	6/25/1991	4.8	5.0	171
WHI0048A	7/23/1991	6.1	4.0	159
WHI0048A	8/27/1991			156
WHI0048A	9/24/1991			166
WHI0048A	10/22/1991			180
WHI0048A	11/19/1991	3.5	5.8	160
WHI0048A	12/17/1991	4.1	5.9	197
WHI0048A	1/7/1992	4.2	8.0	191
WHI0048A	2/4/1992	6.0	8.0	189
WHI0048A	3/3/1992	5.2	8.5	196
WHI0048A	4/7/1992	6.2	7.8	176
WHI0048A	5/12/1992	5.0	8.1	188
WHI0048A	6/9/1992	3.3	6.0	169
WHI0048A	7/7/1992	4.3	1.6	172
WHI0048A	8/4/1992	5.1	7.4	174
WHI0048A	9/1/1992	6.1	6.3	164
WHI0048A	9/29/1992	5.7	5.8	190
WHI0048A	10/27/1992	7.3	6.9	183
WHI0048A	11/23/1992	3.0	4.5	159
WHI0048A	1/26/1993	5.4	8.8	196
WHI0048A	2/23/1993	4.0	5.2	171
WHI0048A	3/23/1993	4.2	5.8	172
WHI0048A	4/27/1993	4.4	5.4	178
WHI0048A	5/25/1993	3.8	6.1	188
WHI0048A	6/22/1993	4.4	5.3	187
WHI0048A	7/20/1993	5.9	5.0	183
WHI0048A	8/17/1993	7.0	8.2	164
WHI0048A	9/28/1993	5.2	7.8	182
WHI0048A	10/19/1993	8.8	6.5	187
WHI0048A	11/23/1993	4.4	5.5	214
WHI0048A	12/7/1993	5.1	9.0	211
WHI0048A	1/4/1994	5.7	6.8	203
WHI0048A	2/8/1994	4.9	6.8	192
WHI0048A	3/22/1994	4.6	5.2	187
WHI0048A	4/12/1994	3.4	4.8	174
WHI0048A	5/17/1994	4.6	4.8	182

Site ID	Date Collected	Chloride (mg/L)	Sulfate (mg/L)	TDS (mg/L)
WHI0048A	6/14/1994	5.5	7.8	190
WHI0048A	7/26/1994	6.9	5.1	166
WHI0048A	8/30/1994	10.8	8.5	153
WHI0048A	10/18/1994	10.0	9.6	184
WHI0048A	11/15/1994	4.1	8.4	181
WHI0048A	12/13/1994	4.8	5.3	196
WHI0048A	1/24/1995	4.9	8.4	196
WHI0048A	2/6/1995	5.0	4.9	197
WHI0048A	3/14/1995	4.8	6.4	191
WHI0048A	4/18/1995	4.2	10.2	177
WHI0048A	5/16/1995	4.5	6.9	194
WHI0048A	6/13/1995	3.9	3.5	183
WHI0048A	7/11/1995	5.5	3.5	184
WHI0048A	8/15/1995	7.4	4.1	156
WHI0048A	9/5/1995	9.1	8.6	162
WHI0048A	10/3/1995	8.4	9.3	157
WHI0048A	10/31/1995	9.0	8.8	184
WHI0048A	11/28/1995	8.9	11.6	185
WHI0048A	1/9/1996	10.6	10.6	210
WHI0048A	2/6/1996	7.6	7.6	207
WHI0048A	3/5/1996	8.2	7.0	179
WHI0048A	4/9/1996	5.8	8.5	181
WHI0048A	5/7/1996	5.4	5.4	182*
WHI0048A	6/11/1996	6.6	8.4	188
WHI0048A	9/17/1996	6.7	5.8	161
WHI0048A	10/8/1996	6.8	10.6	207
WHI0048A	11/5/1996	7.3	8.2	215
WHI0048A	12/10/1996	5.4	2.7	206
WHI0048A	1/28/1997	6.2	9.7	209
WHI0048A	2/25/1997	4.9	6.9	196
WHI0048A	3/25/1997	5.1	7.1	183
WHI0048A	4/29/1997	4.9	5.6	192
WHI0048A	5/20/1997	7.7	5.7	190
WHI0048A	6/10/1997	7.5	7.4	197
WHI0048A	7/29/1997	6.0	8.5	148
WHI0048A	8/19/1997	7.0	6.1	180
WHI0048A	9/23/1997	8.8	8.6	157
WHI0048A	10/14/1997	9.6	7.7	166
WHI0048A	11/12/1997	10.1	8.0	201
WHI0048A	12/9/1997	8.4	8.4	209
WHI0048A	1/13/1998	5.8	5.7	201
WHI0048A	2/10/1998	6.3	6.9	191
WHI0048A	3/10/1998	4.0	5.9	175
WHI0048A	4/7/1998	4.3	5.3	174
WHI0048A	5/12/1998	4.5	5.2	191
WHI0048A	6/16/1998	6.5	5.8	178
WHI0048A	7/7/1998	8.9	5.8	159
WHI0048A	8/18/1998	7.9*	5.6	150

Site ID	Date Collected	Chloride (mg/L)	Sulfate (mg/L)	TDS (mg/L)
WHI0048A	9/22/1998	10.8	7.9	168
WHI0048A	10/20/1998	8.0	7.9	194
WHI0048A	11/17/1998	8.0	8.1	194
WHI0048A	12/15/1998	5.2	6.0	209
WHI0048A	1/12/1999	6.6	6.8	206
WHI0048A	2/2/1999	6.4	6.9	192
WHI0048A	3/2/1999	6.5	6.0	192
WHI0048A	4/6/1999	4.1	5.5	179
WHI0048A	5/11/1999	4.4	5.3	204
WHI0048A	6/15/1999	5.1	5.0	196
WHI0048A	7/20/1999	6.8	5.0	190
WHI0048A	8/24/1999	8.3	5.6	160
WHI0048A	9/21/1999	9.6	6.7	156
WHI0048A	11/2/1999	11.4	6.9	179
WHI0048A	11/30/1999	11.5	8.4	191
WHI0048A	1/11/2000	8.1	8.1	191
WHI0048A	2/8/2000	10.2	8.7	198
WHI0048A	3/14/2000	9.0	8.7	192
WHI0048A	4/11/2000	8.9	8.6	182
WHI0048A	5/23/2000	10.5	8.7	177
WHI0048A	6/20/2000	4.5	6.4	
WHI0048A	7/25/2000	8.0	6.2	177
WHI0048A	8/22/2000	9.1	5.7	161
WHI0048A	10/17/2000	10.0	8.5	176
WHI0048A	10/31/2000	11.0	8.2	186
WHI0048A	1/9/2001	10.9	7.6	206
WHI0048A	2/6/2001	4.6	4.4	207
WHI0048A	3/13/2001	6.6	6.1	194
WHI0048A	4/10/2001	8.4	6.8	189
WHI0048A	5/8/2001	7.6	5.9	189*
WHI0048A	6/5/2001	9.3	5.8	182
WHI0048A	7/10/2001	7.2	5.2	179
WHI0048A	8/14/2001	7.0	5.1	182
WHI0048A	9/11/2001	10.1	7.9	198
WHI0048A	10/9/2001	10.7	7.2	183
WHI0048A	11/6/2001	12.7	7.8	193
WHI0048A	12/4/2001	8.2	7.8	216
WHI0048A	1/8/2002	7.7	6.5	231
WHI0048A	2/5/2002	5.5	5.6	206*
WHI0048A	3/5/2002	6.2	6.1	208
WHI0048A	4/2/2002	5.3	5.4	198
WHI0048A	5/7/2002	5.6	4.8	184
WHI0048A	6/4/2002	5.9	5.3	189
WHI0048A	7/9/2002	7.7	4.9	189
WHI0048A	9/10/2002	10.3	5.9	162
WHI0048A	10/1/2002	10.2	7.4	159
WHI0048A	11/5/2002	9.9	7.8	190
WHI0048A	12/3/2002	10.5	7.4	189

Site ID	Date Collected	Chloride (mg/L)	Sulfate (mg/L)	TDS (mg/L)
WHI0048A	1/7/2003	9.2	8.4	201
WHI0048A	2/4/2003	10.8	8.4	186
WHI0048A	3/11/2003	9.2	7.7	200
WHI0048A	4/1/2003	8.9	7.0	174
WHI0048A	5/6/2003	7.6	6.5	198
WHI0048A	6/24/2003	8.2	6.2	198
WHI0048A	7/22/2003	8.9	5.9	168
WHI0048A	8/19/2003	10.3	6.1	163
WHI0048A	9/16/2003	9.4	6.4	184
WHI0048A	10/14/2003	10.0	7.7	189
WHI0048A	11/4/2003	11.2	8.1	201
WHI0048A	12/9/2003	7.5	7.4	190
WHI0048A	1/13/2004	8.8	8.7	226
WHI0048A	2/3/2004	7.8	7.6	221
WHI0048A	3/9/2004	6.8	6.9	212
WHI0048A	4/6/2004	7.5	6.5	210
WHI0048A	5/11/2004	36.1	19.3	343
WHI0048A	6/8/2004	7.3	5.0	205
WHI0048A	7/6/2004	7.3	5.8	188
WHI0048A	8/10/2004	9.5	6.7	164
WHI0048A	11/2/2004	5.4	6.0	201
WHI0048A	12/7/2004	5.7	5.6	218
WHI0048A	1/4/2005	3.8	4.7	169
WHI0048A	2/1/2005	7.1	5.9	226
WHI0048A	3/1/2005	6.3	5.9	213
WHI0048A	4/5/2005	6.0	5.3	199
WHI0048A	5/10/2005	7.0	5.5	212
WHI0048A	6/7/2005	7.8	5.6	206
WHI0048A	7/5/2005	9.7	7.1	175
WHI0048A	10/4/2005	9.4	7.7	185
WHI0048A	11/8/2005	11.8	8.2	190
WHI0048A	12/6/2005	10.3	8.4	210
WHI0048A	1/10/2006	10.5	9.8	198
WHI0048A	2/7/2006	9.6	9.4	204
WHI0048A	4/4/2006	8.2	7.2	192
WHI0048A	5/2/2006	4.6	5.7	198
WHI0048A	6/6/2006	7.7	5.8	205
WHI0048A	7/11/2006	8.3	6.5	166
WHI0193	8/8/2006	10.2	6.5	173
WHI0193	9/19/2006	11.9	9.7	186
WHI0193	10/17/2006	4.2	5.2	145
WHI0193	11/28/2006	7.5	6.3	221
WHI0193	12/19/2006	8.0	6.6	228
WHI0193	1/23/2007	6.5	5.8	204
WHI0193	2/6/2007	7.1	6.0	210
WHI0193	3/13/2007	7.3	6.4	195
WHI0193	4/3/2007	7.9	6.3	196
WHI0193	5/1/2007	6.0	6.2	189

Site ID	Date Collected	Chloride (mg/L)	Sulfate (mg/L)	TDS (mg/L)
WHI0193	6/5/2007	7.8	6.6	197
WHI0193	7/10/2007	5.6	5.4	183
WHI0193	8/7/2007	10.1	6.7	184
WHI0193	9/18/2007	10.4	8.9	179
WHI0193	10/16/2007	10.7	8.2	178
WHI0193	11/27/2007	11.9	9.3	210
WHI0193	12/11/2007	10.4	9.4	211
WHI0193	1/8/2008	10.0	9.3	207
WHI0193	2/4/2008	10.7	10.9	200
WHI0193	3/11/2008	7.1	6.6	217
WHI0193	4/15/2008	5.1	5.2	192
WHI0193	5/20/2008	5.3	4.9	182
WHI0193	6/10/2008	6.8	6.0	203
WHI0193	7/8/2008	5.2	4.9	189
WHI0193	8/12/2008	4.5	4.7	188
WHI0193	9/9/2008	4.6	4.5	226
WHI0193	10/7/2008	6.1	5.2	215
WHI0193	11/18/2008	7.5	5.3	201
WHI0193	12/9/2008	8.3	6.1	204
WHI0193	1/20/2009	8.2	7.2	193
WHI0193	2/10/2009	5.6	5.7	209
WHI0193	3/10/2009	6.9	6.6	202
WHI0193	4/28/2009	5.6	5.5	209
WHI0193	5/5/2009	4.1	5.2	197
WHI0193	6/9/2009	6.4	5.2	208
WHI0193	8/19/2009	7.1	6.8	205
WHI0193	9/1/2009	7.6	5.8	184
WHI0193	10/20/2009	5.0	5.4	236
WHI0193	11/17/2009	5.1	4.9	206
WHI0193	12/8/2009	5.4	5.2	204

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

Summary:

Period of Record	9/25/90 - 12/08/09		
No. of Values	215	216	215
Minimum (mg/L)	3.0	1.6	145
Maximum (mg/L)	36.1	19.3	343
Median (mg/L)	7.0	6.4	190
Criterion from standards (mg/L)	20	20	200
No. values > criterion	1	0	60
% values > criterion	0.5%	0.0%	27.9%

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Table B.4 Historical Water Quality Data for Crooked Creek 2 miles south of Flippin, AR

Site ID	Date Collected	Chloride (mg/L)	Sulfate (mg/L)	TDS (mg/L)
WHI0048B	1/13/1998	5.8	5.8	199
WHI0048B	2/10/1998	6.4	7.0	189
WHI0048B	3/10/1998	3.9	6.0	171
WHI0048B	4/07/1998	4.4	5.4	177
WHI0048B	5/12/1998	4.4	5.2	195
WHI0048B	12/15/1998	5.1	6.5	212
WHI0048B	1/12/1999	6.4	6.8	207
WHI0048B	2/02/1999	6.6	6.9	196
WHI0048B	3/02/1999	6.6	6.1	187
WHI0048B	4/06/1999	3.9	5.6	185
WHI0048B	5/11/1999	4.4	5.4	204
WHI0048B	6/15/1999	5.4	4.9	180
WHI0048B	6/20/2000	4.4	6.6	
WHI0048B	1/09/2001	10.1	7.9	198
WHI0048B	2/06/2001	8.1	7.2	204
WHI0048B	3/13/2001	6.7	6.1	197
WHI0048B	4/10/2001	8.3	6.9	163
WHI0048B	12/04/2001	8.0	7.6	215
WHI0048B	1/08/2002	7.6	6.5	228
WHI0048B	2/05/2002	5.5	5.7	203*
WHI0048B	3/05/2002	6.3	6.2	7701.5*
WHI0048B	4/02/2002	5.2	5.4	199
WHI0048B	5/07/2002	5.6	4.9	184
WHI0048B	6/04/2002	5.8	5.0	186
WHI0048B	7/09/2002	7.6	5.0	163
WHI0048B	1/07/2003	8.9	8.6	201
WHI0048B	3/11/2003	9.2	7.7	183
WHI0048B	4/01/2003	8.8	7.0	168
WHI0048B	6/24/2003	8.5	6.4	194
WHI0048B	7/22/2003	2.6	4.8	134
WHI0048B	12/09/2003	7.2	7.8	196
WHI0048B	2/03/2004	7.8	7.5	221
WHI0048B	3/09/2004	6.9	7.1	220
WHI0048B	4/06/2004	7.5	6.6	200
WHI0048B	5/11/2004	6.0	5.3	225
WHI0048B	6/08/2004	7.4	5.0	180
WHI0048B	7/06/2004	7.2	5.7	168
WHI0048B	11/02/2004	4.9	5.8	183
WHI0048B	12/07/2004	5.3	5.7	218
WHI0048B	1/04/2005	5.2	5.5	194
WHI0048B	2/01/2005	7.0	5.9	221
WHI0048B	3/01/2005	6.3	6.0	212

Site ID	Date Collected	Chloride (mg/L)	Sulfate (mg/L)	TDS (mg/L)
WHI0048B	4/05/2005	6.0	5.4	200
WHI0048B	5/10/2005	7.0	5.4	197
WHI0048B	5/02/2006	4.5	5.9	199
WHI0048B	1/23/2007	6.4	5.9	211
WHI0048B	2/06/2007	7.0	6.2	207
WHI0048B	3/13/2007	7.3	6.5	195
WHI0048B	4/03/2007	7.6	6.4	171
WHI0048B	5/01/2007	6.0	6.1	186
WHI0048B	7/10/2007	4.8	5.6	176
WHI0048B	3/11/2008	6.6	6.7	212
WHI0048B	4/15/2008	5.3	5.3	193
WHI0048B	5/20/2008	5.2	5.0	176
WHI0048B	6/10/2008	6.6	5.5	197
WHI0048B	7/08/2008	5.0	5.0	188
WHI0048B	8/12/2008	4.3	4.4	185
WHI0048B	9/09/2008	4.6	4.5	227
WHI0048B	10/07/2008	6.3	5.1	208
WHI0048B	2/10/2009	5.8	5.8	201
WHI0048B	3/10/2009	6.9	6.6	192
WHI0048B	4/28/2009	6.2	5.6	208
WHI0048B	5/05/2009	4.5	5.2	200
WHI0048B	6/09/2009	6.4	5.3	212
WHI0048B	8/19/2009	6.9	5.3	167
WHI0048B	10/20/2009	4.9	5.0	231
WHI0048B	11/17/2009	5.3	4.9	209
WHI0048B	12/08/2009	5.7	5.2	206

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

Summary:

Period of Record	1/13/98 - 12/08/09		
No. of Values	68	68	65
Minimum (mg/L)	2.6	4.4	134
Maximum (mg/L)	10.1	8.6	231
Median (mg/L)	6.3	5.8	197
Criterion from standards (mg/L)	20	20	200
No. Value > criterion	0	0	24
% Values > criterion	0.0%	0.0%	36.9%

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Table B.5 Historical Water Quality Data for Crooked Creek at Hwy 101, 2 mi north of Rea Valley, AR

Site ID	Date Collected	Chloride (mg/L)	Sulfate (mg/L)	TDS (mg/L)
WHI0048C	1/13/1998	6.0	7.2	217
WHI0048C	2/10/1998	6.2	7.2	177
WHI0048C	3/10/1998	3.9	6.1	171
WHI0048C	4/07/1998	4.9	5.6	179
WHI0048C	5/12/1998	4.1	5.3	192
WHI0048C	12/15/1998	5.2	6.4	209
WHI0048C	1/12/1999	6.7	6.8	214
WHI0048C	2/02/1999	7.1	7.1	209
WHI0048C	3/02/1999	6.3	6.5	166
WHI0048C	4/06/1999	3.9	5.7	183
WHI0048C	5/11/1999	4.3	5.4	200
WHI0048C	6/15/1999	4.7	4.9	210
WHI0048C	1/11/2000	3.9	14.2	196
WHI0048C	6/20/2000	4.3	6.6	
WHI0048C	2/06/2001	8.4	8.4	198
WHI0048C	3/13/2001	6.7	6.2	184
WHI0048C	4/10/2001	7.7	7.2	170
WHI0048C	7/10/2001	4.3	4.5	173
WHI0048C	1/08/2002	7.0	7.0	213
WHI0048C	2/05/2002	5.5	6.1	204*
WHI0048C	3/05/2002	6.7	6.6	212
WHI0048C	4/02/2002	5.2	5.6	201
WHI0048C	5/07/2002	5.5	5.0	181
WHI0048C	6/04/2002	5.4	5.1	176
WHI0048C	7/09/2002	6.8	4.0	164
WHI0048C	1/07/2003	10.3	10.4	214
WHI0048C	3/11/2003	11.8	10.6	210
WHI0048C	4/01/2003	9.7	9.0	190
WHI0048C	5/06/2003	6.9	7.0	220
WHI0048C	6/24/2003	7.3	5.8	167
WHI0048C	12/09/2003	7.4	36.5	281
WHI0048C	1/13/2004	8.6	9.0	169
WHI0048C	2/03/2004	7.5	9.9	244
WHI0048C	3/09/2004	6.7	7.2	208
WHI0048C	4/06/2004	7.6	7.1	237
WHI0048C	5/11/2004	6.1	5.3	233
WHI0048C	6/08/2004	6.6	5.1	169
WHI0048C	7/06/2004	6.3	5.9	145
WHI0048C	11/02/2004	4.1	5.3	178
WHI0048C	12/07/2004	5.6	6.6	225
WHI0048C	1/04/2005	11.7	10.1	219
WHI0048C	2/01/2005	7.1	6.2	229
WHI0048C	3/01/2005	6.4	6.2	198
WHI0048C	4/05/2005	6.0	5.5	194

Site ID	Date Collected	Chloride (mg/L)	Sulfate (mg/L)	TDS (mg/L)
WHI0048C	5/10/2005	6.6	5.2	192
WHI0048C	6/07/2005	7.0	3.9	189
WHI0048C	2/07/2006	6.5	18.4	245
WHI0048C	4/04/2006	8.1	9.5	221
WHI0048C	5/02/2006	4.6	5.8	197
WHI0048C	6/06/2006	7.1	3.9	202
WHI0048C	1/23/2007	6.4	5.9	213
WHI0048C	2/06/2007	7.4	6.0	207
WHI0048C	3/13/2007	7.2	5.9	196
WHI0048C	4/03/2007	7.5	5.9	189
WHI0048C	5/01/2007	6.4	6.2	178
WHI0048C	7/10/2007	1.8	5.4	192
WHI0048C	3/11/2008	6.8	6.8	215
WHI0048C	4/15/2008	5.1	5.3	198
WHI0048C	5/20/2008	5.1	5.0	177
WHI0048C	6/10/2008	6.1	4.2	186
WHI0048C	7/08/2008	4.7	4.6	176
WHI0048C	8/12/2008	4.4	4.4	176
WHI0048C	9/09/2008	4.6	4.5	230
WHI0048C	10/07/2008	6.4	4.7	194
WHI0048C	2/10/2009	5.8	5.7	193
WHI0048C	3/10/2009	6.7	6.2	180
WHI0048C	4/28/2009	6.1	5.5	198
WHI0048C	5/05/2009	3.9	5.2	197
WHI0048C	6/09/2009	6.3	5.1	197
WHI0048C	8/19/2009	5.9	4.1	174
WHI0048C	9/01/2009	6.4	4.6	166
WHI0048C	10/20/2009	4.9	5.0	238
WHI0048C	11/17/2009	5.1	4.9	201
WHI0048C	12/08/2009	5.4	5.0	195

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

Summary:

Period of Record	1/13/98 - 12/08/09		
No. of Values	74	74	72
Minimum (mg/L)	1.8	3.9	145
Maximum (mg/L)	11.8	36.5	281
Median (mg/L)	6.3	5.9	196.5
Criterion from standards (mg/L)	20	20	200
No. Value > criterion	0	1	28
% Values > criterion	0%	1%	39%

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Figure B.1 Time Series Plot of Chloride in Crooked Creek above Harrison (WHI0067)

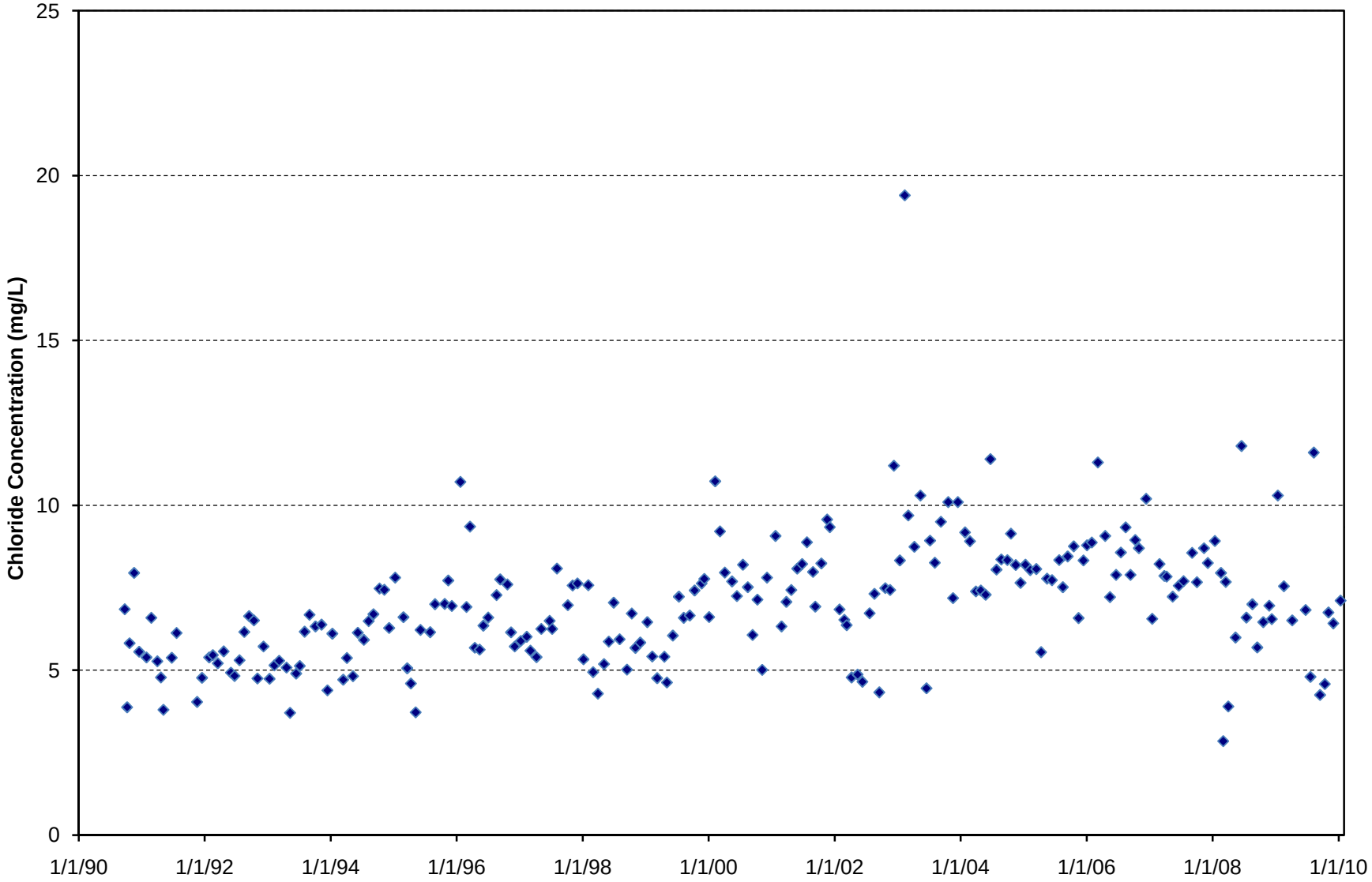


Figure B.2 Time Series Plot of Sulfate in Crooked Creek above Harrison (WHI0067)

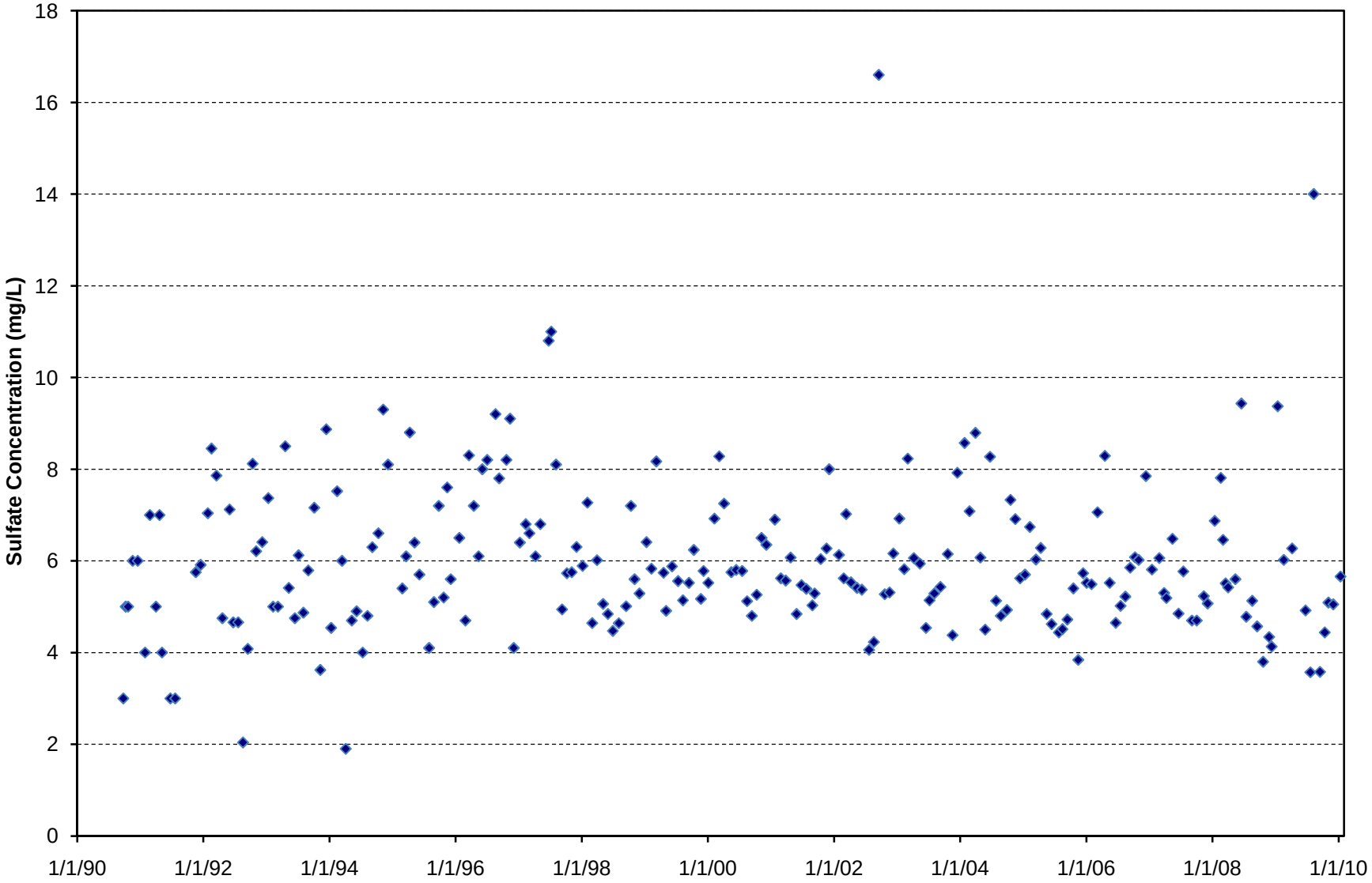


Figure B.3 Time Series Plot of TDS in Crooked Creek above Harrison (WHI0067)

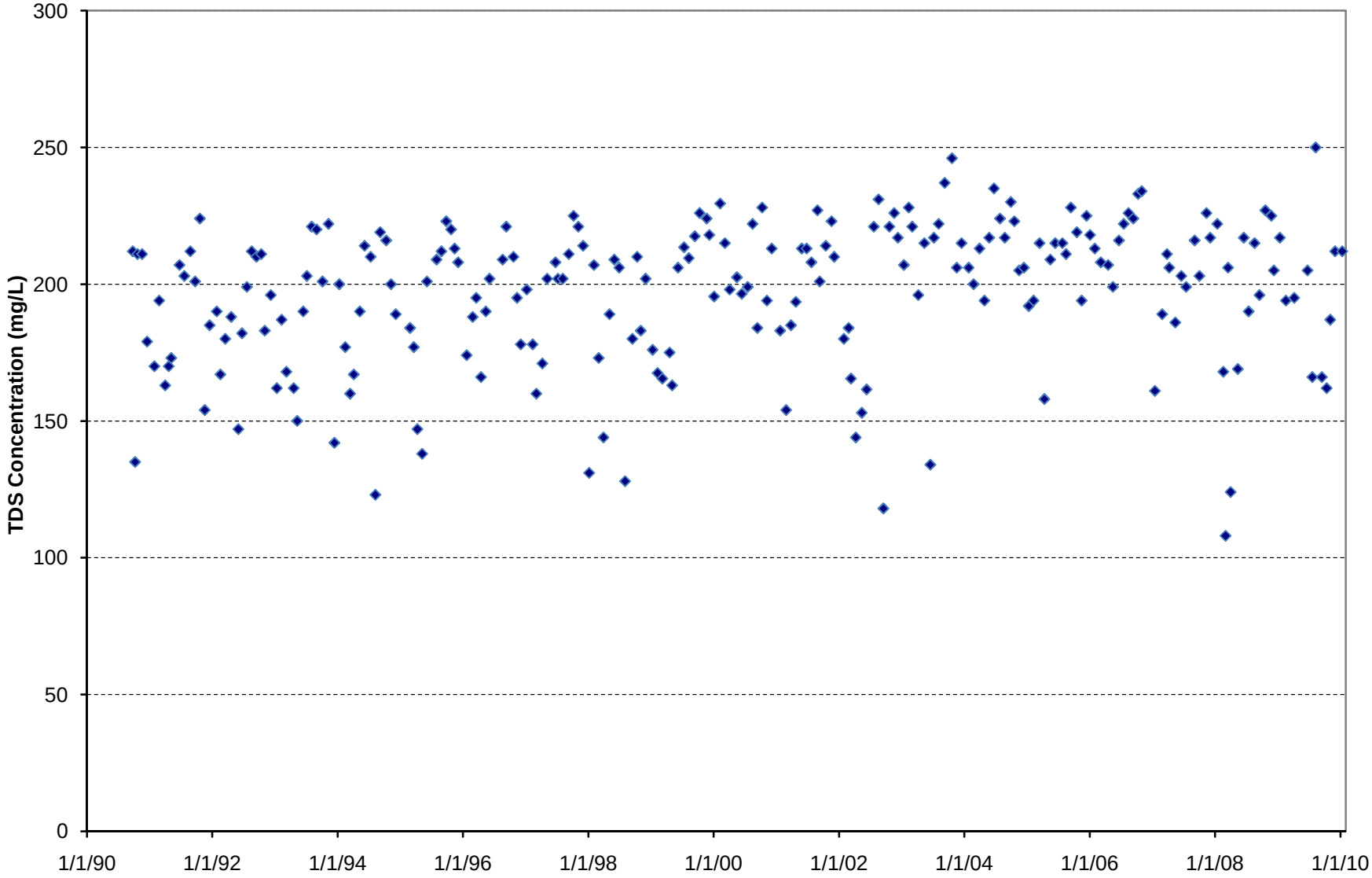


Figure B.4 Time Series Plot of Chloride in Crooked Creek below Harrison (WHI0066)

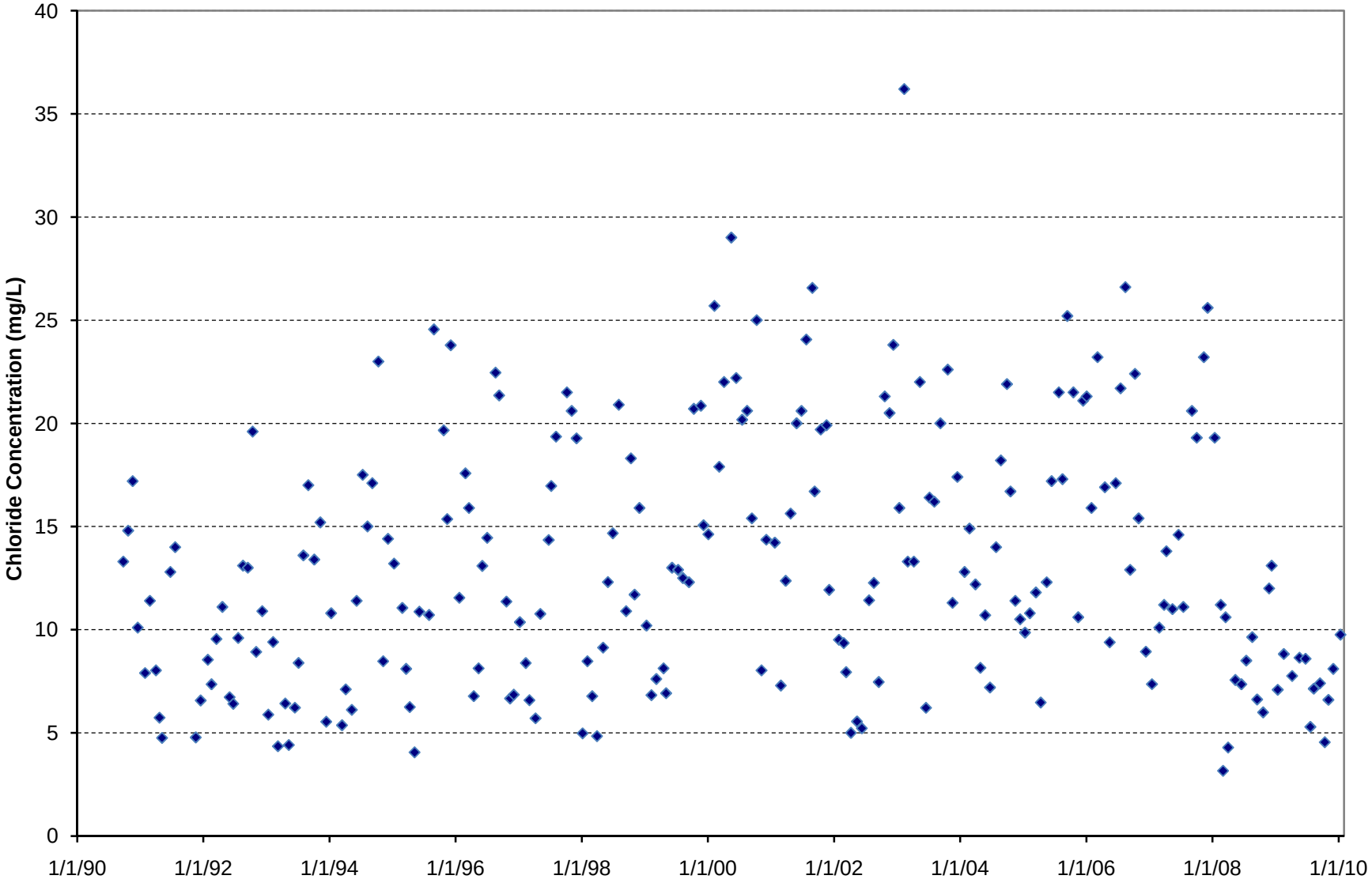


Figure B.5 Time Series Plot of Sulfate in Crooked Creek below Harrison (WHI0066)

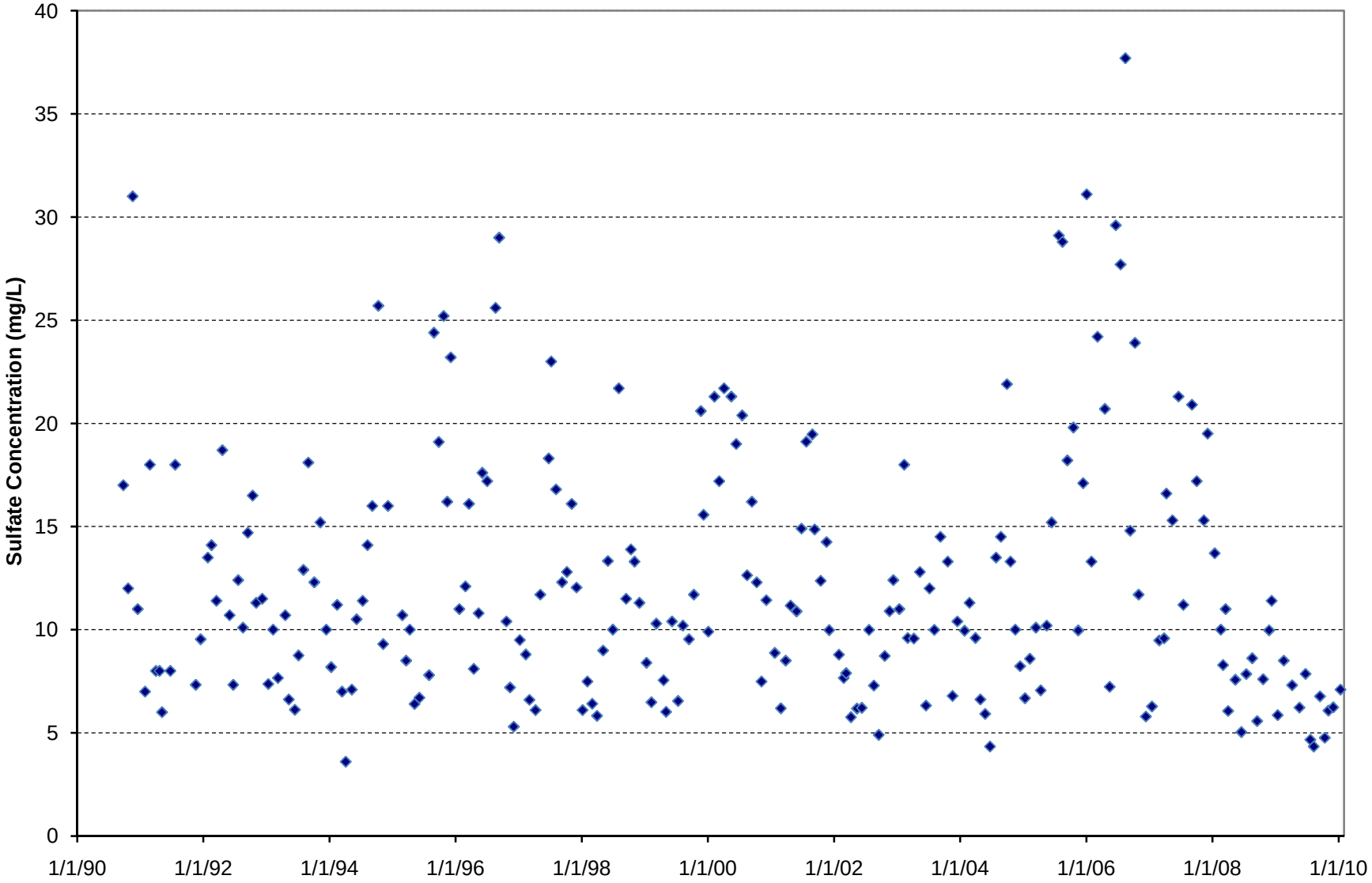


Figure B.6 Time Series Plot of TDS in Crooked Creek below Harrison (WHI0066)

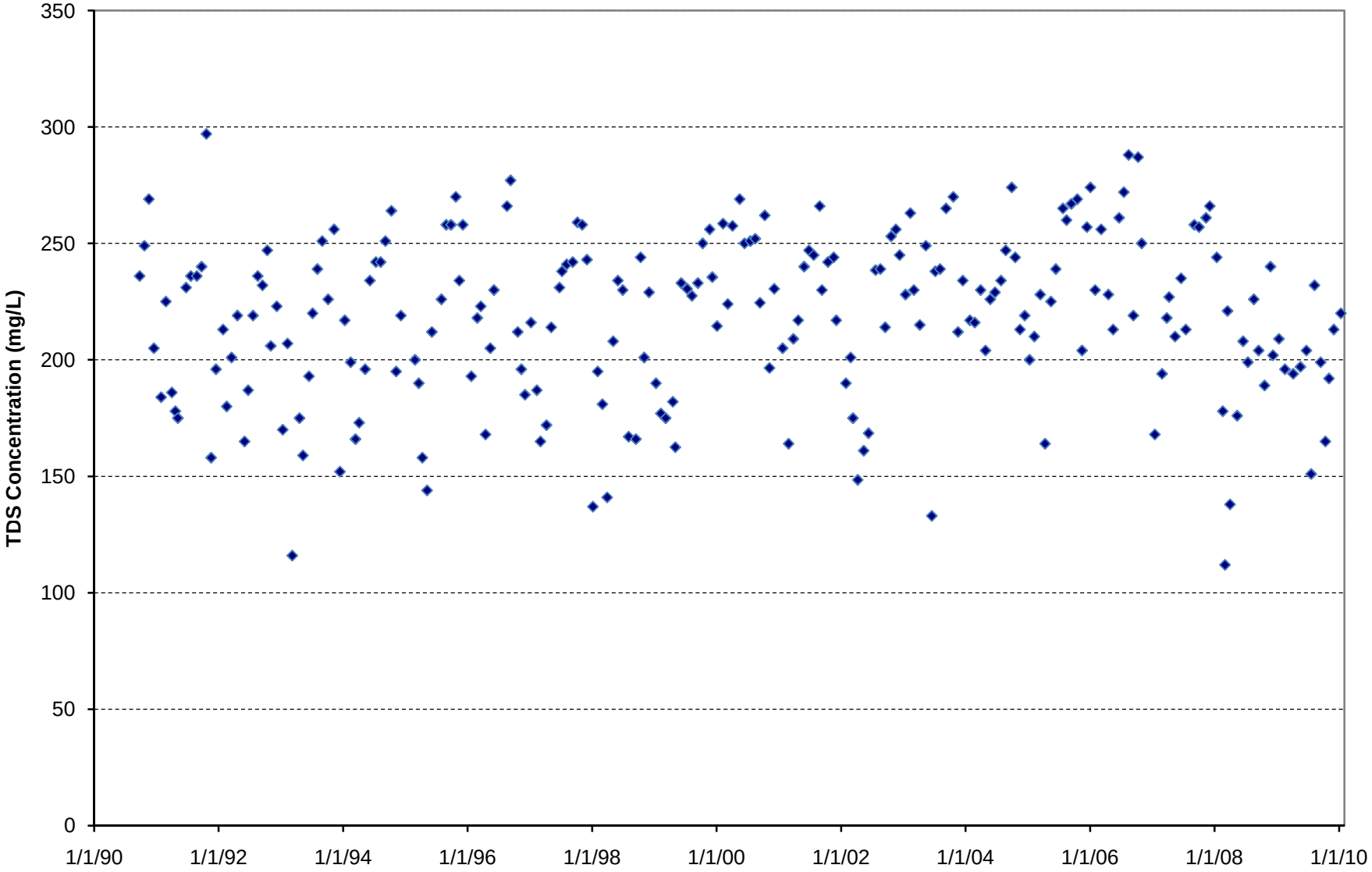


Figure B.7 Time Series Plot of Chloride in Crooked Creek at Yellville (WHI0048A / WHI0193)

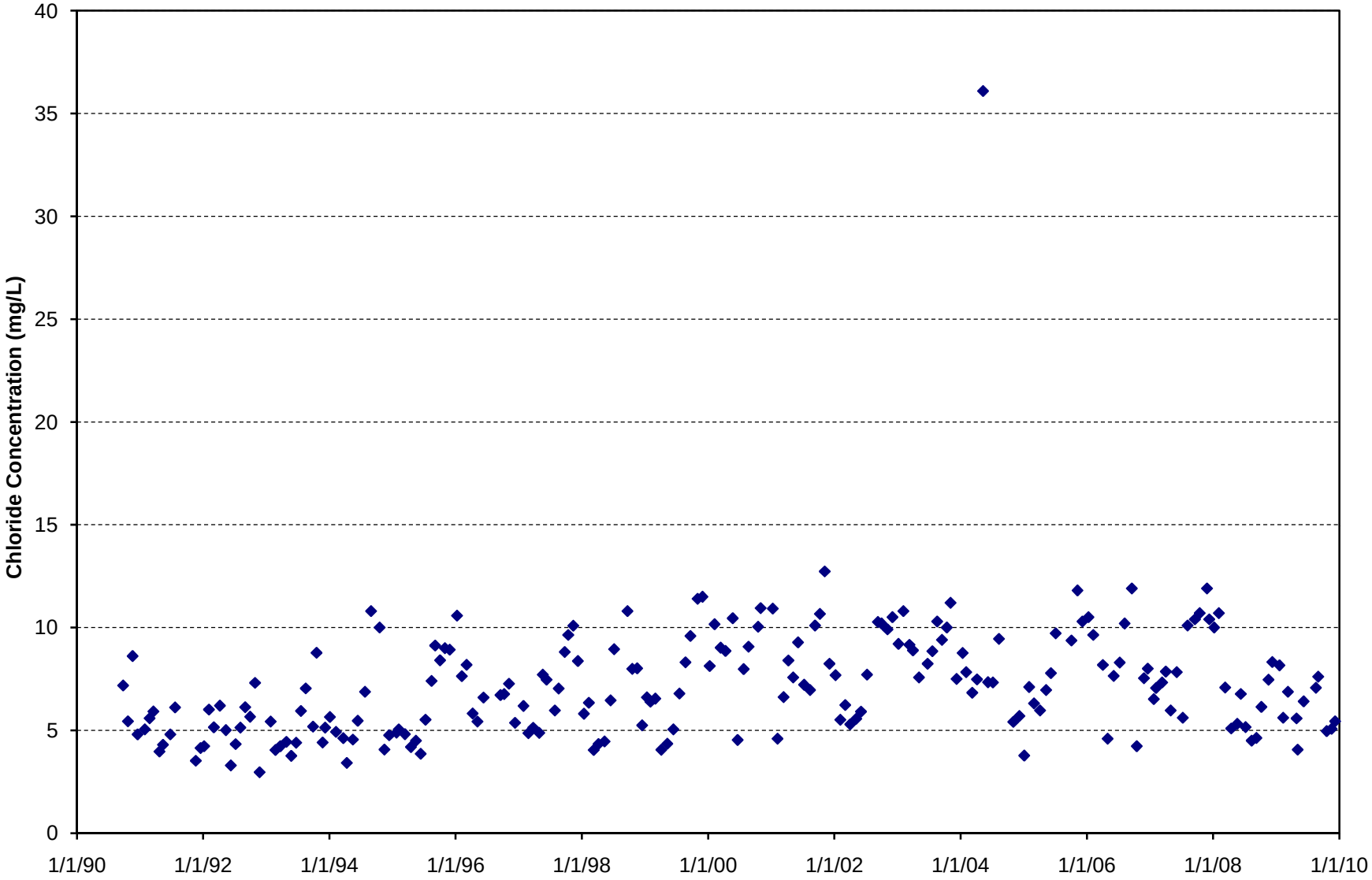


Figure B.8 Time Series Plot of Sulfate in Crooked Creek at Yellville (WHI0048A / WHI0193)

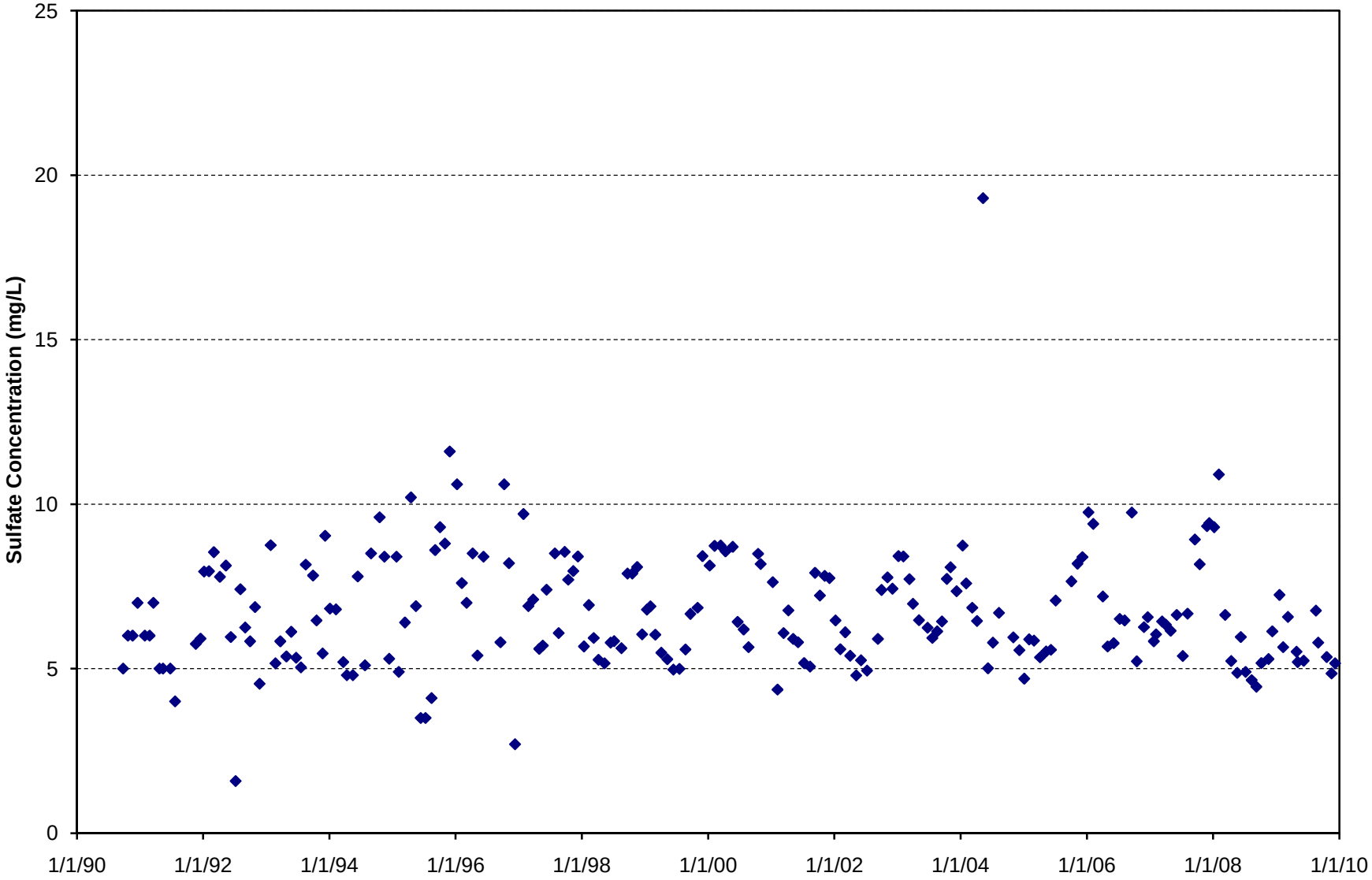


Figure B.9 Time Series Plot of TDS in Crooked Creek at Yellville (WHI0048A / WHI0193)

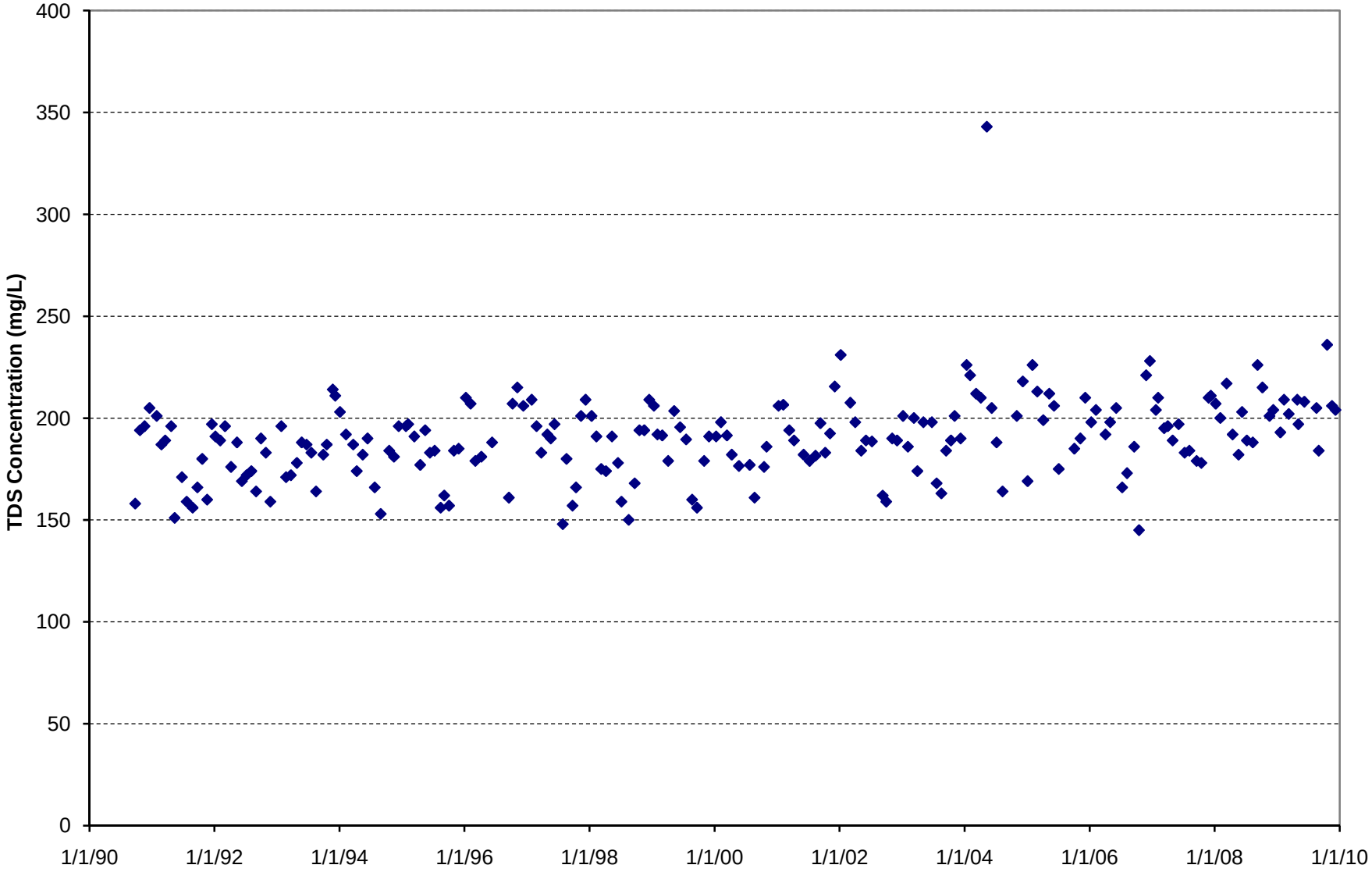


Figure B.10 Time Series Plot of Chloride in Crooked Creek 2 mi S of Flippin (WHI0048B)

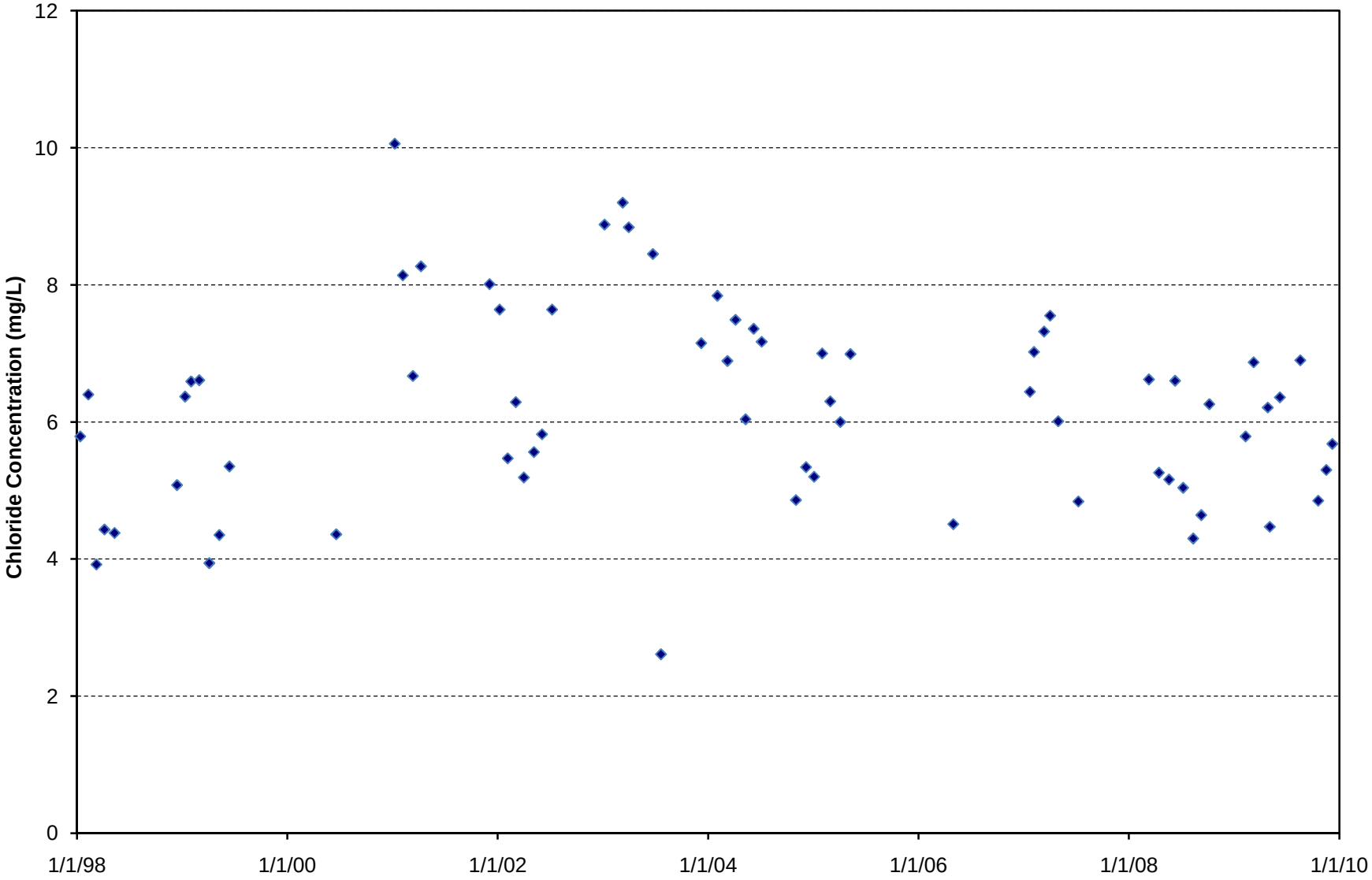


Figure B.11 Time Series Plot of Sulfate in Crooked Creek 2 mi S of Flippin (WHI0048B)

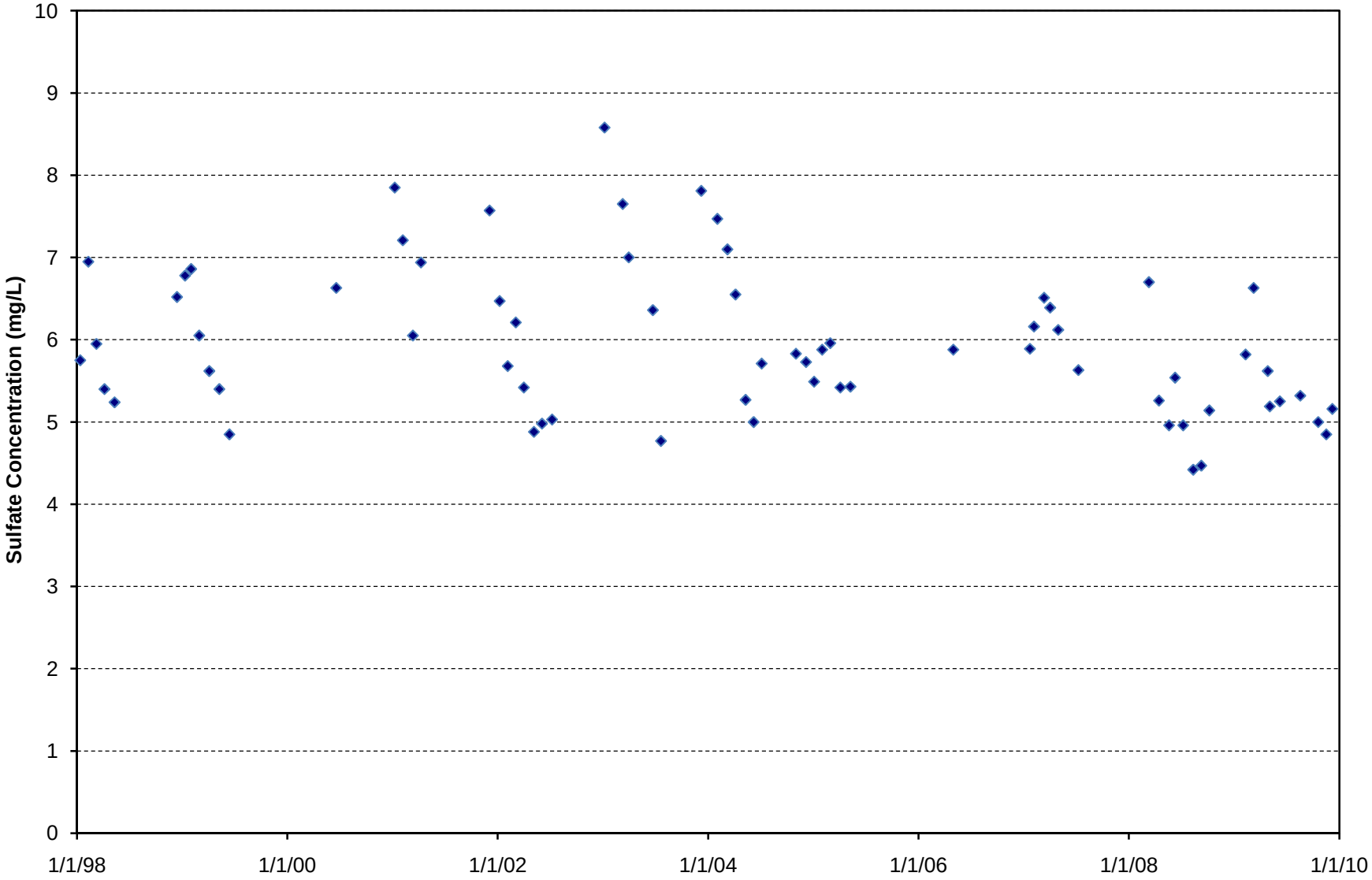


Figure B.12 Time Series Plot of TDS in Crooked Creek 2 mi S of Flippin (WHI0048B)

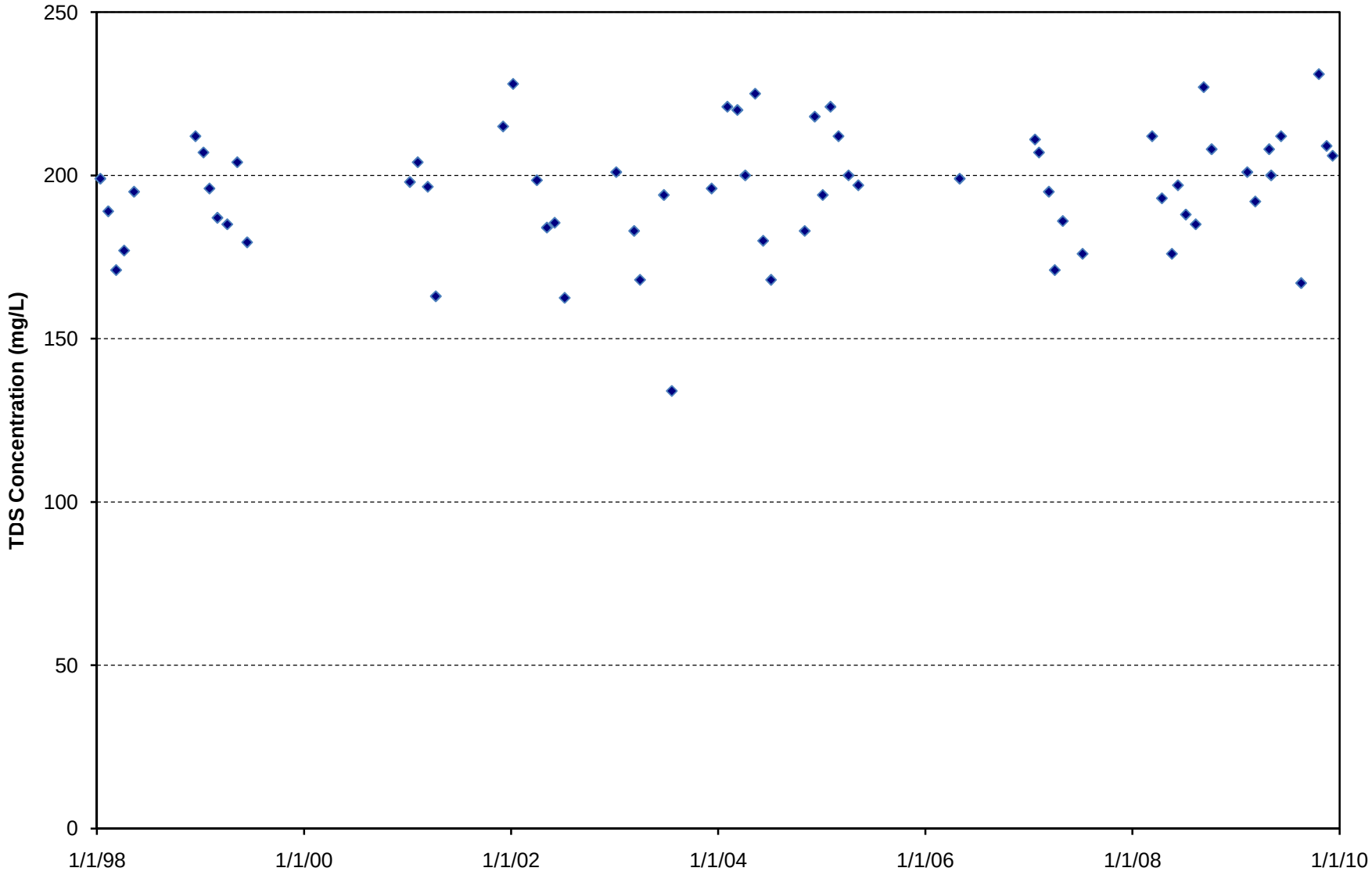


Figure B.13 Time Series Plot of Chloride in Crooked Creek north of Rea Valley (WHI0048C)

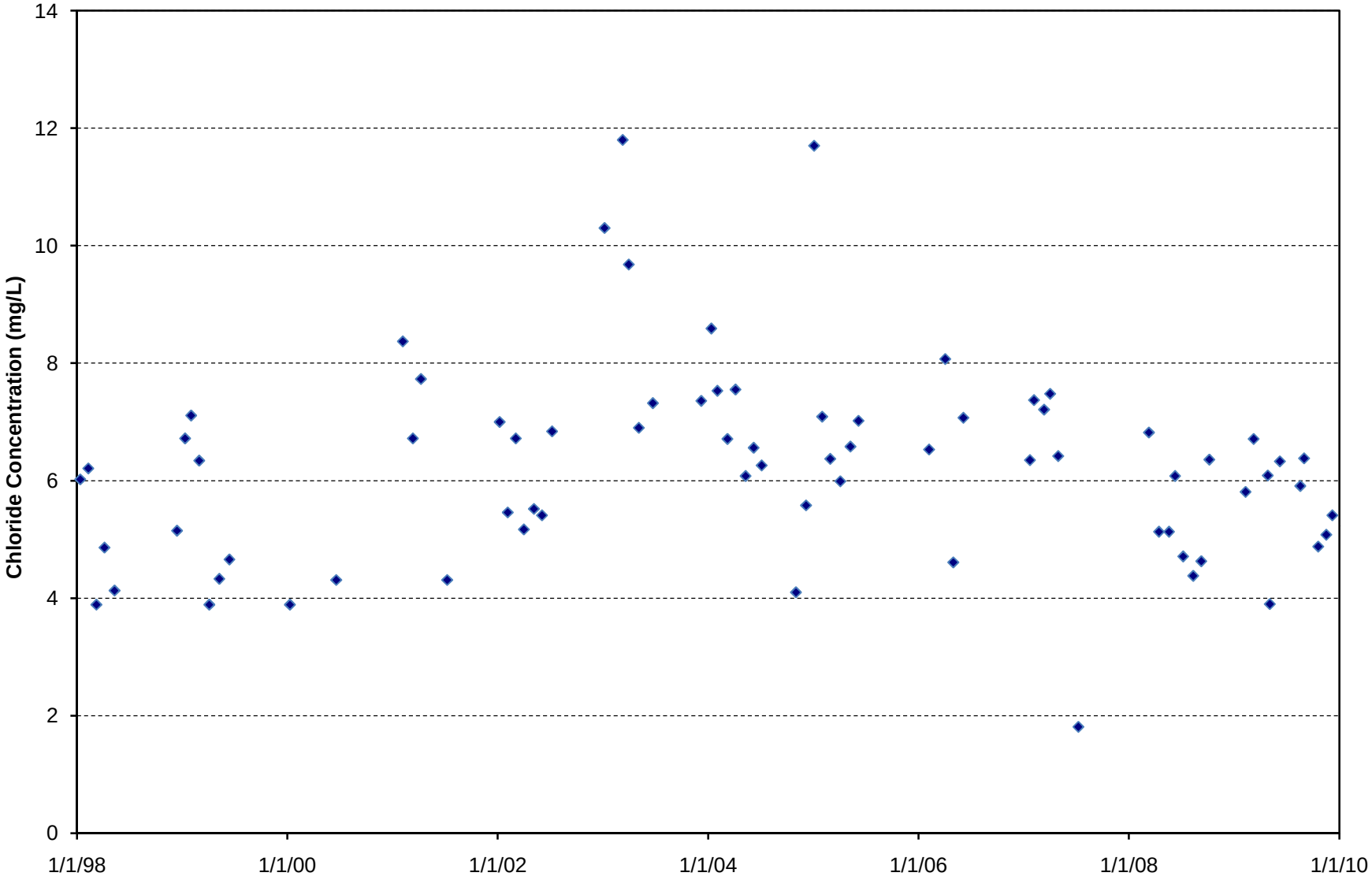


Figure B.14 Time Series Plot of Sulfate in Crooked Creek north of Rea Valley (WHI0048C)

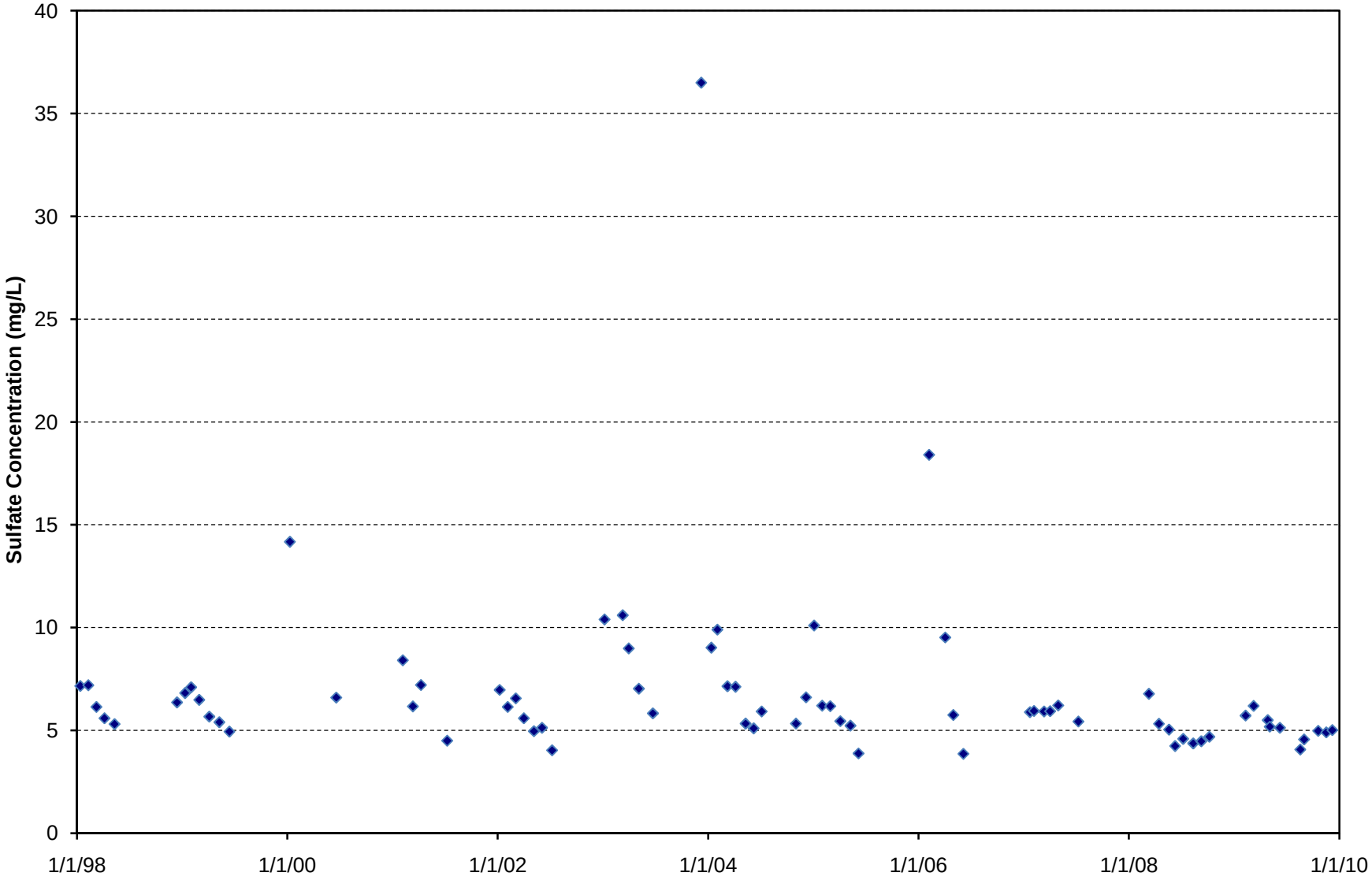
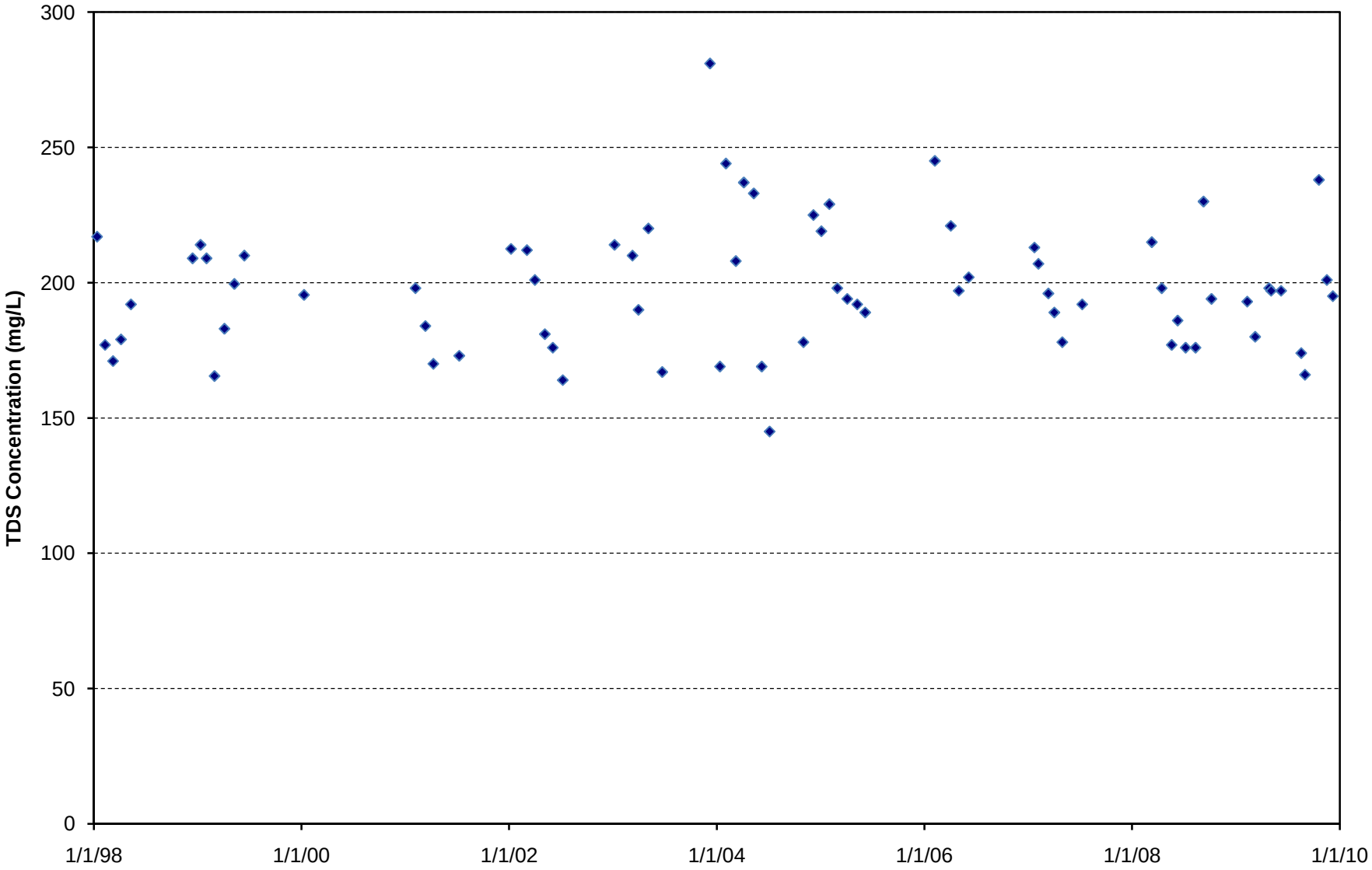


Figure B.15 Time Series Plot of TDS in Crooked Creek north of Rea Valley (WHI0048C)



APPENDIX C

Seasonal Plots of Water Quality Data

Figure C.1 Seasonal Plot of Chloride in Crooked Creek above Harrison (WHI0067)

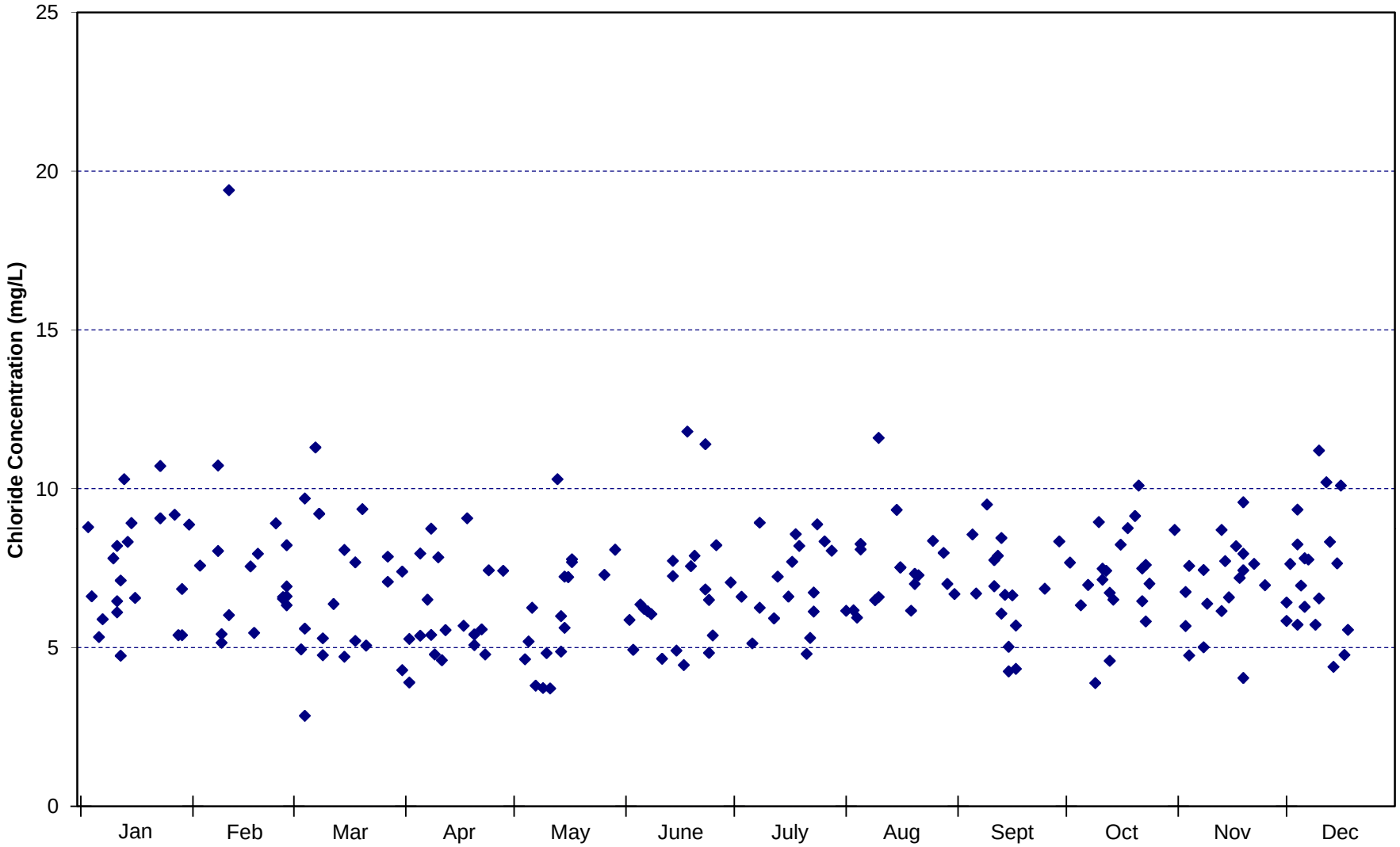


Figure C.2 Seasonal Plot of Sulfate in Crooked Creek above Harrison (WHI0067)

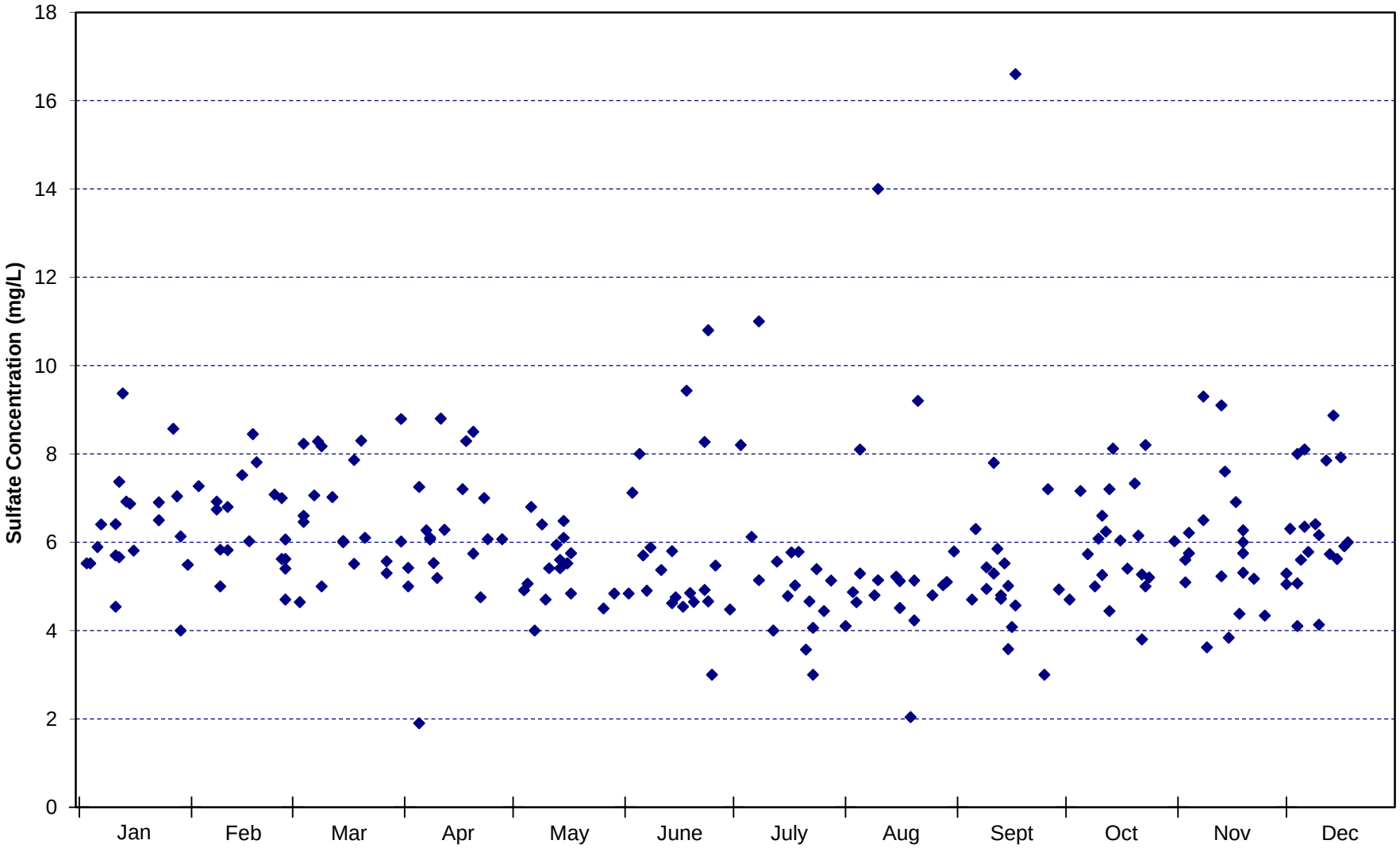


Figure C.3 Seasonal Plot of TDS in Crooked Creek above Harrison (WHI0067)

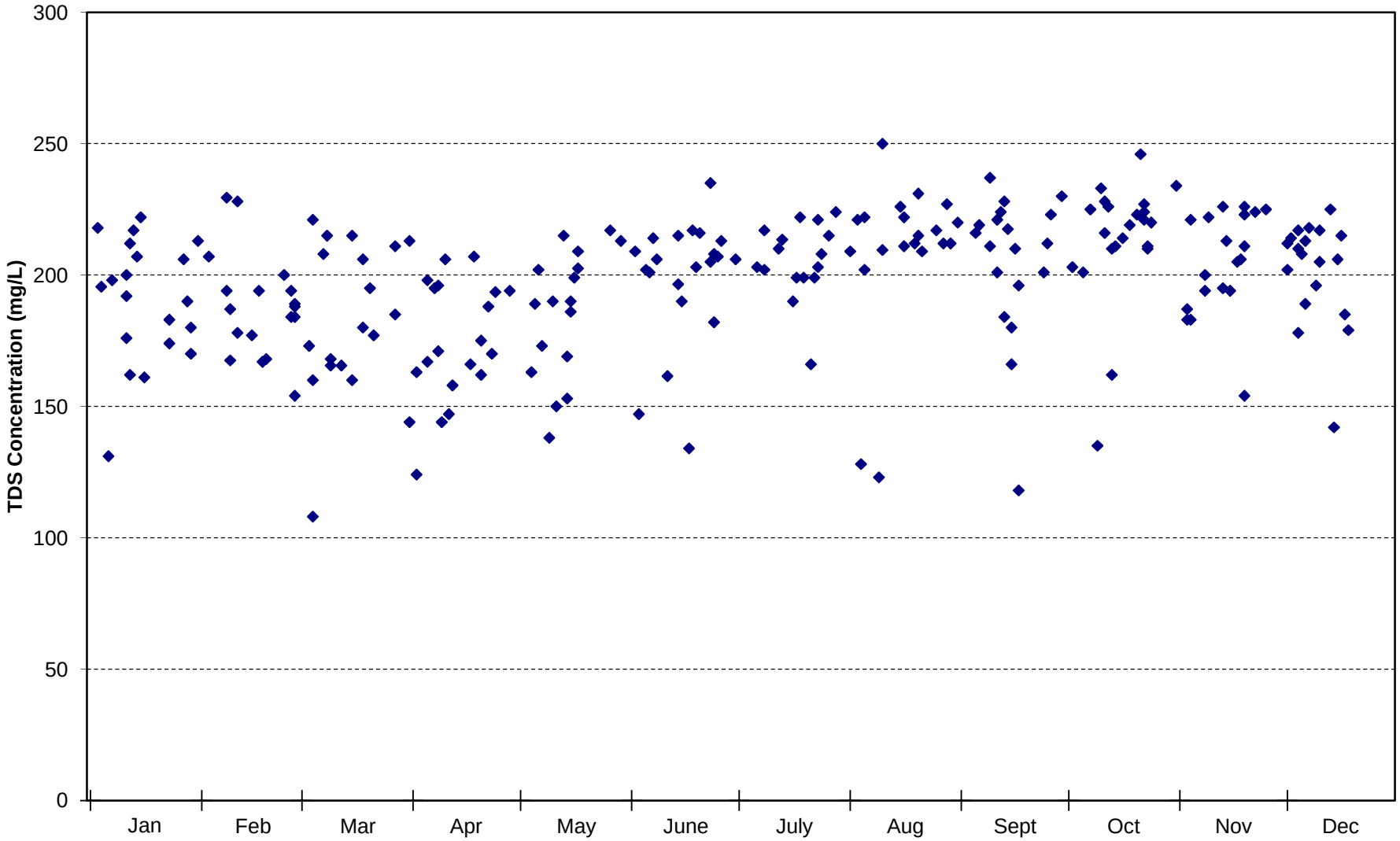


Figure C.4 Seasonal Plot of Chloride in Crooked Creek below Harrison (WHI0066)

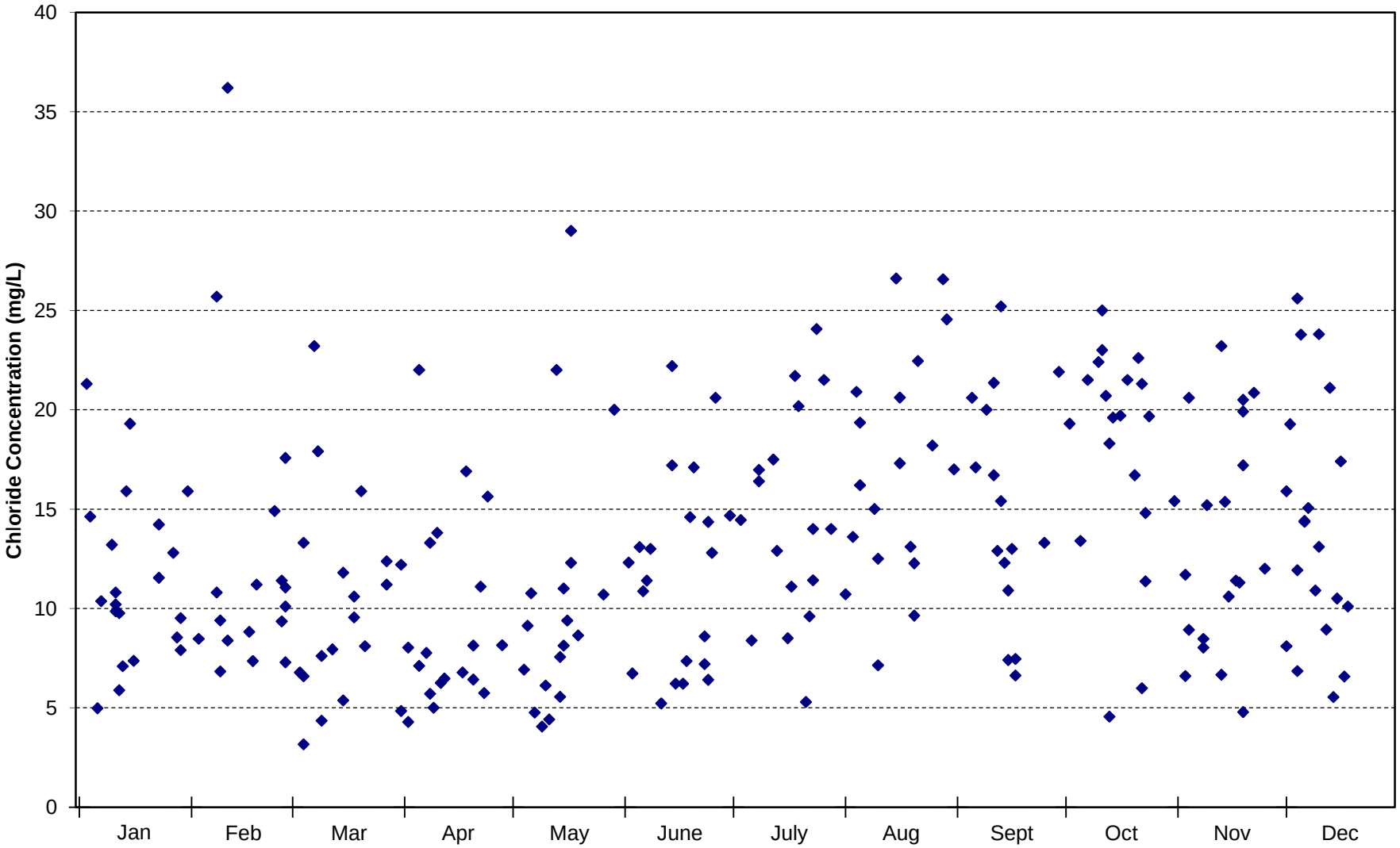


Figure C.5 Seasonal Plot of Sulfate in Crooked Creek below Harrison (WHI0066)

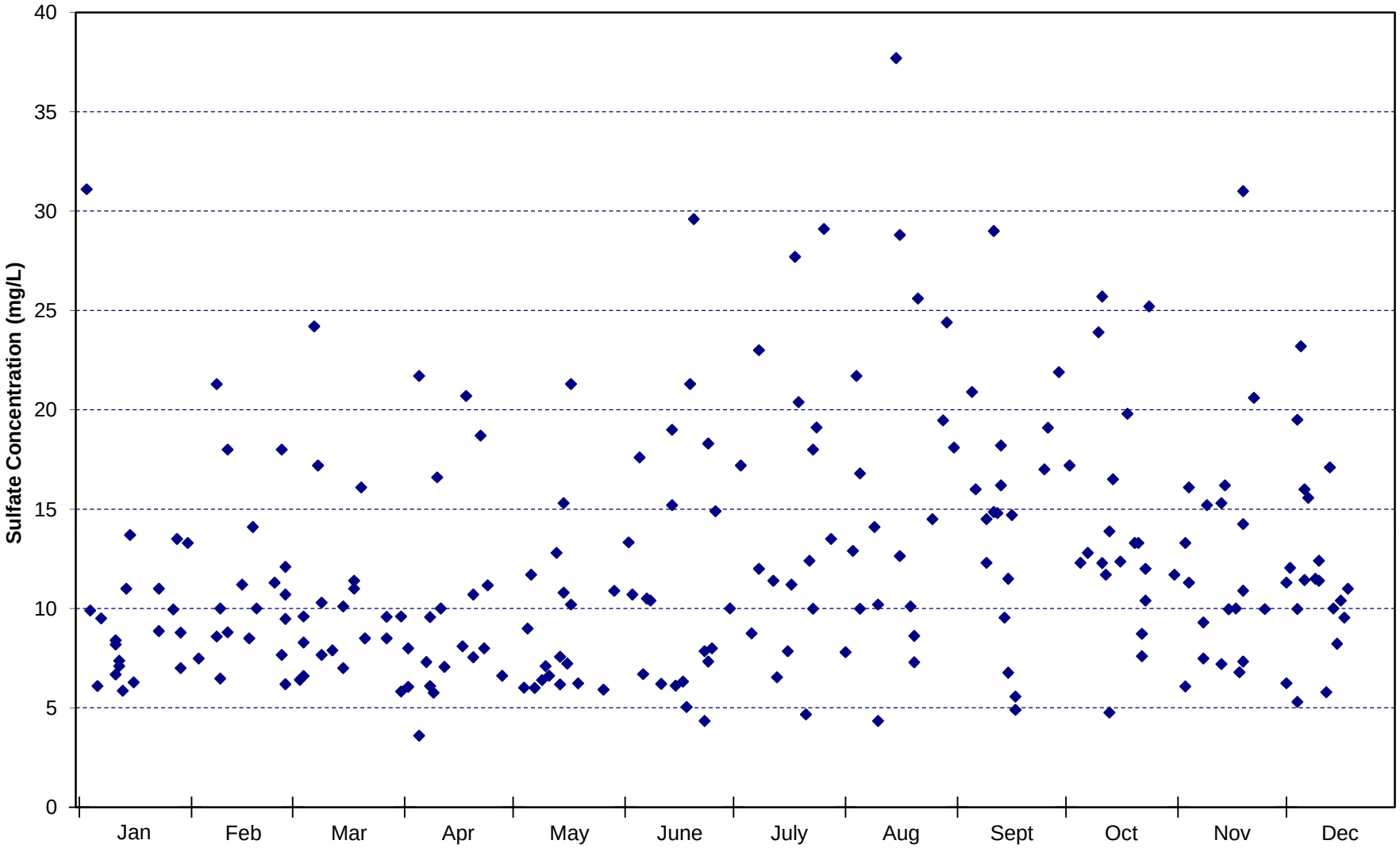


Figure C.6 Seasonal Plot of TDS in Crooked Creek below Harrison (WHI0066)

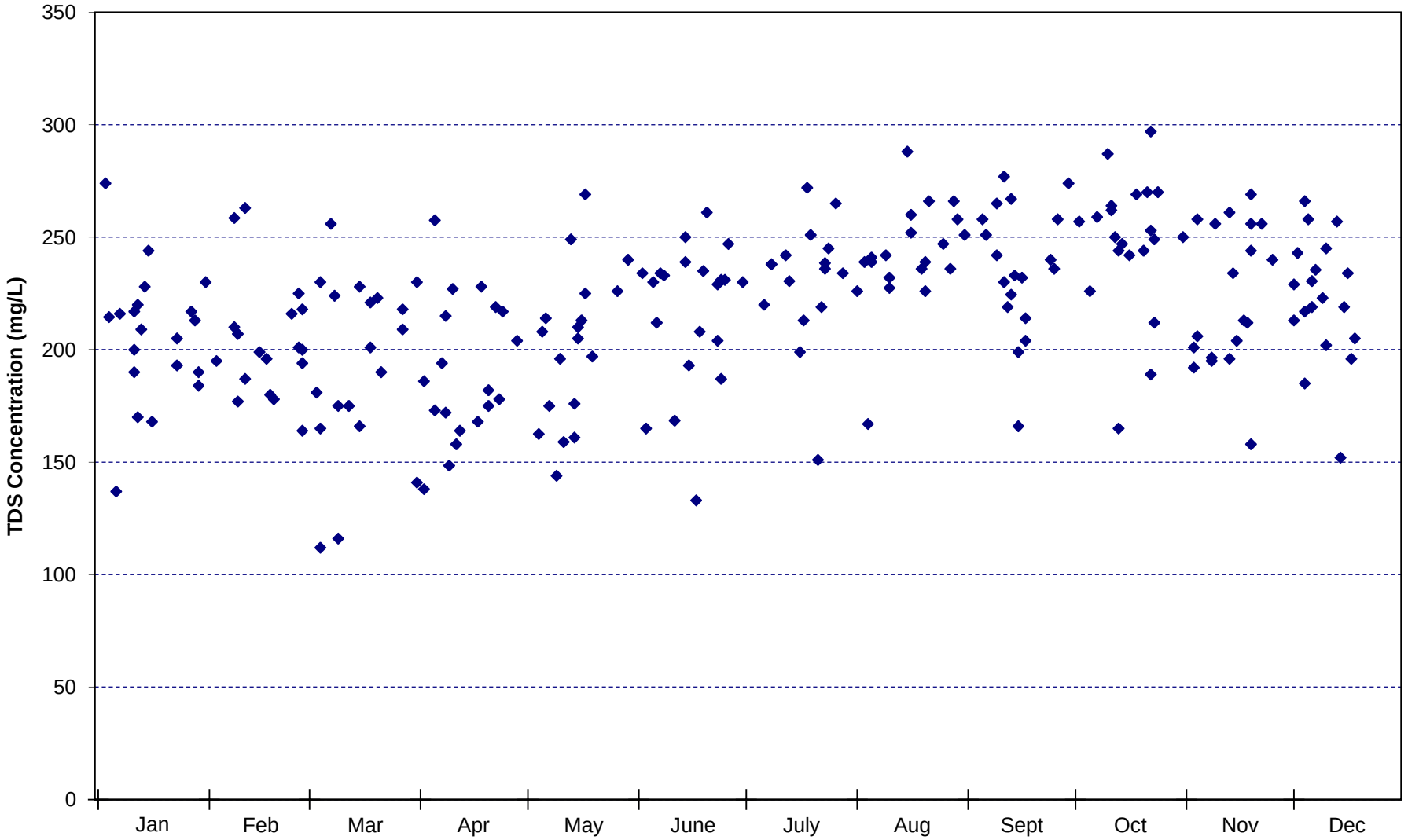


Figure C.7 Seasonal Plot of Chloride in Crooked Creek at Yellville (WHI0048A / WHI0193)

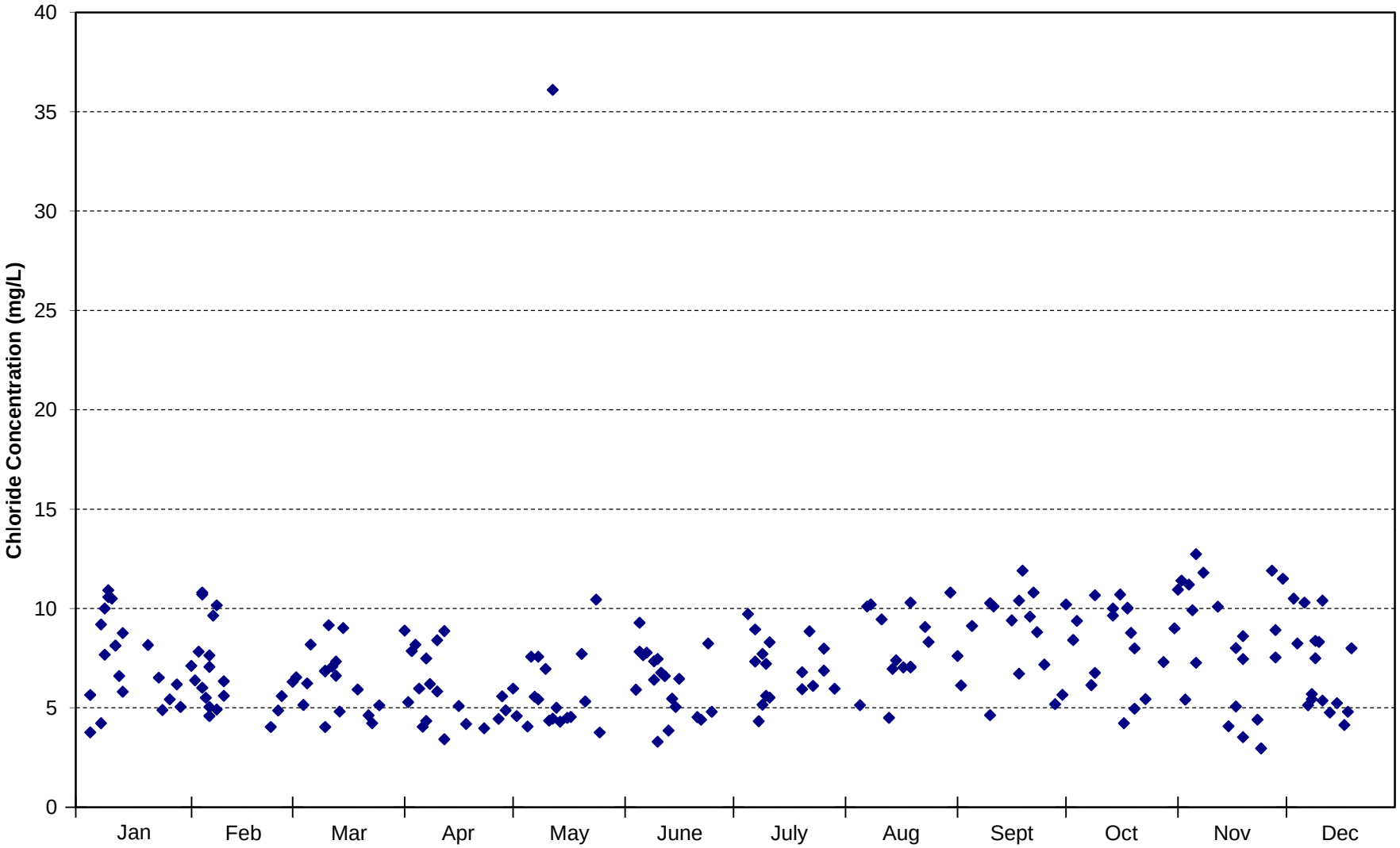


Figure C.8 Seasonal Plot of Sulfate in Crooked Creek at Yellville (WHI0048A / WHI0193)

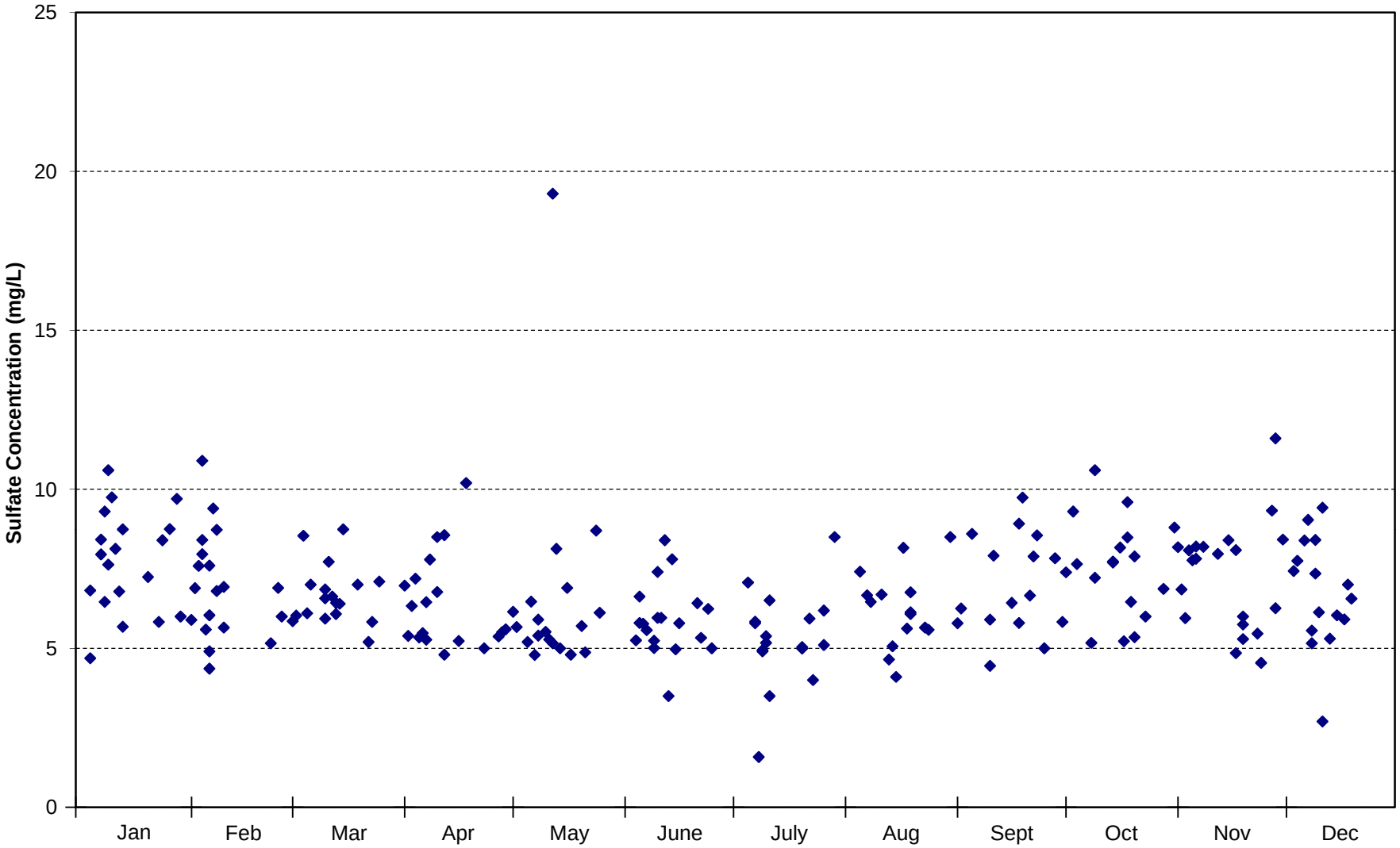


Figure C.9 Seasonal Plot of TDS in Crooked Creek at Yellville (WHI0048A / WHI0193)

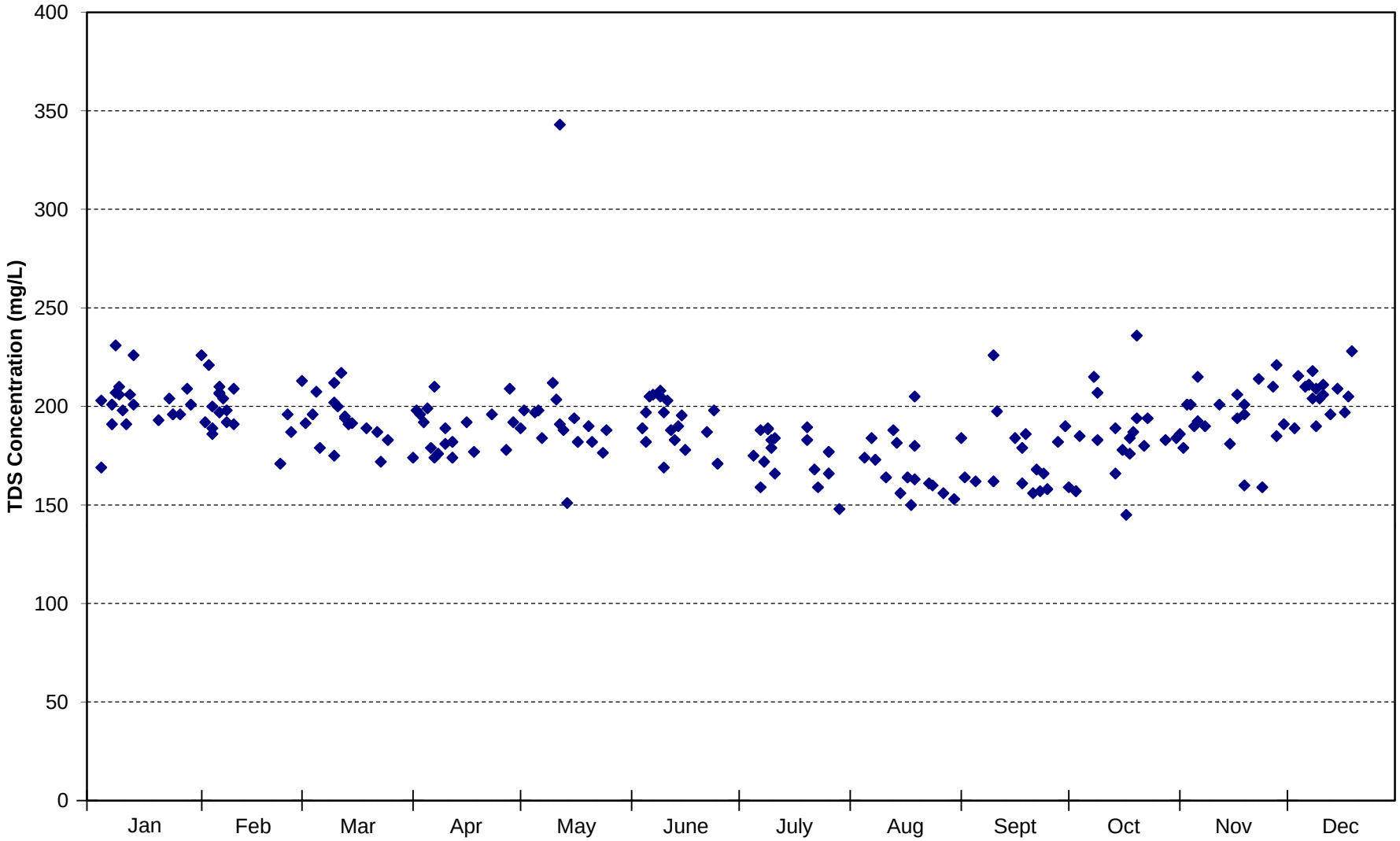


Figure C.10 Seasonal Plot of Chloride in Crooked Creek 2 mi S of Flippin (WHI0048B)

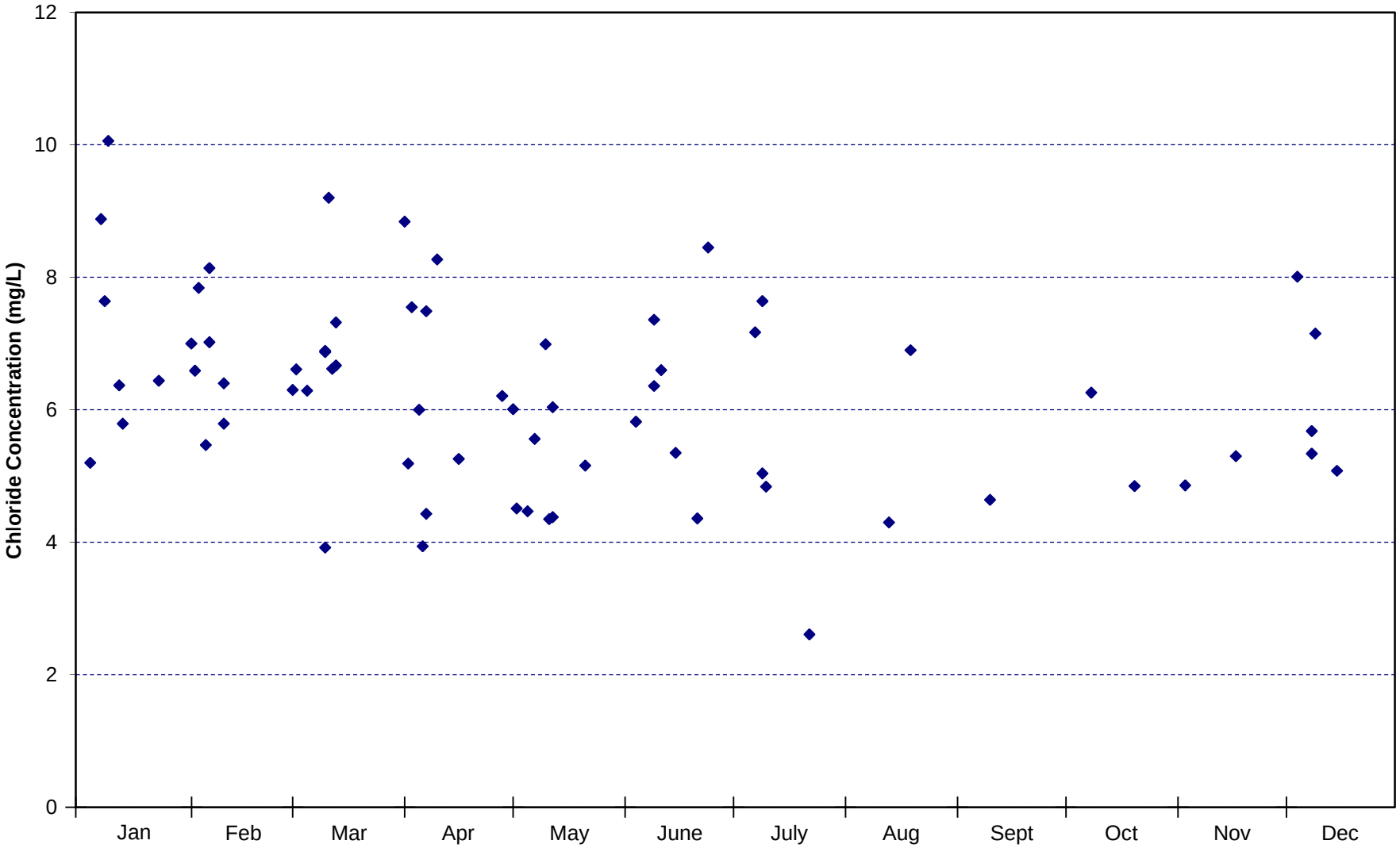


Figure C.11 Seasonal Plot of Sulfate in Crooked Creek 2 mi S of Flippin (WHI0048B)

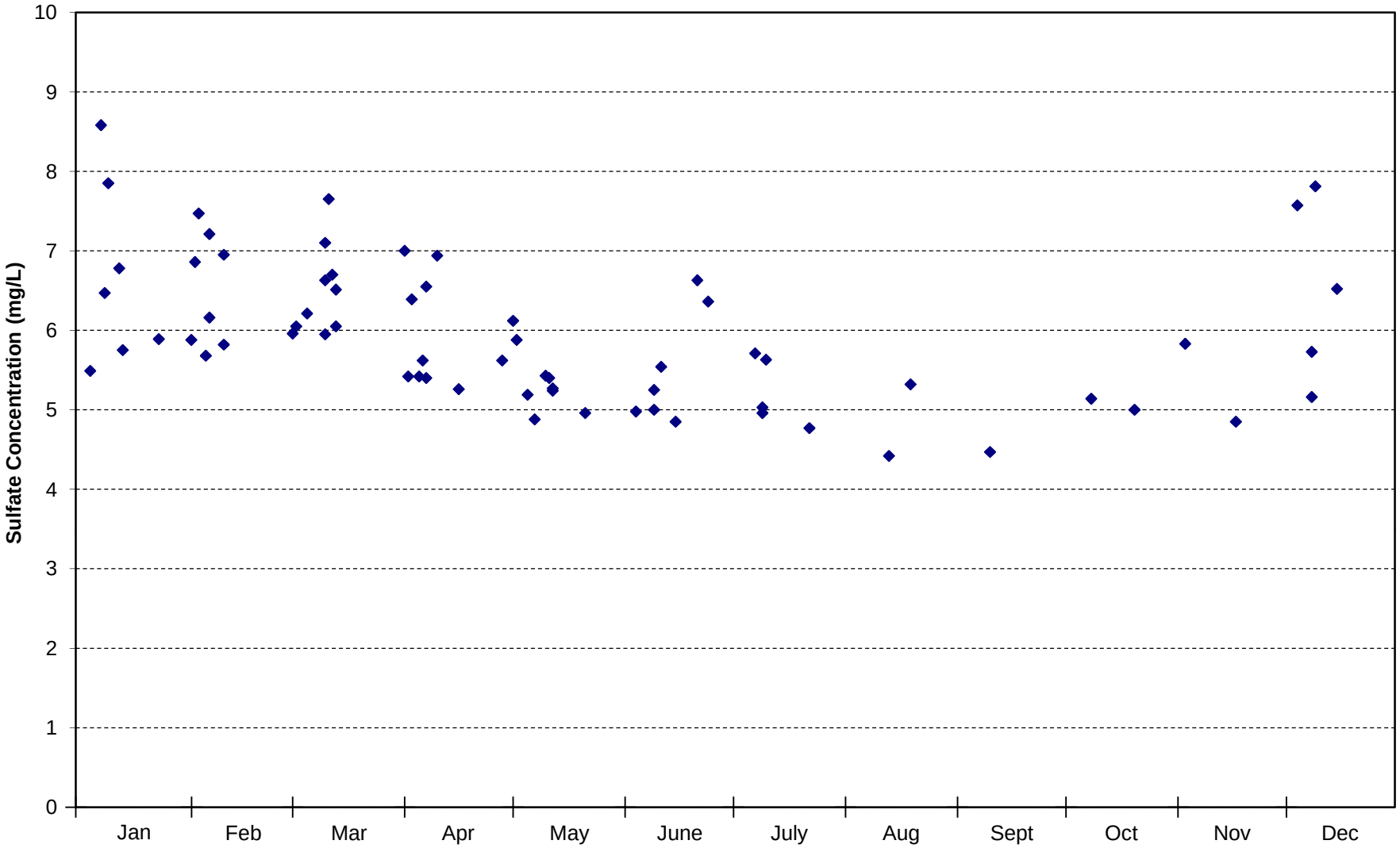


Figure C.12 Seasonal Plot of TDS in Crooked Creek 2 mi S of Flippin (WHI0048B)

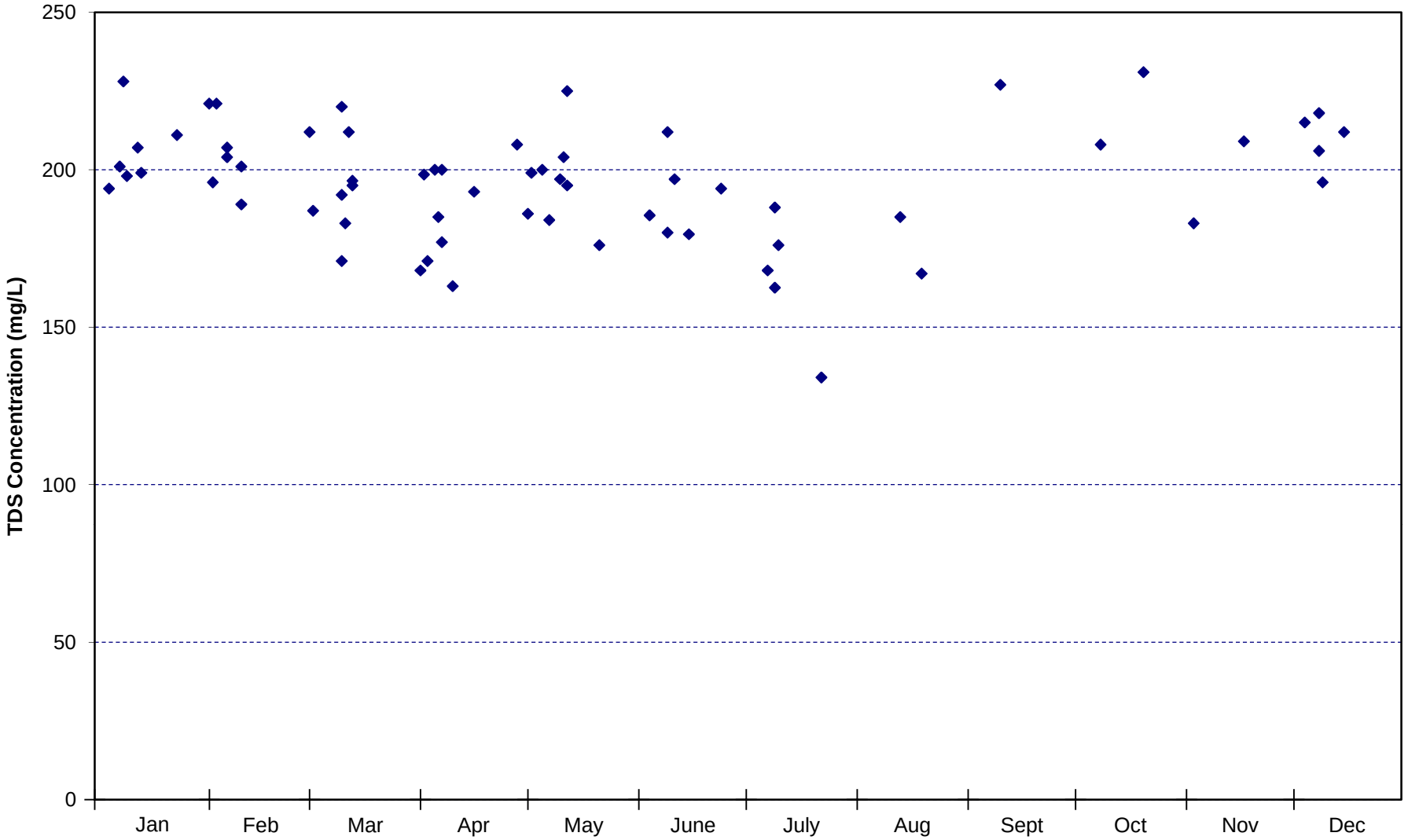


Figure C.13 Seasonal Plot of Chloride in Crooked Creek north of Rea Valley (WHI0048C)

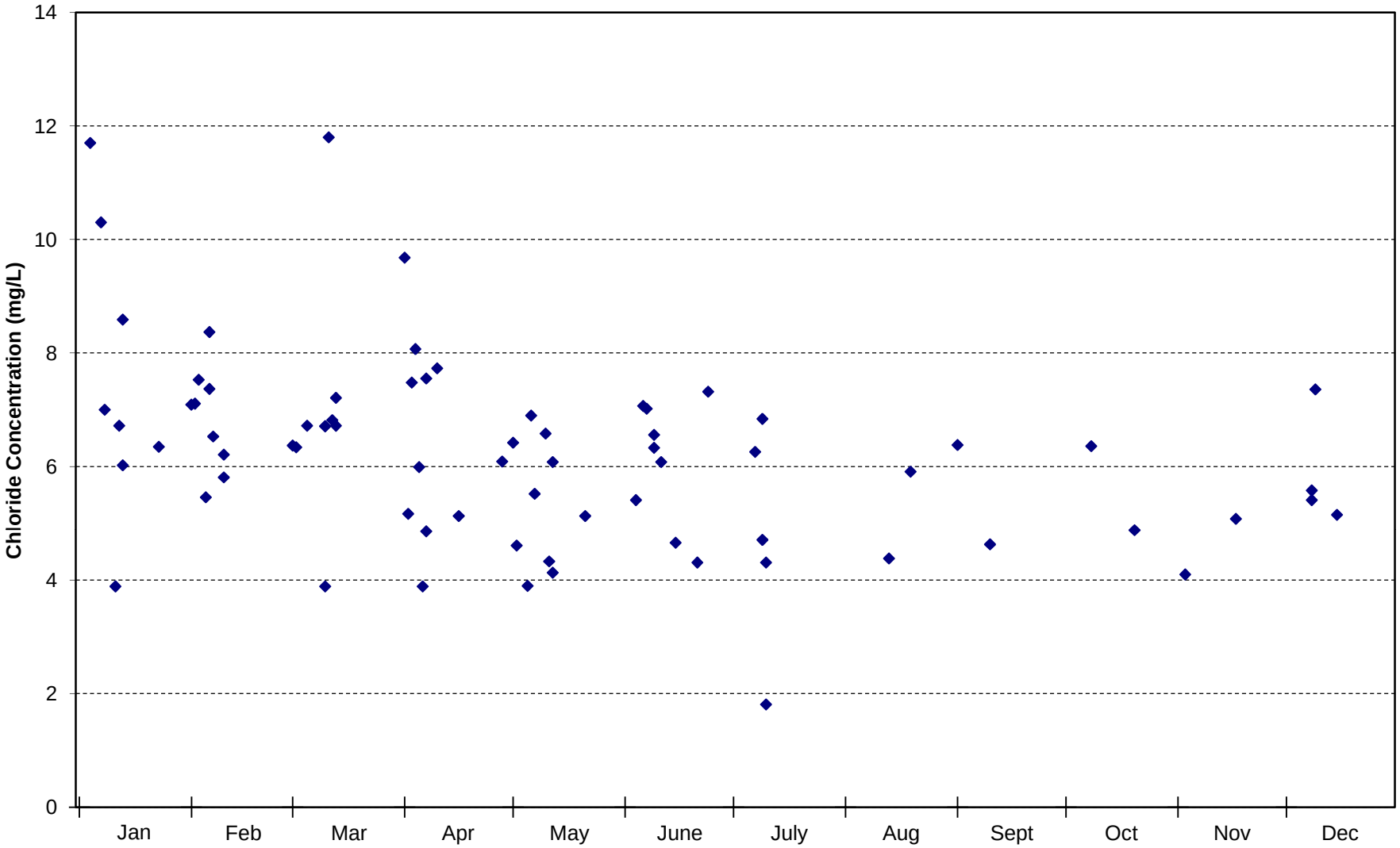


Figure C.14 Seasonal Plot of Sulfate in Crooked Creek north of Rea Valley (WHI0048C)

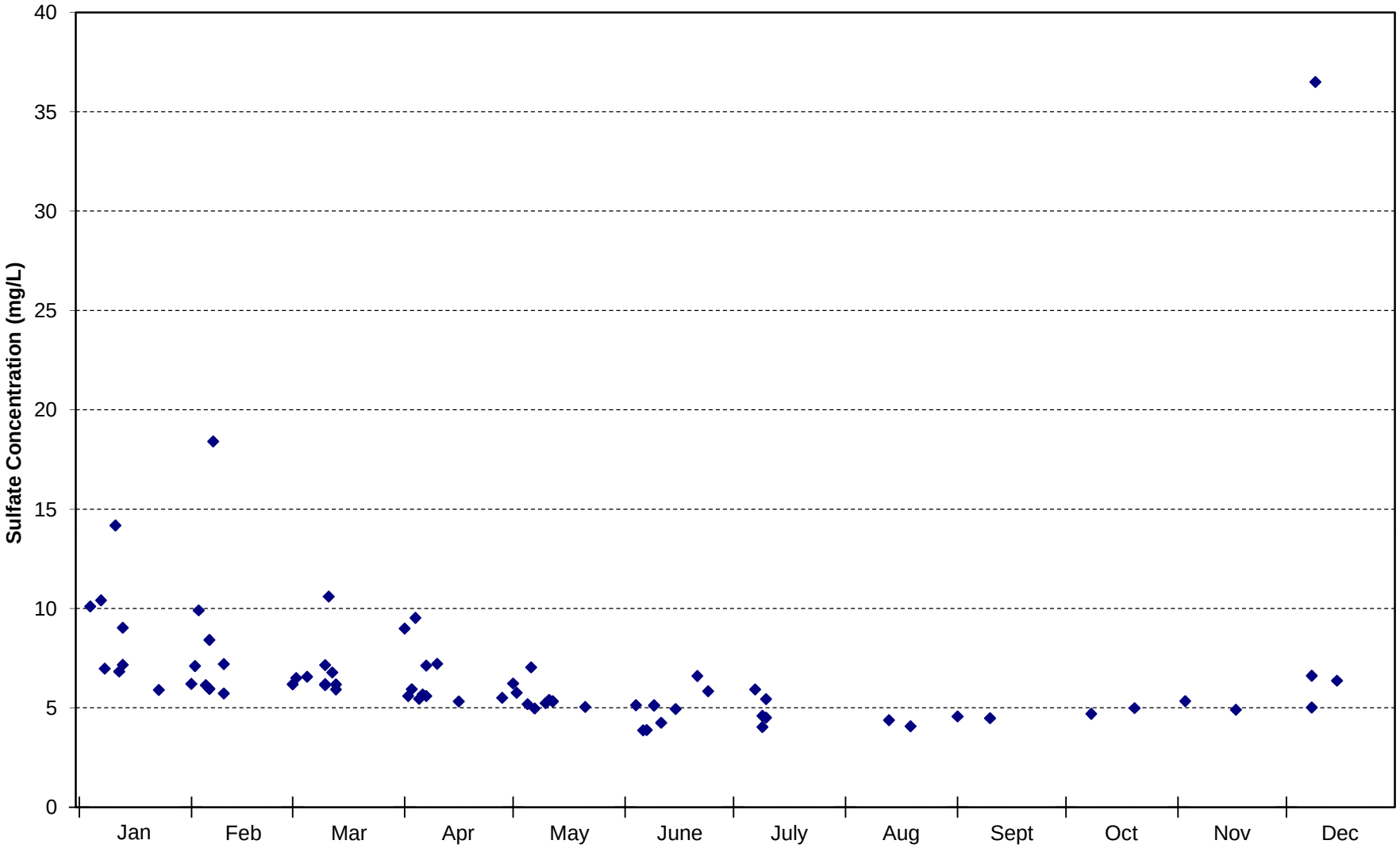
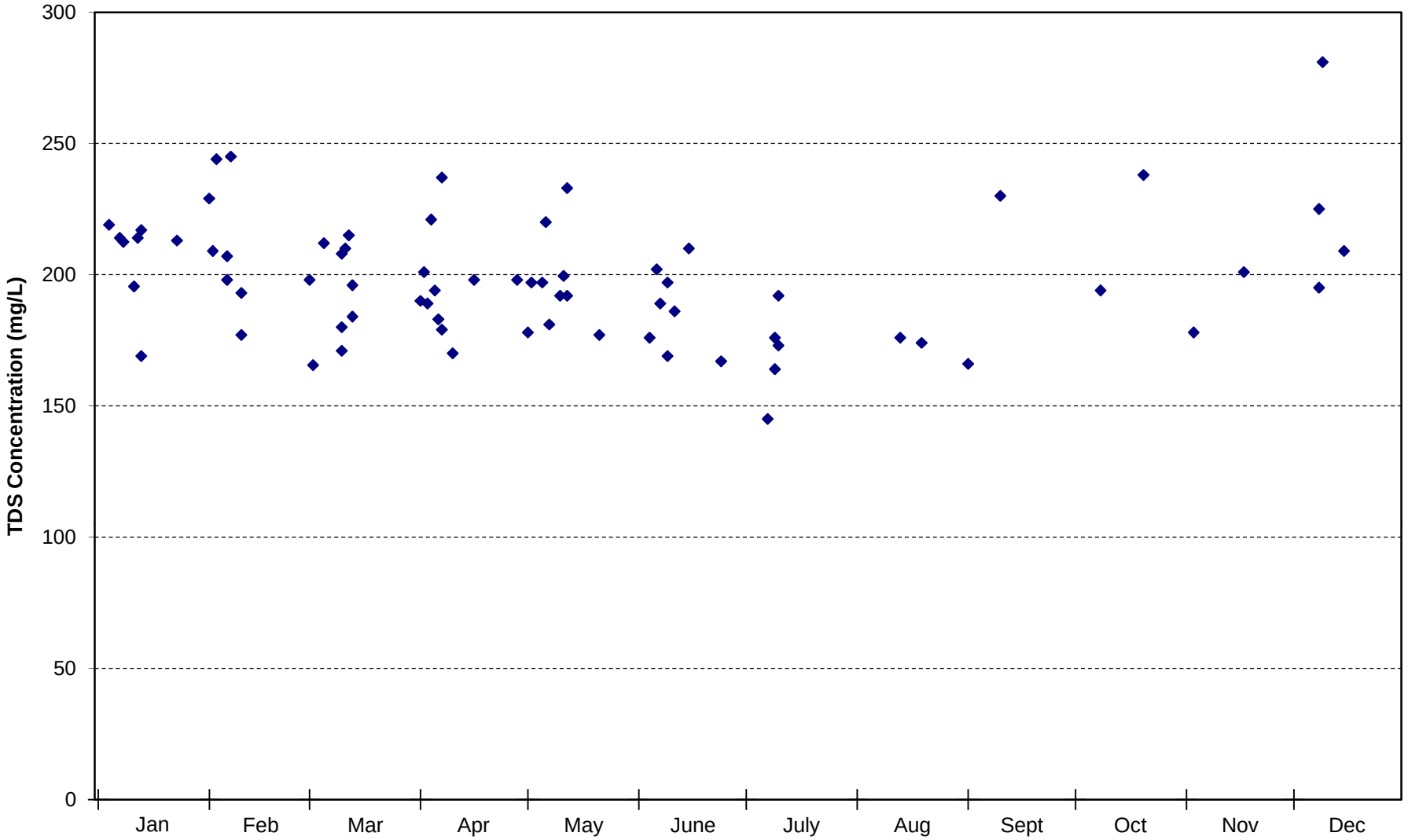


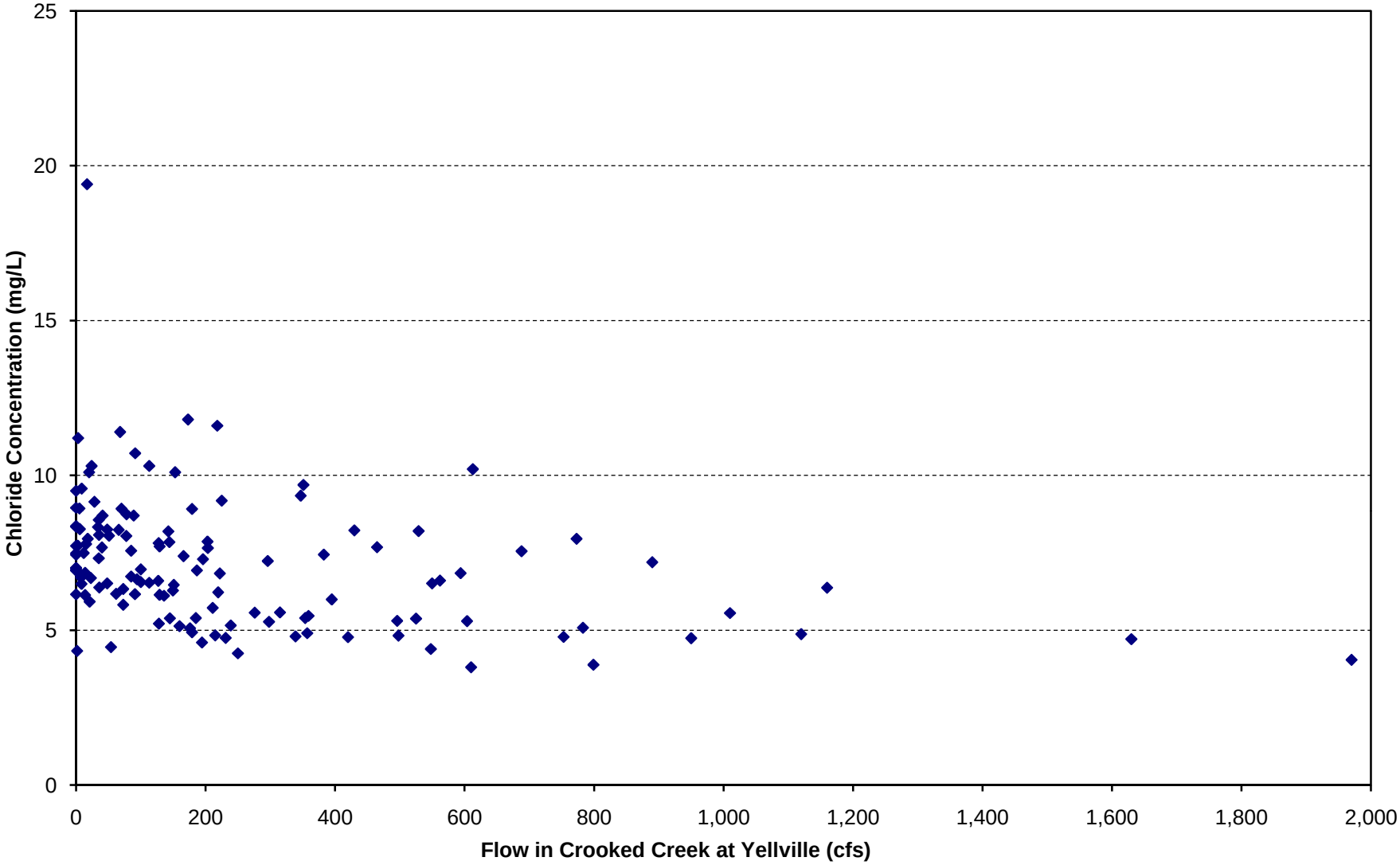
Figure C.15 Seasonal Plot of TDS in Crooked Creek north of Rea Valley (WHI0048C)



APPENDIX D

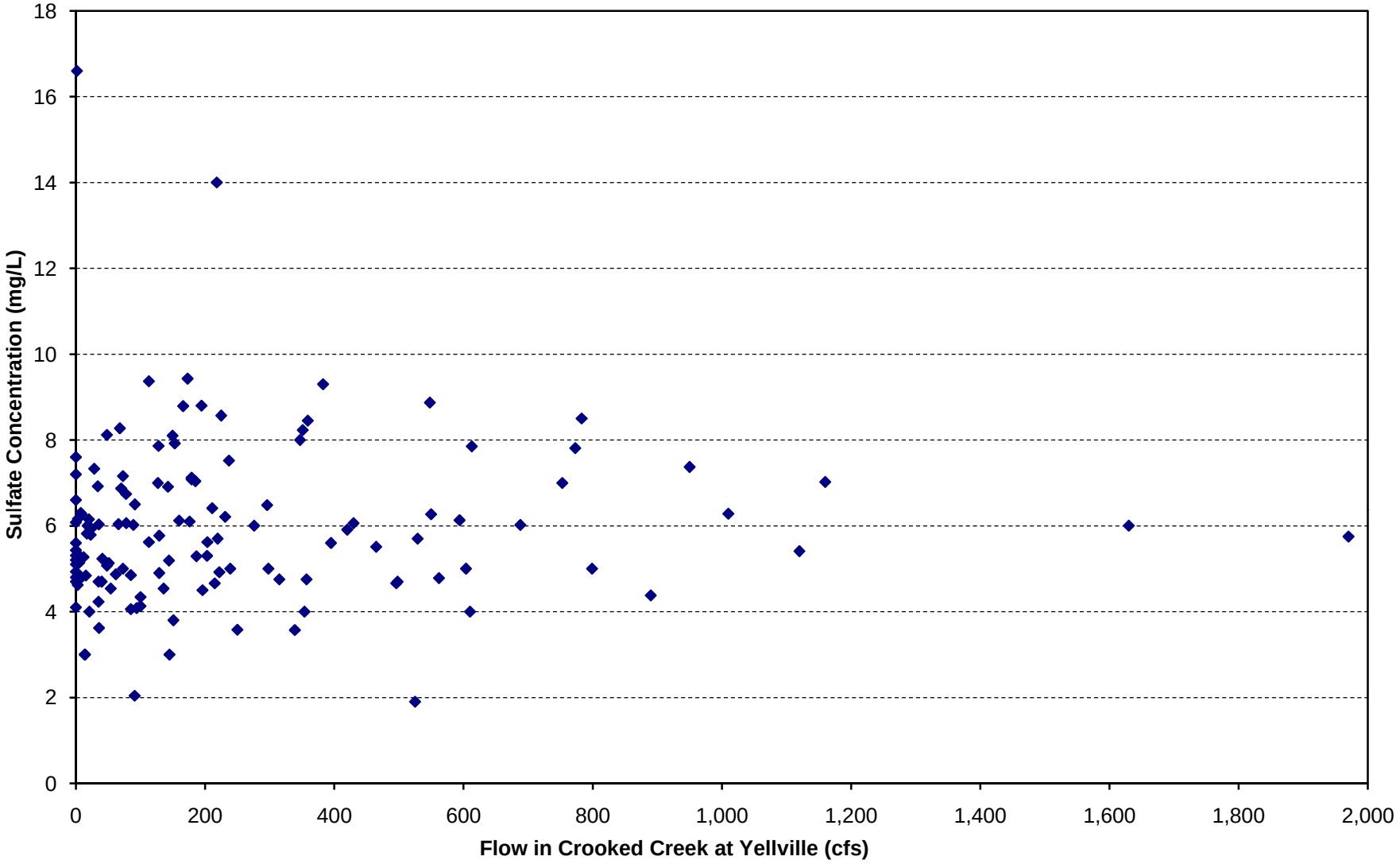
Concentration vs. Flow Plots for Water Quality Data

Figure D.1 Conc. versus Flow for Chloride in Crooked Creek above Harrison (WHI0067)



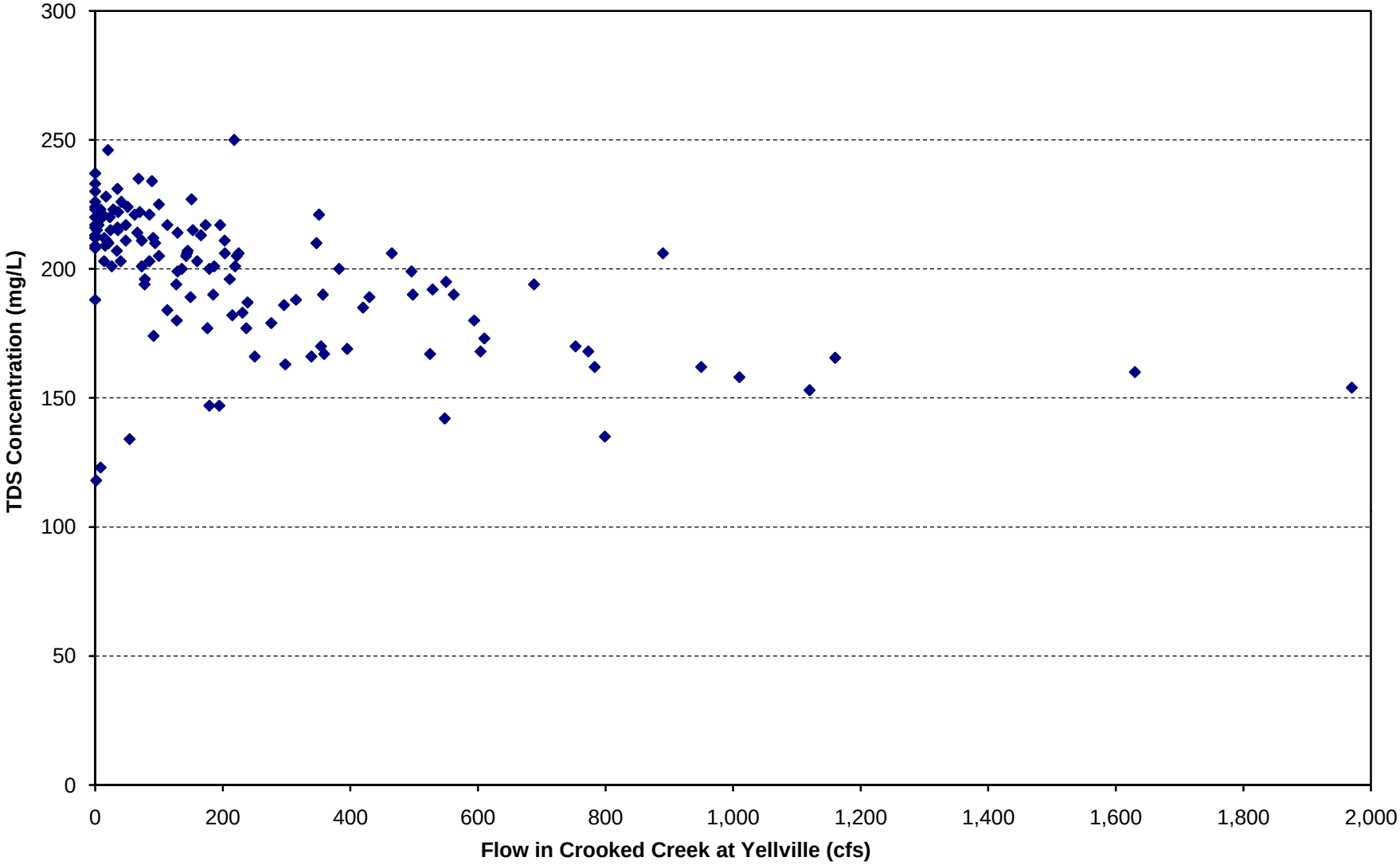
Note: Data points shown only for those dates when both concentration and flow are available.

Figure D.2 Conc. versus Flow for Sulfate in Crooked Creek above Harrison (WHI0067)



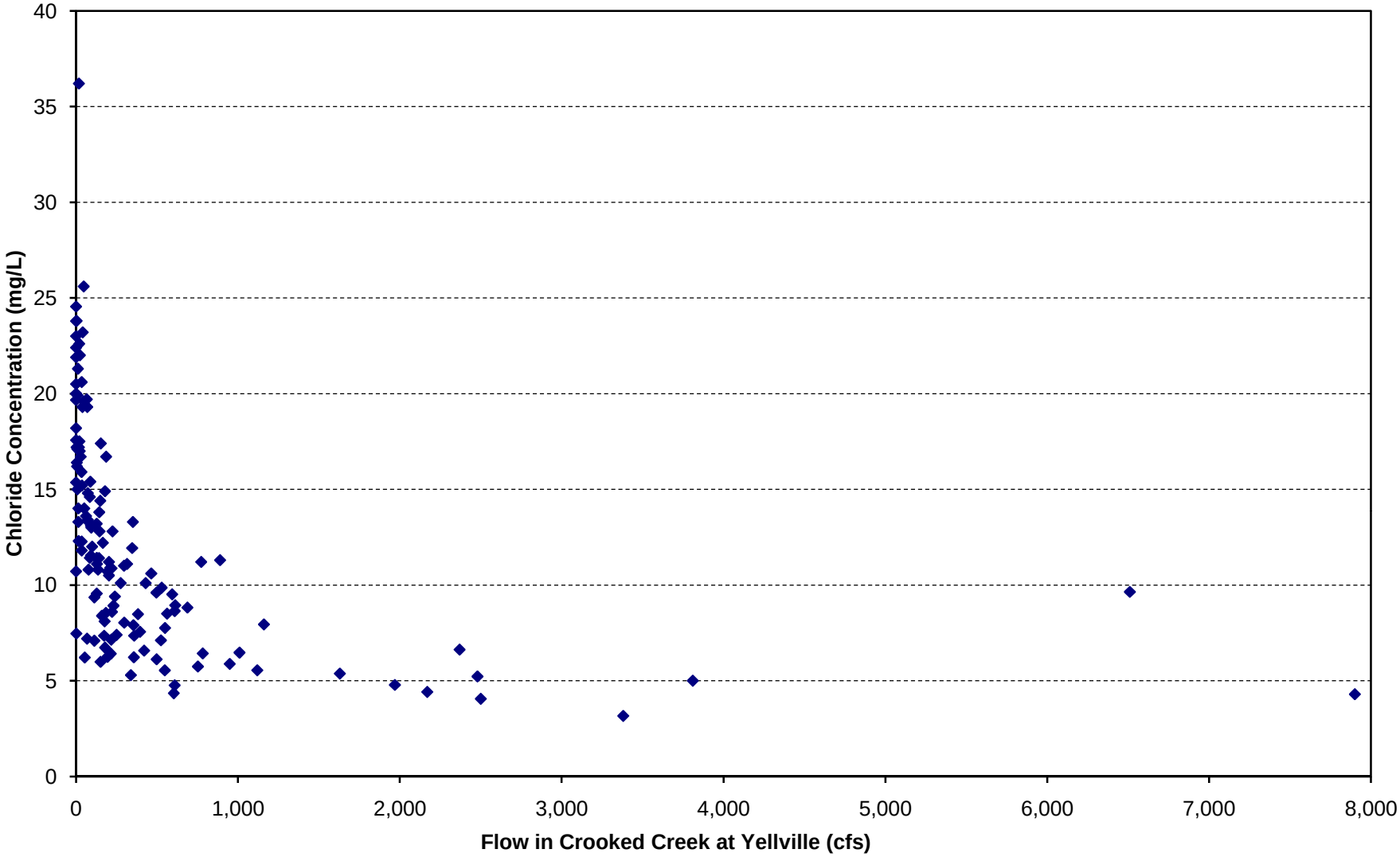
Note: Data points shown only for those dates when both concentration and flow are available.

Figure D.3 Conc. versus Flow for TDS in Crooked Creek above Harrison (WHI0067)



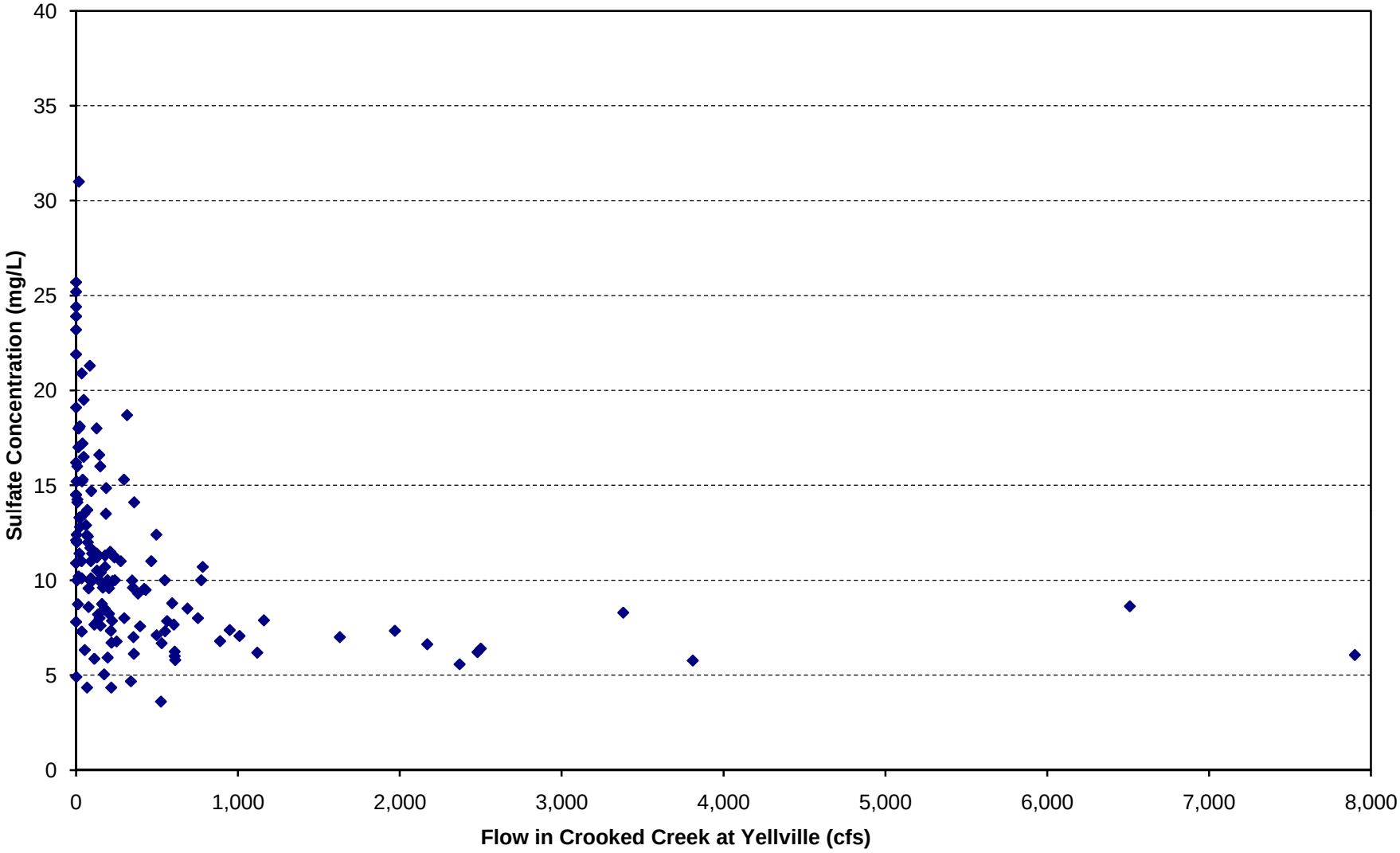
Note: Data points shown only for those dates when both concentration and flow are available.

Figure D.4 Conc. versus Flow for Chloride in Crooked Creek below Harrison (WHI0066)



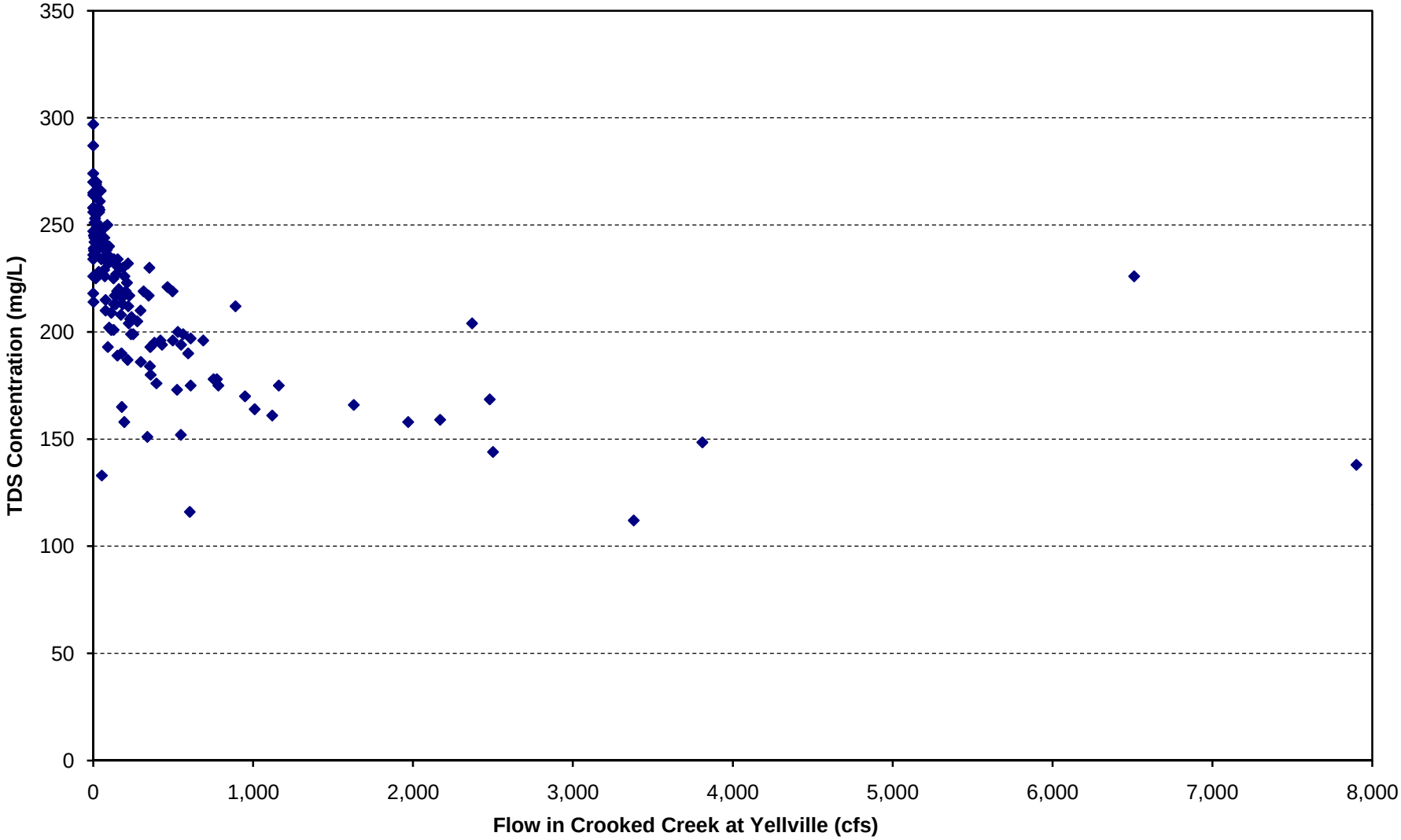
Note: Data points shown only for those dates when both concentration and flow are available.

Figure D.5 Conc. versus Flow for Sulfate in Crooked Creek below Harrison (WHI0066)



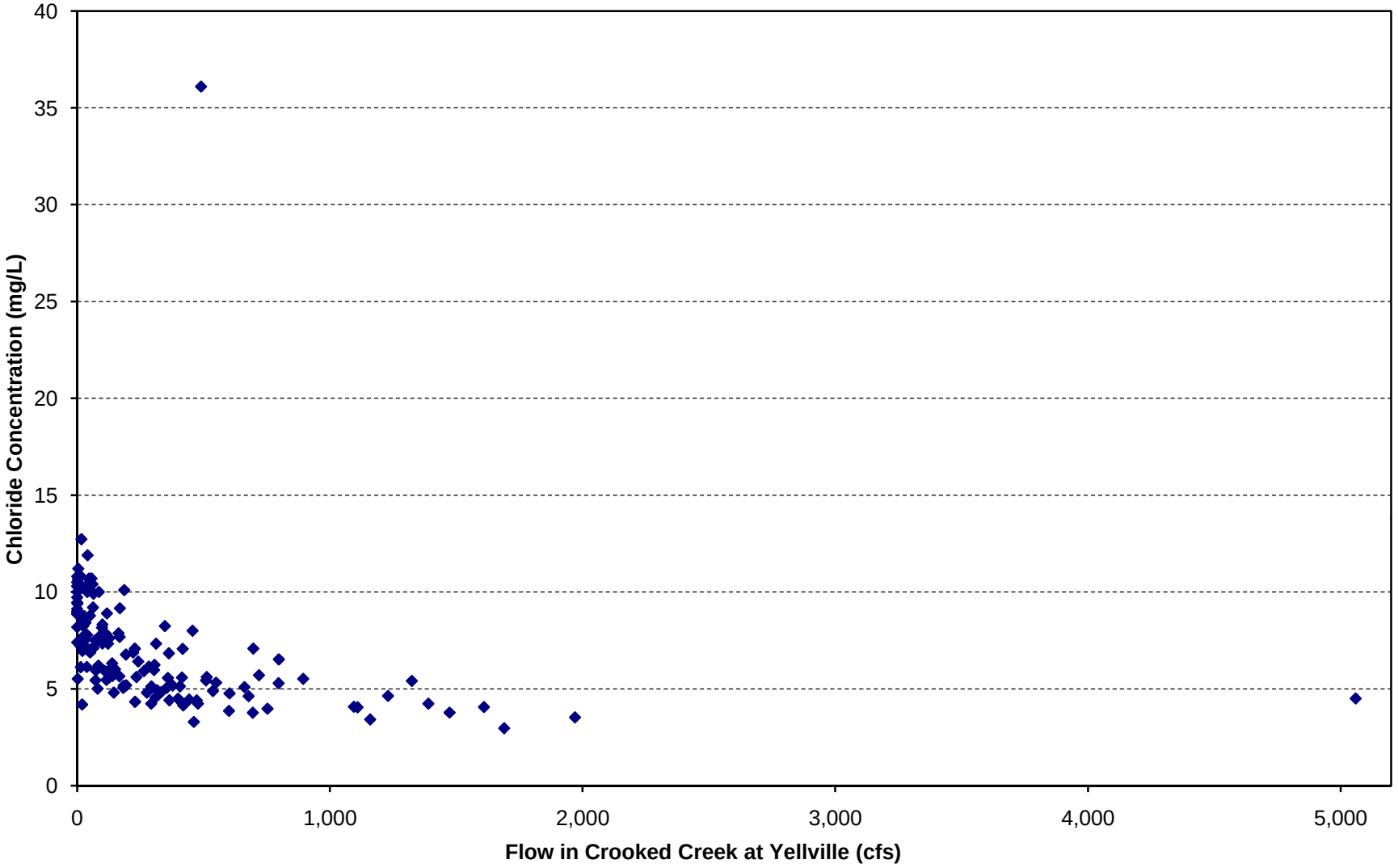
Note: Data points shown only for those dates when both concentration and flow are available.

Figure D.6 Conc. versus Flow for TDS in Crooked Creek below Harrison (WHI0066)



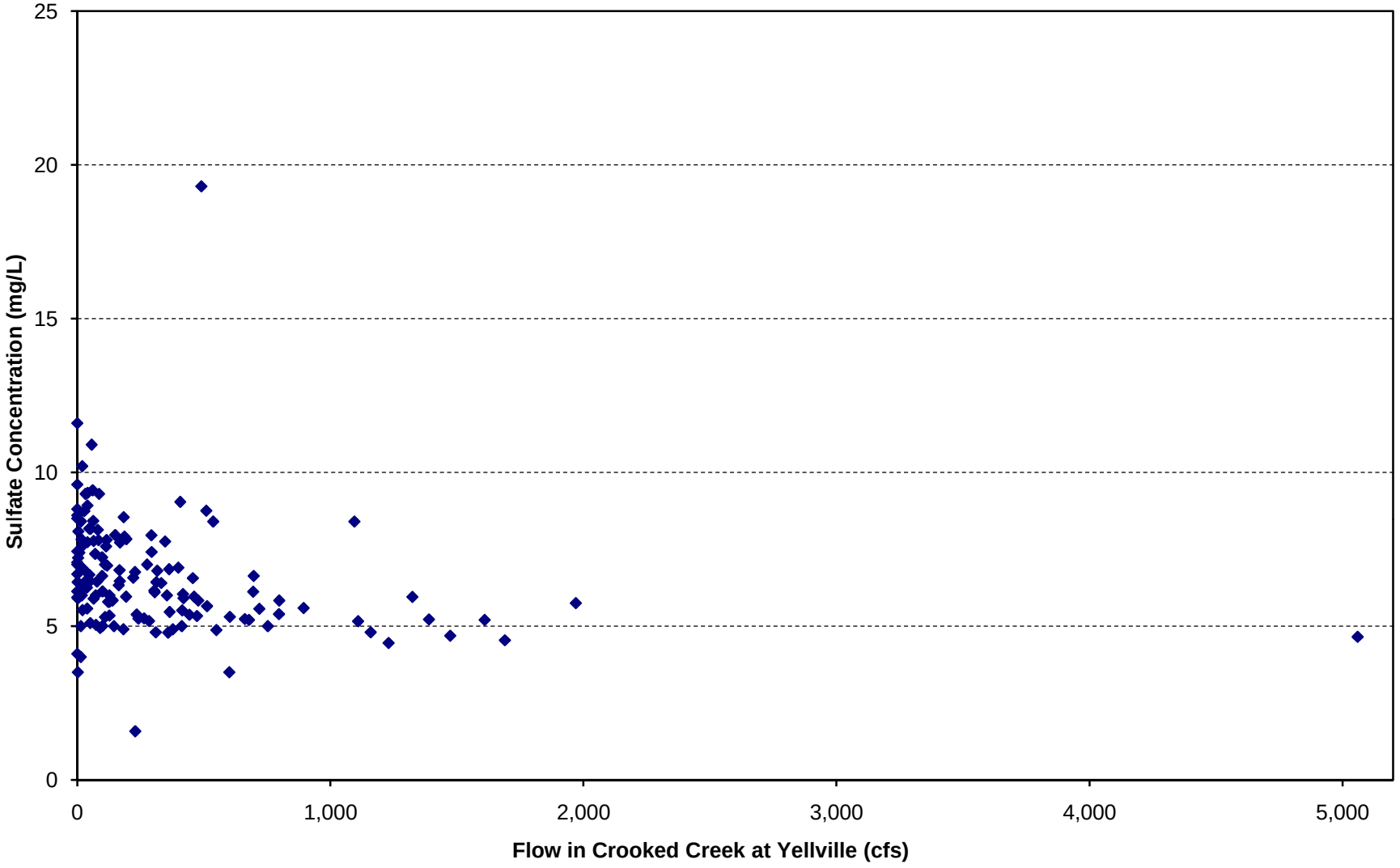
Note: Data points shown only for those dates when both concentration and flow are available.

Figure D.7 Conc. versus Flow for Chloride in Crooked Creek at Yellville (WHI0048A/WHI0193)



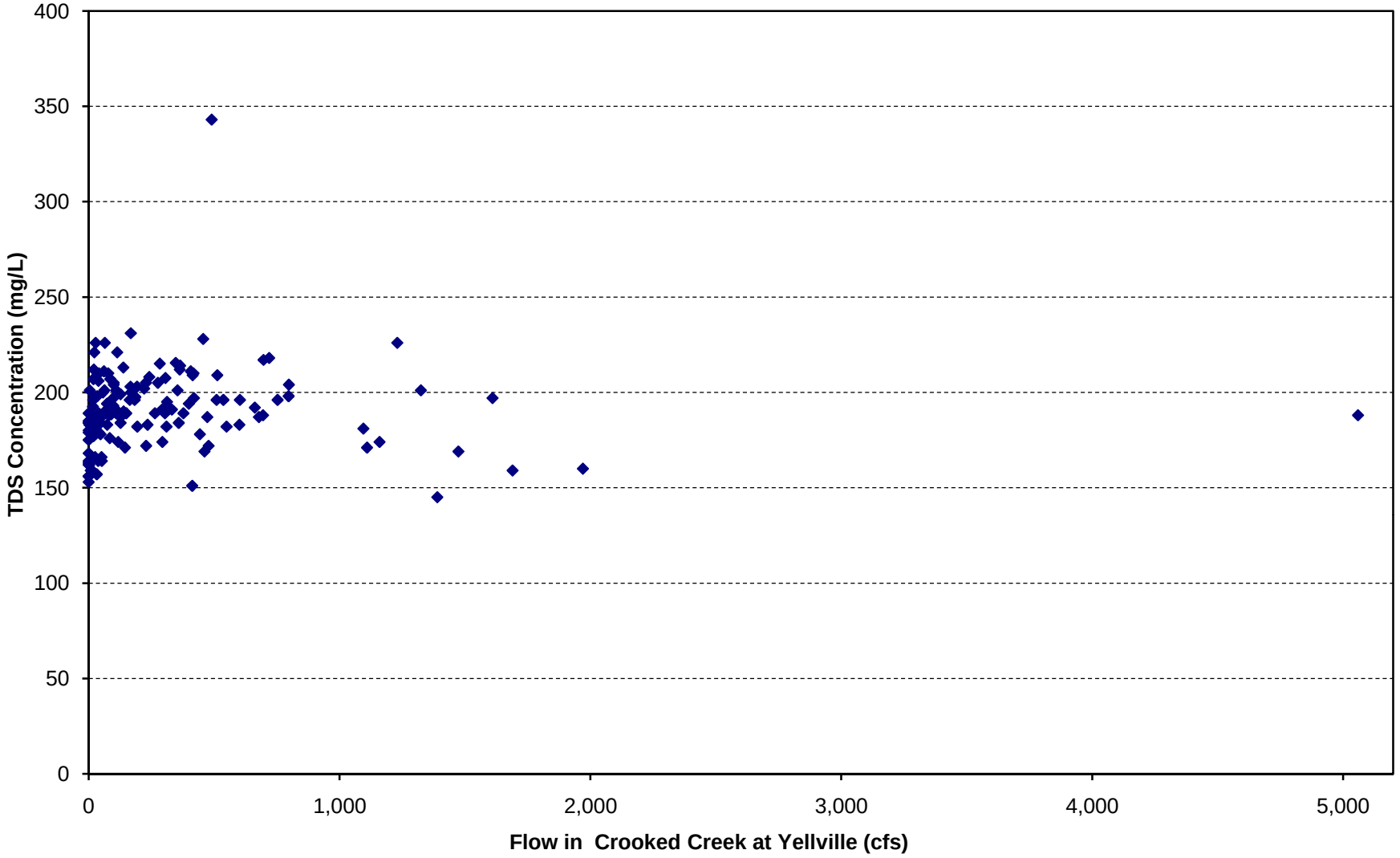
Note: Data points shown only for those dates when both concentration and flow are available.

Figure D.8 Conc. versus Flow for Sulfate in Crooked Creek at Yellville (WHI0048A / WHI0193)



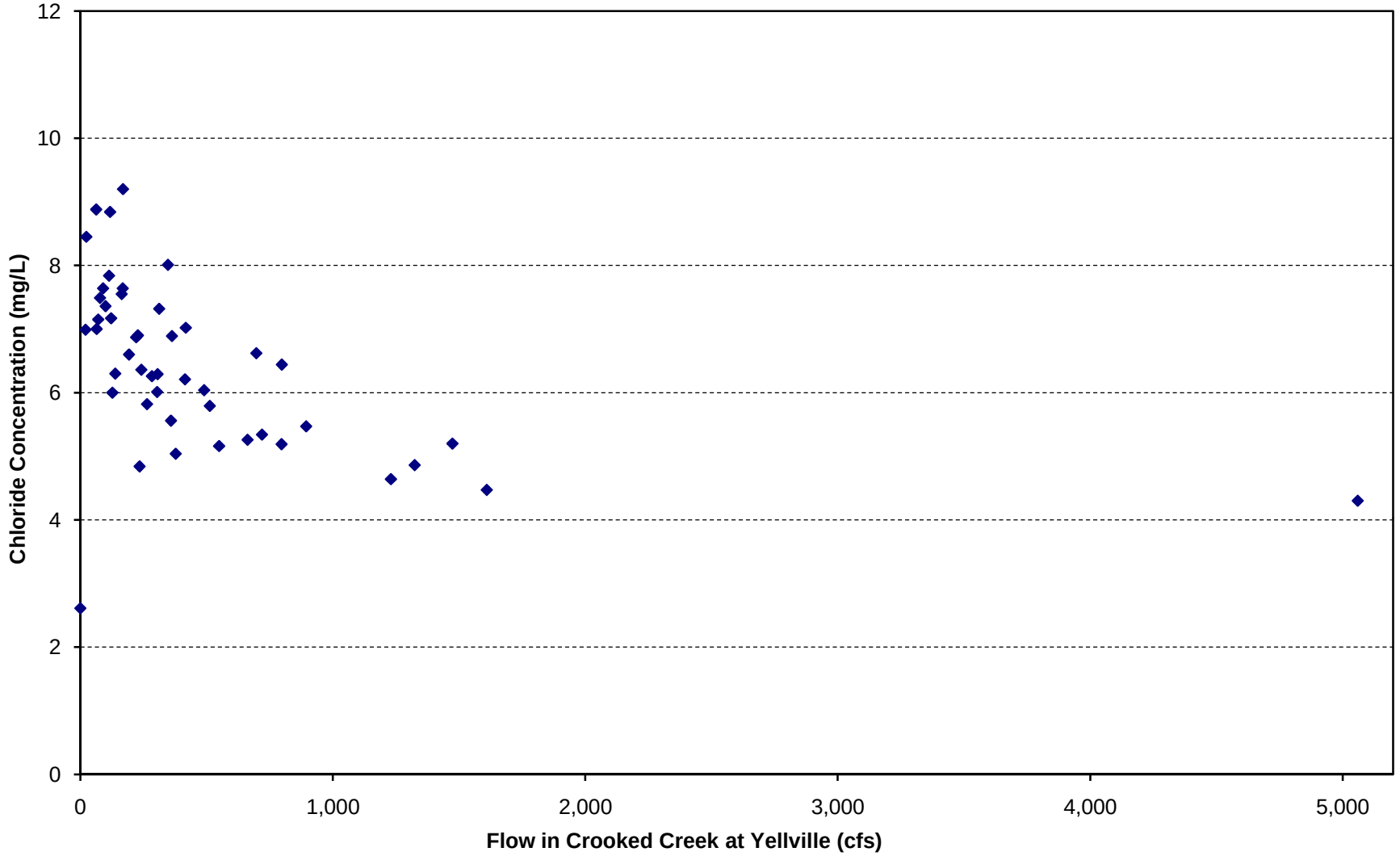
Note: Data points shown only for those dates when both concentration and flow are available.

Figure D.9 Conc. versus Flow for TDS in Crooked Creek at Yellville (WHI0048A / WHI0193)



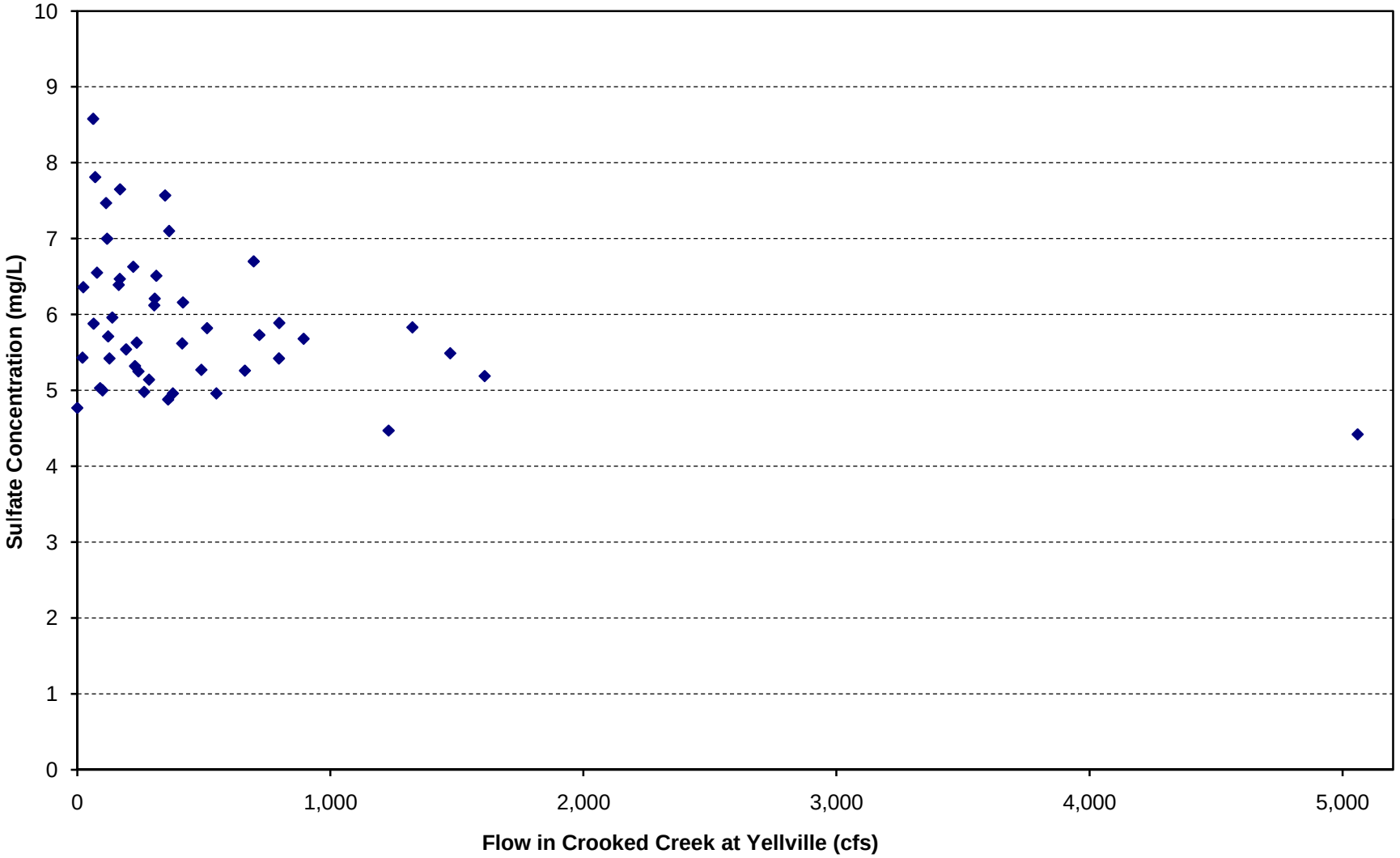
Note: Data points shown only for those dates when both concentration and flow are available.

Figure D.10 Conc. versus Flow for Chloride in Crooked Creek 2 mi S of Flippin (WHI0048B)



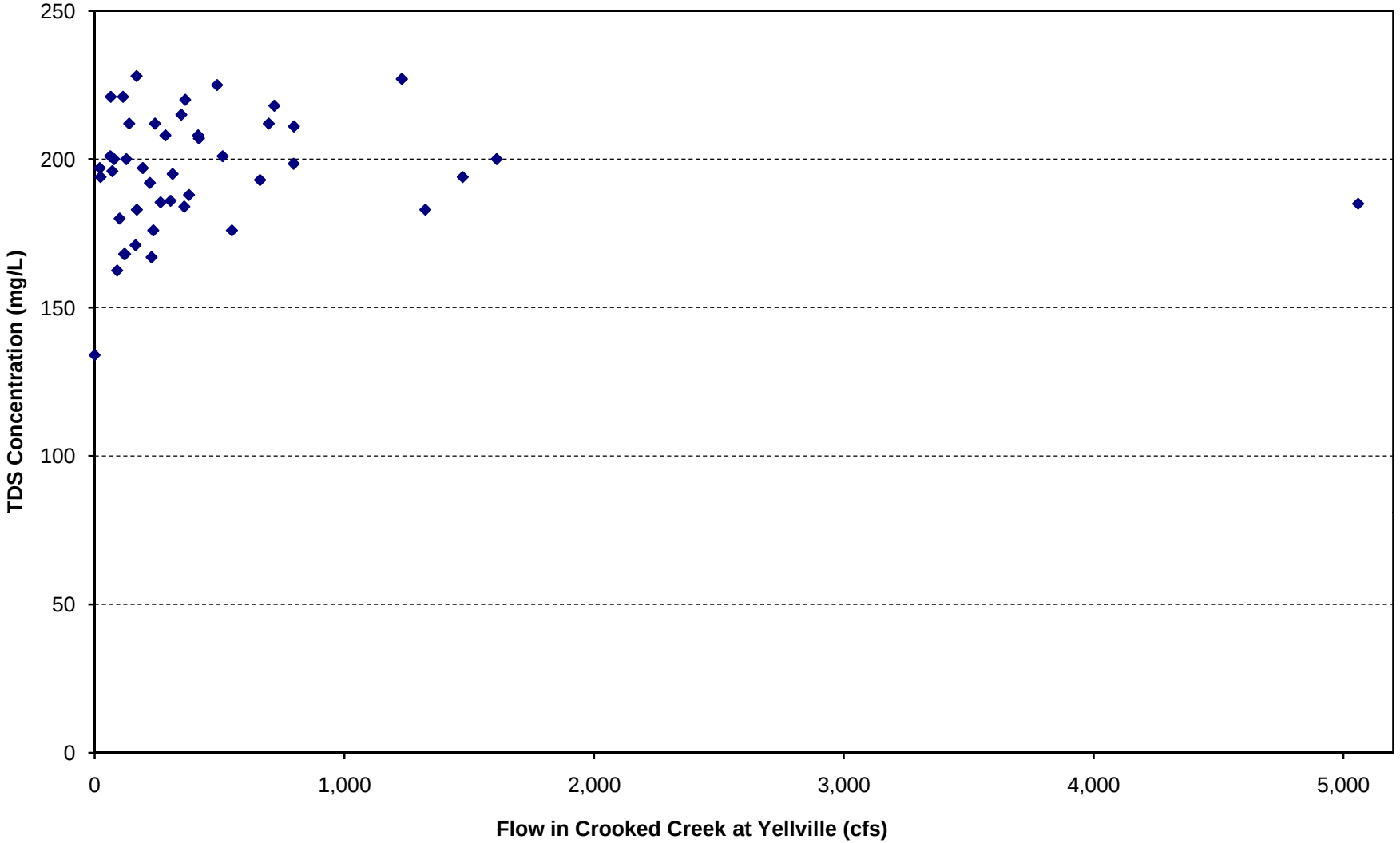
Note: Data points shown only for those dates when both concentration and flow are available.

Figure D.11 Conc. versus Flow for Sulfate in Crooked Creek 2 mi S of Flippin (WHI0048B)



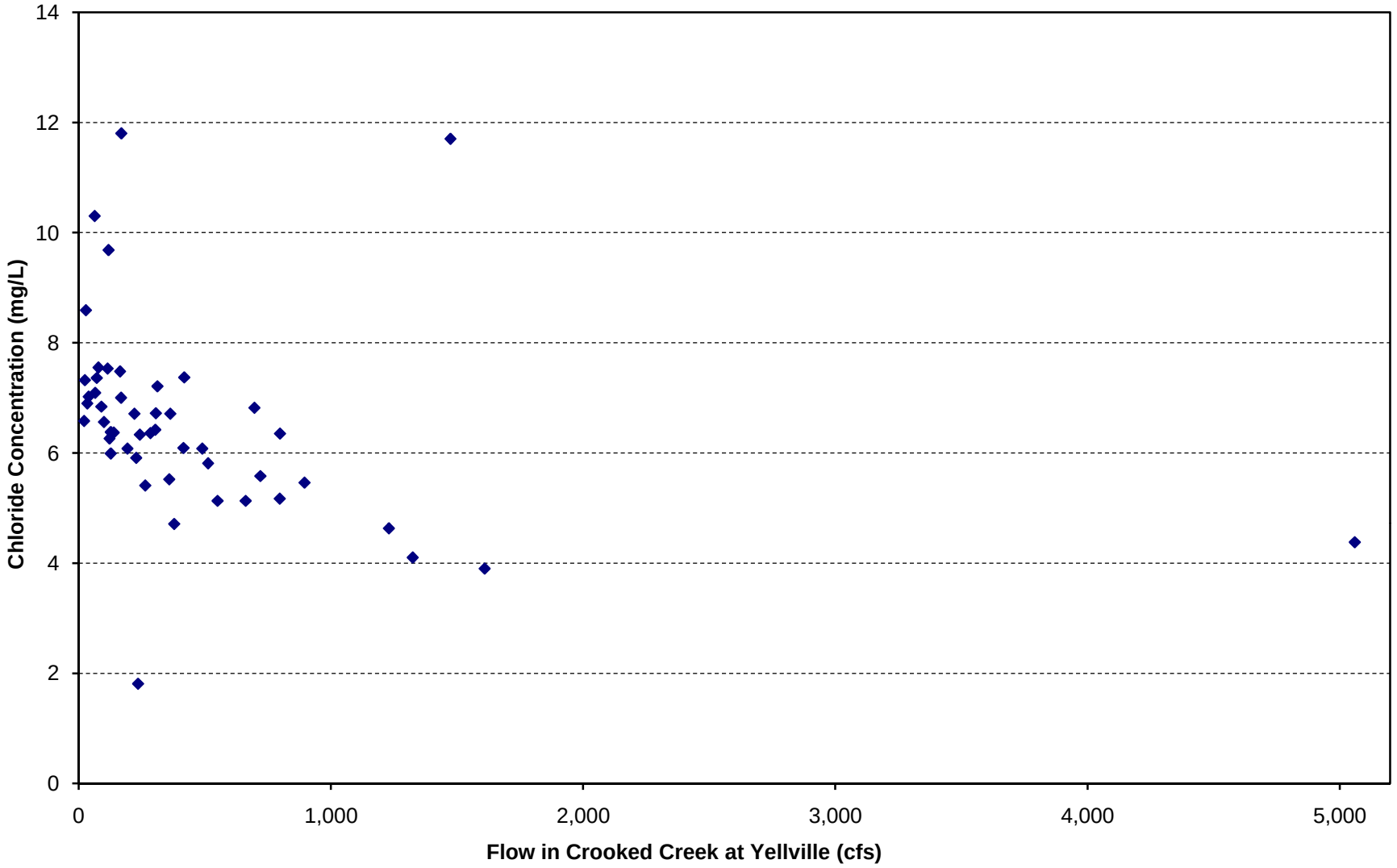
Note: Data points shown only for those dates when both concentration and flow are available.

Figure D.12 Conc. versus Flow for TDS in Crooked Creek 2 mi S of Flippin (WHI0048B)



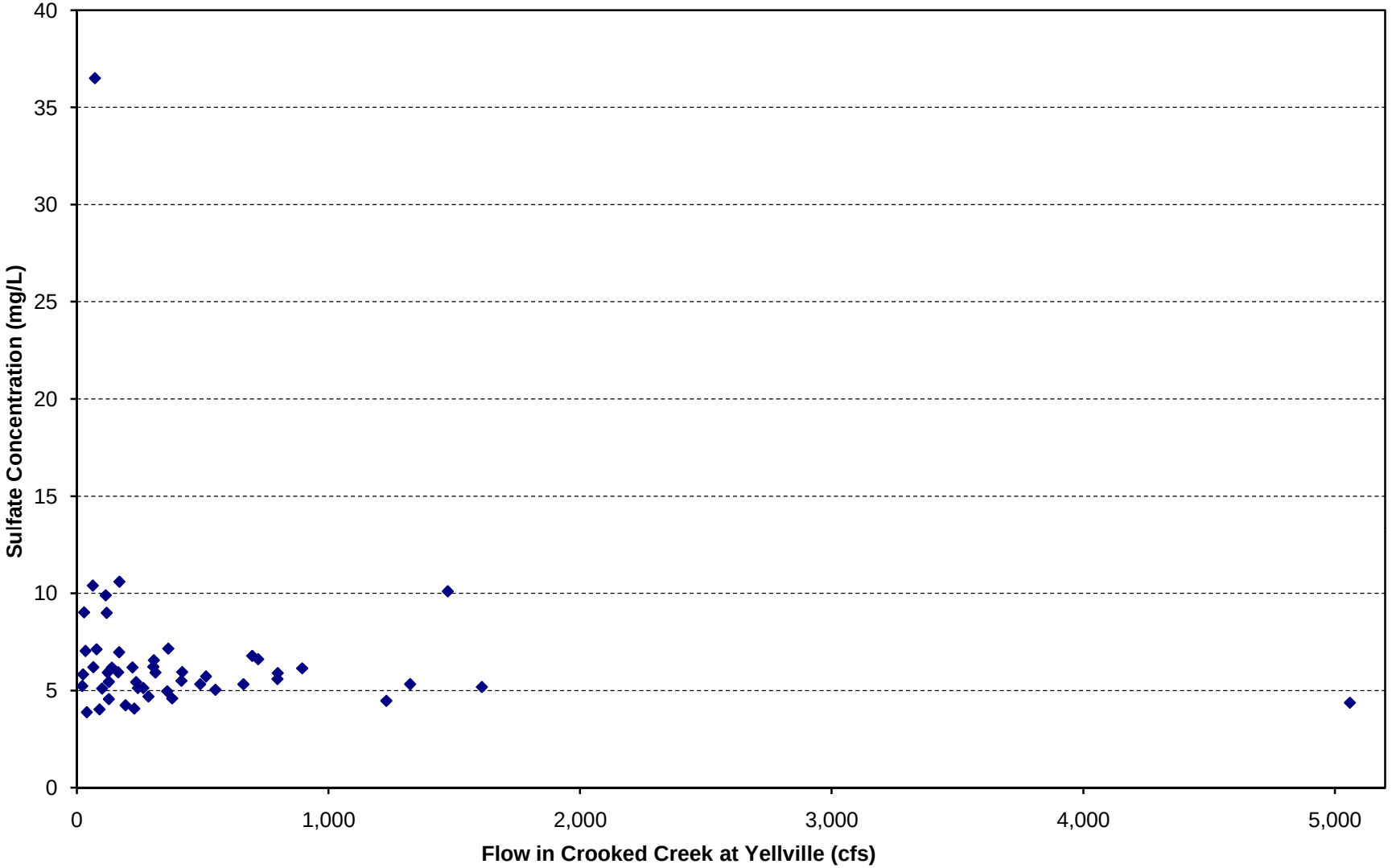
Note: Data points shown only for those dates when both concentration and flow are available.

Figure D.13 Conc. versus Flow for Chloride in Crooked Creek north of Rea Valley (WHI0048C)



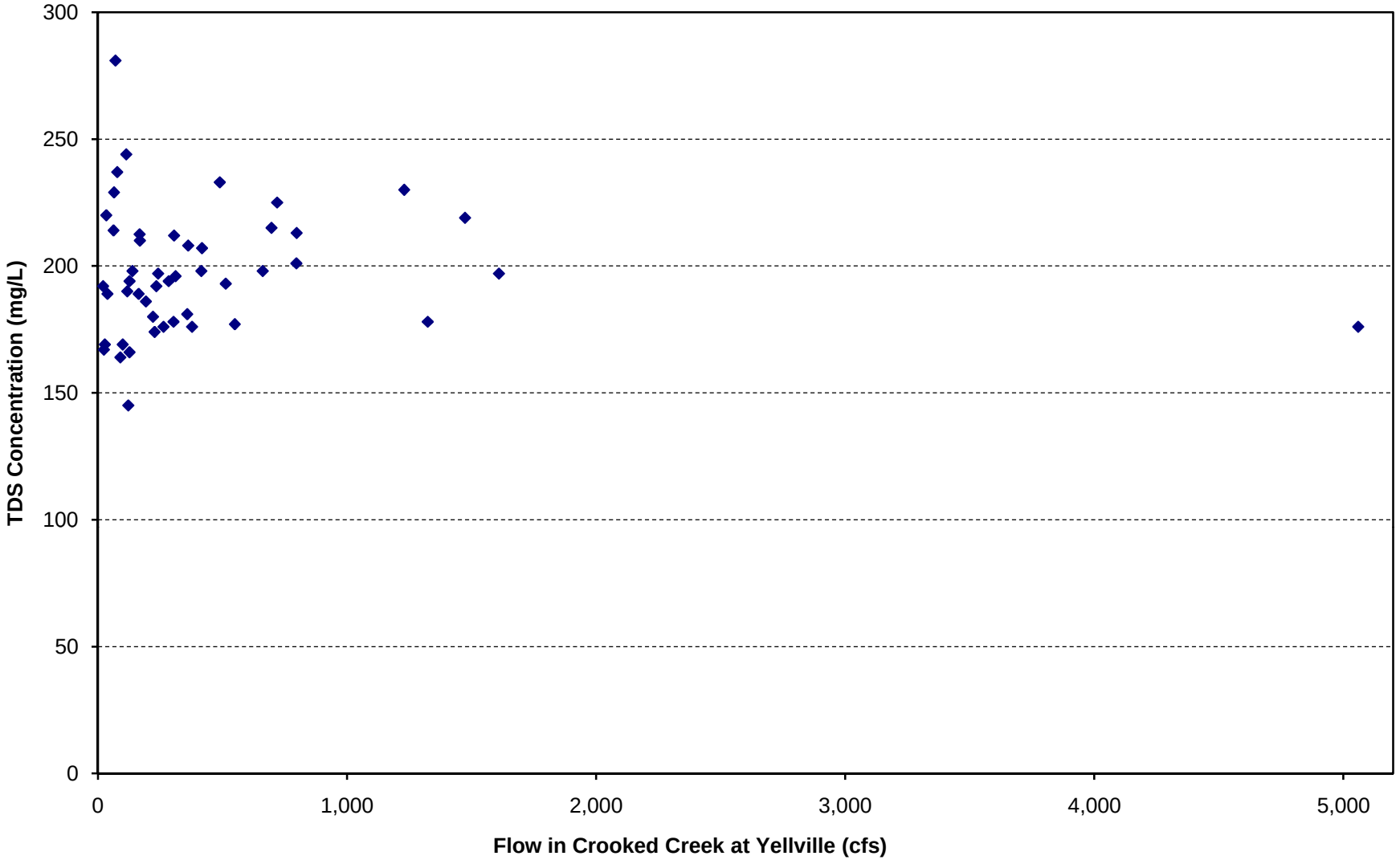
Note: Data points shown only for those dates when both concentration and flow are available.

Figure D.14 Conc. versus Flow for Sulfate in Crooked Creek north of Rea Valley (WHI0048C)



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

Figure D.15 Conc. versus Flow for TDS in Crooked Creek north of Rea Valley (WHI0048C)



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

APPENDIX E

TMDL Calculations for Reach 11010003-048

TABLE E.1 ALLOWABLE LOADS OF TDS FOR CROOKED CREEK REACH 11010003-048

Drainage area at flow gage (Crooked Creek at Yellville) = 406 square miles
Drainage area at downstream end of reach 11010003-048 = 462 square miles

				TDS (criterion = 200 mg/L)		
Flow in Crooked Creek at Yellville (cfs)	Flow at downstream end of reach 11010003-048 (cfs)	Percent exceedance for flow	Width on plot between data points (unitless)	Assimilative capacity, or TMDL (tons/day)	TMDL minus MOS (tons/day)	Area under TMDL curve (width times assimilative capacity) (tons/day)
0.01	0.01	99.9	0.5500	6.1E-03	5.8E-03	3.4E-05
0.01	0.01	99	0.9500	6.1E-03	5.8E-03	5.8E-05
0.01	0.01	98	1.5000	6.1E-03	5.8E-03	9.2E-05
0.01	0.01	96	2.0000	6.1E-03	5.8E-03	1.2E-04
0.01	0.01	94	2.0000	6.1E-03	5.8E-03	1.2E-04
0.41	0.46	92	2.0000	0.25	0.24	5.0E-03
3.20	3.64	90	2.0000	1.96	1.9	0.039
5.70	6.49	88	2.0000	3.5	3.3	0.070
9.70	11.0	86	2.0000	6.0	5.7	0.12
14.0	15.9	84	2.0000	8.6	8.2	0.17
18.0	20.5	82	2.0000	11.0	10.5	0.22
23.0	26.2	80	2.0000	14.1	13.4	0.28
29.0	33.0	78	2.0000	17.8	16.9	0.36
34.0	38.7	76	2.0000	20.9	19.8	0.42
38.0	43.2	74	2.0000	23.3	22.2	0.47
41.0	46.7	72	2.0000	25.2	23.9	0.50
45.0	51.2	70	2.0000	27.6	26.2	0.55
51.0	58.0	68	2.0000	31.3	29.7	0.63
58.0	66.0	66	2.0000	35.6	33.8	0.71
67.0	76.2	64	2.0000	41.1	39.1	0.82
77.0	87.6	62	2.0000	47.3	44.9	0.95
87.0	99.0	60	2.0000	53.4	50.7	1.07
96.0	109	58	2.0000	58.9	56.0	1.18
105	119	56	2.0000	64.4	61.2	1.29
117	133	54	2.0000	71.8	68.2	1.44
128	146	52	2.0000	78.6	74.6	1.57
141	160	50	2.0000	86.5	82.2	1.73
154	175	48	2.0000	94.5	89.8	1.89
169	192	46	2.0000	104	98.5	2.07
184	209	44	2.0000	113	107	2.26
199	226	42	2.0000	122	116	2.44
216	246	40	2.0000	133	126	2.65
232	263	38	2.0000	142	135	2.84
252	287	36	2.0000	155	147	3.09
273	311	34	2.0000	168	159	3.35
300	341	32	2.0000	184	175	3.68
329	374	30	2.0000	202	192	4.04
356	405	28	2.0000	219	208	4.37
385	438	26	2.0000	236	225	4.73
419	477	24	2.0000	257	244	5.14

				TDS (criterion = 200 mg/L)		
Flow in Crooked Creek at Yellville (cfs)	Flow at downstream end of reach 11010003-048 (cfs)	Percent exceedance for flow	Width on plot between data points (unitless)	Assimilative capacity, or TMDL (tons/day)	TMDL minus MOS (tons/day)	Area under TMDL curve (width times assimilative capacity) (tons/day)
456	519	22	2.0000	280	266	5.60
496	564	20	2.0000	304	289	6.09
537	611	18	2.0000	330	313	6.59
596	678	16	2.0000	366	348	7.32
663	754	14	2.0000	407	387	8.14
754	858	12	2.0000	463	440	9.26
882	1,004	10	1.5000	541	514	8.12
963	1,095	9	1.0000	591	561	5.91
1,040	1,183	8	1.0000	638	606	6.38
1,158	1,317	7	1.0000	711	675	7.11
1,270	1,445	6	1.0000	779	741	7.79
1,447	1,647	5	1.0000	888	844	8.88
1,650	1,878	4	1.0000	1,013	962	10.13
2,006	2,283	3	1.0000	1,231	1,170	12.31
2,842	3,234	2	1.0000	1,744	1,657	17.44
5,005	5,696	1	0.7500	3,072	2,919	23.04
7,210	8,204	0.5	0.4500	4,425	4,204	19.91
10,424	11,862	0.1	0.2450	6,398	6,078	15.68
24,655	28,056	0.01	0.0550	15,133	14,376	8.32

Total area under TMDL curve (tons/day) =			251.17
Explicit MOS (tons/day) = TMDL × 5% =			12.56
Existing load for nonpoint sources (NPS) plus regulated stormwater (SW) in tons/day (from Table E.2) =		232.88	
WLA for regulated stormwater:			
9 facilities × 40 ac each =	360 ac		
Total drainage area for reach 11010003-049 =	295,680 ac		
Regulated % of total area =	0.12%		
Regulated stormwater load: 0.12% × NPS+SW load =			0.28
LA for nonpt sources = 99.88% × NPS+SW load =			232.6
WLA for non-stormwater point sources (tons/day): TMDL – MOS – (WLA for SW) – (LA for NPS) =			5.73

FILE: R:\PROJECTS\3013-380\TECH\ADEQ_WQ_DATA\CROOKED_CREEK\WHI0048C CROOKED CREEK WITH TMDL CALCS MAY 9.XLSX

TABLE E.2 EXISTING NPS LOADS OF TDS FOR CROOKED CREEK REACH 11010003-048

Drainage area at flow gage (Crooked Creek at Yellville) = 406 square miles
Drainage area at downstream end of reach 11010003-048 = 462 square miles

Flow in Crooked Creek at Yellville (cfs)	Flow at downstream end of reach 11010003-048 (cfs)	Percent exceedance for flow	Width on plot between data points (unitless)	TDS conc. interp. from WHI0048A / WHI0193 conc. vs. flow (mg/L)	TDS Exist. load (tons/day)	Area under load curve (width times exist. load) (tons/day)
0.01	0.01	99.9	0.5500	171	5.3E-03	2.9E-05
0.01	0.01	99	0.9500	171	5.3E-03	5.0E-05
0.01	0.01	98	1.5000	171	5.3E-03	7.9E-05
0.01	0.01	96	2.0000	171	5.3E-03	1.1E-04
0.01	0.01	94	2.0000	171	5.3E-03	1.1E-04
0.41	0.46	92	2.0000	172	0.21	4.3E-03
3.20	3.64	90	2.0000	186	1.8	0.037
5.70	6.49	88	2.0000	178	3.1	0.062
9.70	11.0	86	2.0000	172	5.1	0.10
14.0	15.9	84	2.0000	168	7.2	0.14
18.0	20.5	82	2.0000	199	11	0.22
23.0	26.2	80	2.0000	204	14	0.29
29.0	33.0	78	2.0000	185	16	0.33
34.0	38.7	76	2.0000	173	18	0.36
38.0	43.2	74	2.0000	189	22	0.44
41.0	46.7	72	2.0000	192	24	0.48
45.0	51.2	70	2.0000	192	27	0.53
51.0	58.0	68	2.0000	172	27	0.54
58.0	66.0	66	2.0000	195	35	0.69
67.0	76.2	64	2.0000	199	41	0.82
77.0	87.6	62	2.0000	194	46	0.92
87.0	99.0	60	2.0000	192	51	1.0
96.0	109	58	2.0000	196	58	1.2
105	119	56	2.0000	203	65	1.3
117	133	54	2.0000	190	68	1.4
128	146	52	2.0000	197	77	1.5
141	160	50	2.0000	189	82	1.6
154	175	48	2.0000	188	89	1.8
169	192	46	2.0000	209	109	2.2
184	209	44	2.0000	197	111	2.2
199	226	42	2.0000	196	120	2.4
216	246	40	2.0000	196	130	2.6
232	263	38	2.0000	187	133	2.7
252	287	36	2.0000	197	152	3.0

				TDS		
Flow in Crooked Creek at Yellville (cfs)	Flow at downstream end of reach 11010003-048 (cfs)	Percent exceedance for flow	Width on plot between data points (unitless)	TDS conc. interp. from WHI0048A / WHI0193 conc. vs. flow (mg/L)	Exist. load (tons/day)	Area under load curve (width times exist. load) (tons/day)
273	311	34	2.0000	202	170	3.4
300	341	32	2.0000	188	173	3.5
329	374	30	2.0000	198	200	4.0
356	405	28	2.0000	200	218	4.4
385	438	26	2.0000	199	235	4.7
419	477	24	2.0000	200	257	5.1
456	519	22	2.0000	192	269	5.4
496	564	20	2.0000	241	366	7.3
537	611	18	2.0000	196	322	6.4
596	678	16	2.0000	187	342	6.8
663	754	14	2.0000	192	390	7.8
754	858	12	2.0000	204	472	9.4
882	1,004	10	1.5000	195	527	7.9
963	1,095	9	1.0000	190	562	5.6
1,040	1,183	8	1.0000	186	593	5.9
1,158	1,317	7	1.0000	190	674	6.7
1,270	1,445	6	1.0000	196	765	7.6
1,447	1,647	5	1.0000	171	758	7.6
1,650	1,878	4	1.0000	174	879	8.8
2,006	2,283	3	1.0000	169	1,041	10.4
2,842	3,234	2	1.0000	170	1,486	14.9
5,005	5,696	1	0.7500	174	2,671	20.0
7,210	8,204	0.5	0.4500	174	3,850	17.3
10,424	11,862	0.1	0.2450	174	5,566	13.6
24,655	28,056	0.01	0.0550	174	13,165	7.2
				Total area under exist. load curve for TDS (tons/day) =		232.88

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Figure E.1 Flow duration curve for Crooked Creek Reach 11010003-048

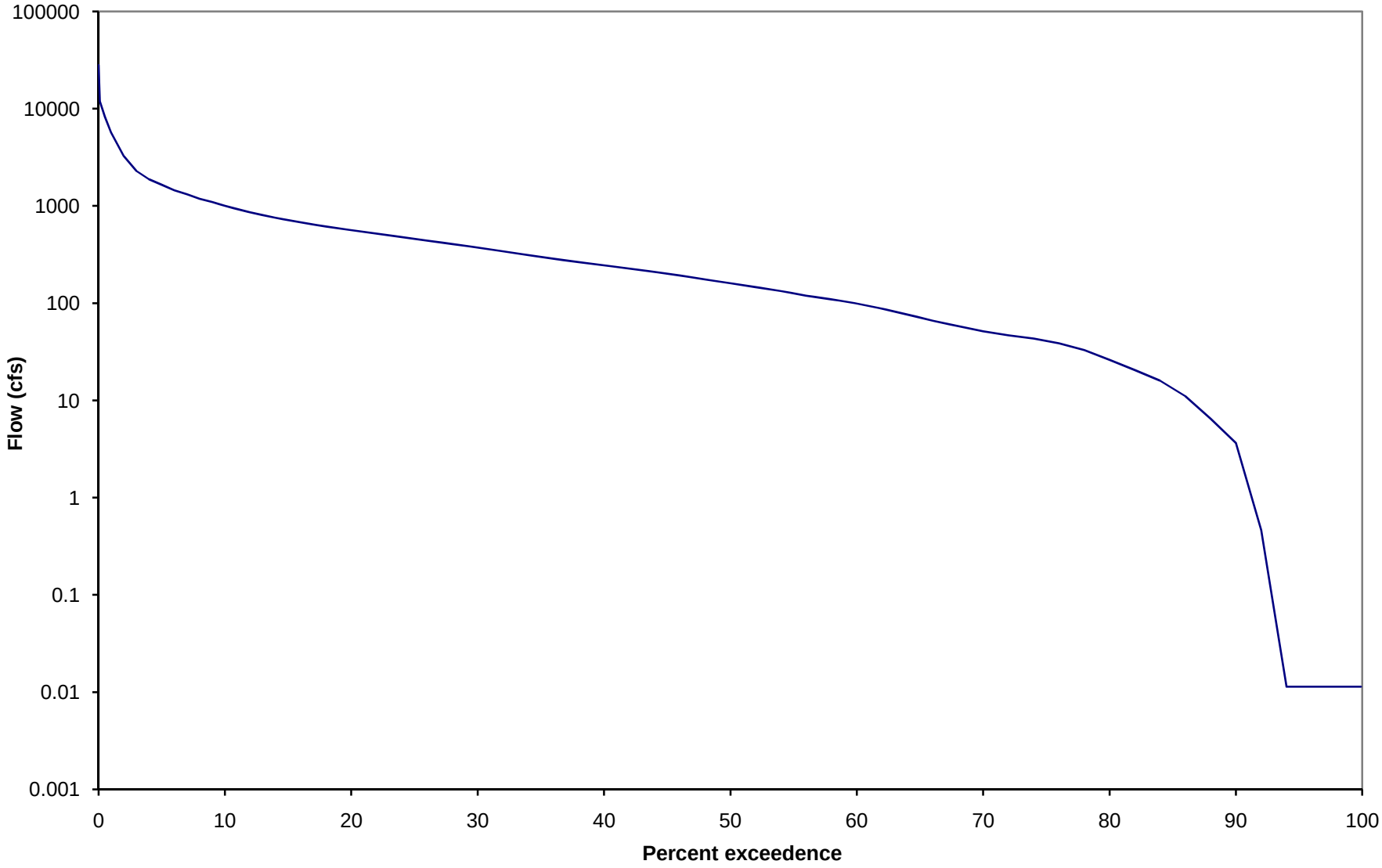
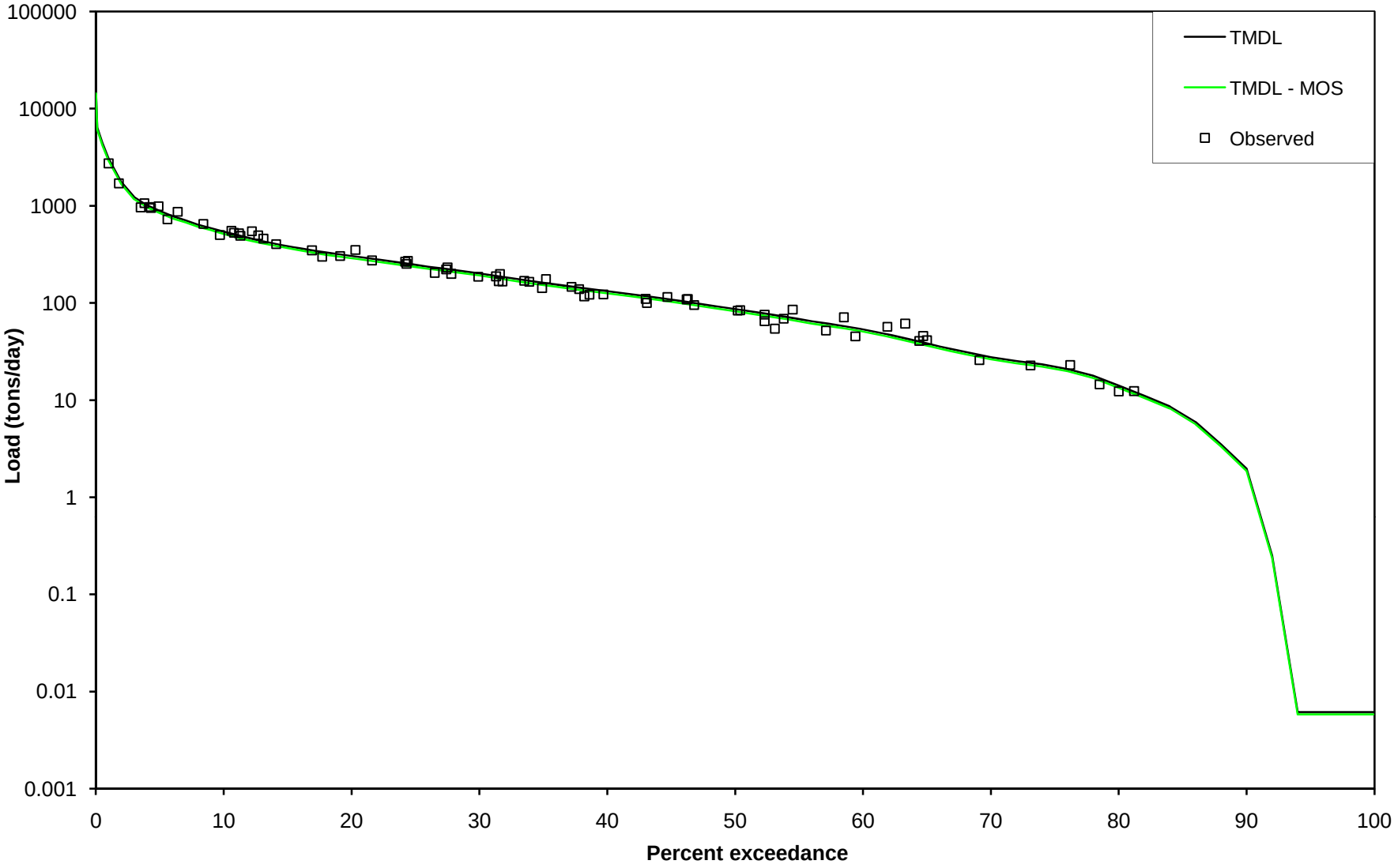


Figure E.2 TDS Load Duration Curve for Crooked Creek Reach 11010003-048



APPENDIX F

TMDL Calculations for Reach 11010003-049

TABLE F.1 ALLOWABLE LOADS OF CHLORIDE, SULFATE, AND TDS FOR CROOKED CREEK REACH 11010003-049

Drainage area at flow gage (Crooked Creek at Yellville) = 406 square miles
Drainage area at downstream end of reach 11010003-049 = 212 square miles

				Chloride (criterion = 20 mg/L)			Sulfate (criterion = 20 mg/L)			TDS (criterion = 200 mg/L)		
Flow in Crooked Creek at Yellville (cfs)	Flow at downstream end of reach 11010003-049 (cfs)	Percent exceedance for flow	Width on plot between data points (unitless)	Assimilative capacity, or TMDL (tons/day)	TMDL minus MOS (tons/day)	Area under TMDL curve (width times assimilative capacity) (tons/day)	Assimilative capacity, or TMDL (tons/day)	TMDL minus MOS (tons/day)	Area under TMDL curve (width times assimilative capacity) (tons/day)	Assimilative capacity, or TMDL (tons/day)	TMDL minus MOS (tons/day)	Area under TMDL curve (width times assimilative capacity) (tons/day)
0.01	0.01	99.9	0.550	2.8E-04	2.7E-04	1.5E-06	2.8E-04	2.7E-04	1.5E-06	2.8E-03	2.7E-03	1.5E-05
0.01	0.01	99	0.950	2.8E-04	2.7E-04	2.7E-06	2.8E-04	2.7E-04	2.7E-06	2.8E-03	2.7E-03	2.7E-05
0.01	0.01	98	1.500	2.8E-04	2.7E-04	4.2E-06	2.8E-04	2.7E-04	4.2E-06	2.8E-03	2.7E-03	4.2E-05
0.01	0.01	96	2.000	2.8E-04	2.7E-04	5.6E-06	2.8E-04	2.7E-04	5.6E-06	2.8E-03	2.7E-03	5.6E-05
0.01	0.01	94	2.000	2.8E-04	2.7E-04	5.6E-06	2.8E-04	2.7E-04	5.6E-06	2.8E-03	2.7E-03	5.6E-05
0.41	0.21	92	2.000	0.011	0.011	2.3E-04	0.011	0.011	2.3E-04	0.11	0.11	2.3E-03
3.20	1.67	90	2.000	0.090	0.086	0.0018	0.090	0.086	0.0018	0.90	0.86	0.018
5.70	2.98	88	2.000	0.16	0.15	0.0032	0.16	0.15	0.0032	1.6	1.5	0.032
9.70	5.07	86	2.000	0.27	0.26	0.0055	0.27	0.26	0.0055	2.7	2.6	0.055
14.0	7.31	84	2.000	0.39	0.37	0.0079	0.39	0.37	0.0079	3.9	3.7	0.079
18.0	9.40	82	2.000	0.51	0.48	0.010	0.51	0.48	0.010	5.1	4.8	0.10
23.0	12.0	80	2.000	0.65	0.62	0.013	0.65	0.62	0.013	6.5	6.2	0.13
29.0	15.1	78	2.000	0.82	0.78	0.016	0.82	0.78	0.016	8.2	7.8	0.16
34.0	17.8	76	2.000	1.0	0.91	0.019	1.0	0.91	0.019	9.6	9.1	0.19
38.0	19.8	74	2.000	1.1	1.0	0.021	1.1	1.0	0.021	10.7	10.2	0.21
41.0	21.4	72	2.000	1.2	1.1	0.023	1.2	1.1	0.023	11.5	11.0	0.23
45.0	23.5	70	2.000	1.3	1.2	0.025	1.3	1.2	0.025	12.7	12.0	0.25
51.0	26.6	68	2.000	1.4	1.4	0.029	1.4	1.4	0.029	14.4	13.6	0.29
58.0	30.3	66	2.000	1.6	1.6	0.033	1.6	1.6	0.033	16.3	15.5	0.33
67.0	35.0	64	2.000	1.9	1.8	0.038	1.9	1.8	0.038	18.9	17.9	0.38
77.0	40.2	62	2.000	2.2	2.1	0.043	2.2	2.1	0.043	21.7	20.6	0.43
87.0	45.4	60	2.000	2.5	2.3	0.049	2.5	2.3	0.049	24.5	23.3	0.49
96.0	50.1	58	2.000	2.7	2.6	0.054	2.7	2.6	0.054	27.0	25.7	0.54
105	54.8	56	2.000	3.0	2.8	0.059	3.0	2.8	0.059	29.6	28.1	0.59
117	61.1	54	2.000	3.3	3.1	0.066	3.3	3.1	0.066	33.0	31.3	0.66
128	66.8	52	2.000	3.6	3.4	0.072	3.6	3.4	0.072	36.1	34.2	0.72
141	73.6	50	2.000	4.0	3.8	0.079	4.0	3.8	0.079	39.7	37.7	0.79
154	80.4	48	2.000	4.3	4.1	0.087	4.3	4.1	0.087	43.4	41.2	0.87
169	88.2	46	2.000	4.8	4.5	0.10	4.8	4.5	0.10	47.6	45.2	0.95
184	96.1	44	2.000	5.2	4.9	0.10	5.2	4.9	0.10	51.8	49.2	1.04
199	104	42	2.000	5.6	5.3	0.11	5.6	5.3	0.11	56.0	53.2	1.12
216	113	40	2.000	6.1	5.8	0.12	6.1	5.8	0.12	60.8	57.8	1.22
232	121	38	2.000	6.5	6.2	0.13	6.5	6.2	0.13	65.2	61.9	1.30
252	132	36	2.000	7.1	6.7	0.14	7.1	6.7	0.14	71.0	67.4	1.42
273	143	34	2.000	7.7	7.3	0.15	7.7	7.3	0.15	76.9	73.0	1.54
300	157	32	2.000	8.4	8.0	0.17	8.4	8.0	0.17	84.5	80.3	1.69
329	172	30	2.000	9.3	8.8	0.19	9.3	8.8	0.19	92.7	88.0	1.85
356	186	28	2.000	10.0	9.5	0.20	10.0	9.5	0.20	100	95.3	2.01
385	201	26	2.000	10.8	10.3	0.22	10.8	10.3	0.22	108	103.0	2.17
419	219	24	2.000	11.8	11.2	0.24	11.8	11.2	0.24	118	112	2.36
456	238	22	2.000	12.8	12.2	0.26	12.8	12.2	0.26	128	122	2.57

Flow in Crooked Creek at Yellville (cfs)	Flow at downstream end of reach 11010003-049 (cfs)	Percent exceedance for flow	Width on plot between data points (unitless)	Chloride (criterion = 20 mg/L)			Sulfate (criterion = 20 mg/L)			TDS (criterion = 200 mg/L)		
				Assimilative capacity, or TMDL (tons/day)	TMDL minus MOS (tons/day)	Area under TMDL curve (width times assimilative capacity) (tons/day)	Assimilative capacity, or TMDL (tons/day)	TMDL minus MOS (tons/day)	Area under TMDL curve (width times assimilative capacity) (tons/day)	Assimilative capacity, or TMDL (tons/day)	TMDL minus MOS (tons/day)	Area under TMDL curve (width times assimilative capacity) (tons/day)
496	259	20	2.000	14.0	13.3	0.28	14.0	13.3	0.28	140	133	2.79
537	280	18	2.000	15.1	14.4	0.30	15.1	14.4	0.30	151	144	3.02
596	311	16	2.000	16.8	15.9	0.34	16.8	15.9	0.34	168	159	3.36
663	346	14	2.000	18.7	17.7	0.37	18.7	17.7	0.37	187	177	3.73
754	394	12	2.000	21.2	20.2	0.42	21.2	20.2	0.42	212	202	4.25
882	461	10	1.500	24.8	23.6	0.37	24.8	23.6	0.37	248	236	3.73
963	503	9	1.000	27.1	25.8	0.27	27.1	25.8	0.27	271	258	2.71
1,040	543	8	1.000	29.3	27.8	0.29	29.3	27.8	0.29	293	278	2.93
1,158	605	7	1.000	32.6	31.0	0.33	32.6	31.0	0.33	326	310	3.26
1,270	663	6	1.000	35.8	34.0	0.36	35.8	34.0	0.36	358	340	3.58
1,447	756	5	1.000	40.8	38.7	0.41	40.8	38.7	0.41	408	387	4.08
1,650	862	4	1.000	46.5	44.1	0.46	46.5	44.1	0.46	465	441	4.65
2,006	1,048	3	1.000	56.5	53.7	0.57	56.5	53.7	0.57	565	537	5.65
2,842	1,484	2	1.000	80.0	76.0	0.80	80.0	76.0	0.80	800	760	8.00
5,005	2,614	1	0.750	141	134	1.06	141	134	1.06	1,410	1,339	10.57
7,210	3,765	0.5	0.450	203	193	0.91	203	193	0.91	2,031	1,929	9.14
10,424	5,443	0.1	0.245	294	279	0.72	294	279	0.72	2,936	2,789	7.19
24,655	12,874	0.01	0.055	694	660	0.38	694	660	0.38	6,944	6,597	3.82
Total area under TMDL curve (tons/day) =						11.53			11.53			115.26
Explicit MOS (tons/day) = TMDL × 5% =						0.58			0.58			5.76
Existing load for nonpoint sources (NPS) plus regulated stormwater (SW) in tons/day (from Table F.2) =					3.25			3.38			98.27	
WLA for regulated stormwater:												
24 facilities × 40 ac each = 960 ac												
Total drainage area for reach 11010003-049 = 135,680 ac												
Regulated % of total area = 0.71%												
Regulated stormwater load:												
0.71% × NPS+SW load =						0.02			0.02			0.70
LA for nonpt sources = 99.29% × NPS+SW load =						3.23			3.36			97.57
WLA for non-stormwater point sources (tons/day):												
TMDL – MOS – (WLA for SW) – (LA for NPS) =						7.70			7.57			11.23

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TABLE F.2 EXISTING NONPOINT SOURCE LOADS OF CHLORIDE, SULFATE, AND TDS FOR CROOKED CREEK REACH 11010003-049

Drainage area at flow gage (Crooked Creek at Yellville) = 406 square miles
Drainage area at downstream end of reach 11010003-049 = 212 square miles

				Chloride			Sulfate			TDS		
Flow in Crooked Creek at Yellville (cfs)	Flow at downstream end of reach 11010003-049 (cfs)	Percent exceedance for flow	Width on plot between data points (unitless)	Cl conc. interp. from WHI0067 conc. vs. flow (mg/L)	Exist. load (tons/day)	Area under load curve (width times exist. load) (tons/day)	SO4 conc. interp. from WHI0067 conc. vs. flow (mg/L)	Exist. load (tons/day)	Area under load curve (width times exist. load) (tons/day)	TDS conc. interp. from WHI0067 conc. vs. flow (mg/L)	Exist. load (tons/day)	Area under load curve (width times exist. load) (tons/day)
0.01	0.01	99.9	0.550	7.6	1.1E-04	5.9E-07	5.6	7.9E-05	4.3E-07	218	3.1E-03	1.7E-05
0.01	0.01	99	0.950	7.6	1.1E-04	1.0E-06	5.6	7.9E-05	7.5E-07	218	3.1E-03	2.9E-05
0.01	0.01	98	1.500	7.6	1.1E-04	1.6E-06	5.6	7.9E-05	1.2E-06	218	3.1E-03	4.6E-05
0.01	0.01	96	2.000	7.6	1.1E-04	2.2E-06	5.6	7.9E-05	1.6E-06	218	3.1E-03	6.1E-05
0.01	0.01	94	2.000	7.6	1.1E-04	2.2E-06	5.6	7.9E-05	1.6E-06	218	3.1E-03	6.1E-05
0.41	0.21	92	2.000	7.4	4.2E-03	8.4E-05	6.5	3.7E-03	7.5E-05	209	0.12	2.4E-03
3.20	1.67	90	2.000	9.0	0.040	8.1E-04	6.1	0.027	5.5E-04	210	0.95	0.019
5.70	2.98	88	2.000	8.2	0.066	0.0013	5.6	0.045	8.9E-04	219	1.8	0.035
9.70	5.07	86	2.000	7.9	0.11	0.0021	5.3	0.072	0.0014	198	2.7	0.054
14.0	7.31	84	2.000	7.3	0.14	0.0029	4.4	0.086	0.0017	213	4.2	0.084
18.0	9.40	82	2.000	12.5	0.32	0.0063	6.0	0.15	0.0030	228	5.8	0.12
23.0	12.0	80	2.000	7.6	0.25	0.0049	5.2	0.17	0.0034	215	7.0	0.14
29.0	15.1	78	2.000	9.0	0.37	0.0074	6.9	0.28	0.0056	211	8.6	0.17
34.0	17.8	76	2.000	8.5	0.41	0.0081	6.2	0.30	0.0060	218	10	0.21
38.0	19.8	74	2.000	7.5	0.40	0.0080	4.7	0.25	0.0050	215	12	0.23
41.0	21.4	72	2.000	7.9	0.46	0.0091	5.5	0.32	0.0064	214	12	0.25
45.0	23.5	70	2.000	8.0	0.51	0.010	5.6	0.35	0.0071	218	14	0.28
51.0	26.6	68	2.000	6.6	0.48	0.010	5.4	0.39	0.0078	191	14	0.27
58.0	30.3	66	2.000	6.3	0.51	0.010	5.0	0.41	0.0082	191	16	0.31
67.0	35.0	64	2.000	9.1	0.85	0.017	6.7	0.63	0.013	224	21	0.42
77.0	40.2	62	2.000	7.6	0.83	0.017	6.3	0.69	0.014	200	22	0.43
87.0	45.4	60	2.000	7.8	1.0	0.019	4.8	0.59	0.012	217	27	0.53
96.0	50.1	58	2.000	7.8	1.1	0.021	5.0	0.68	0.014	203	27	0.55
105	54.8	56	2.000	7.3	1.1	0.021	5.6	0.83	0.017	206	31	0.61
117	61.1	54	2.000	7.4	1.2	0.024	6.5	1.1	0.022	201	33	0.66
128	66.8	52	2.000	6.6	1.2	0.024	6.9	1.2	0.025	191	34	0.69
141	73.6	50	2.000	7.3	1.5	0.029	5.6	1.1	0.022	204	40	0.81
154	80.4	48	2.000	7.3	1.6	0.032	6.2	1.3	0.027	214	46	0.93
169	88.2	46	2.000	8.1	1.9	0.039	8.1	1.9	0.039	207	49	0.99
184	96.1	44	2.000	6.3	1.6	0.033	6.5	1.7	0.034	187	48	0.97
199	104	42	2.000	7.0	2.0	0.039	5.7	1.6	0.032	200	56	1.1
216	113	40	2.000	7.4	2.3	0.045	8.3	2.5	0.050	210	64	1.3
232	121	38	2.000	6.2	2.0	0.040	7.3	2.4	0.048	188	61	1.2
252	132	36	2.000	5.0	1.8	0.036	4.9	1.7	0.035	177	63	1.3
273	143	34	2.000	5.6	2.2	0.043	5.3	2.0	0.041	177	68	1.4

				Chloride			Sulfate			TDS		
Flow in Crooked Creek at Yellville (cfs)	Flow at downstream end of reach 11010003-049 (cfs)	Percent exceedance for flow	Width on plot between data points (unitless)	Cl conc. interp. from WHI0067 conc. vs. flow (mg/L)	Exist. load (tons/day)	Area under load curve (width times exist. load) (tons/day)	SO4 conc. interp. from WHI0067 conc. vs. flow (mg/L)	Exist. load (tons/day)	Area under load curve (width times exist. load) (tons/day)	TDS conc. interp. from WHI0067 conc. vs. flow (mg/L)	Exist. load (tons/day)	Area under load curve (width times exist. load) (tons/day)
300	157	32	2.000	5.9	2.5	0.050	5.3	2.2	0.045	178	75	1.5
329	172	30	2.000	6.0	2.8	0.056	5.0	2.3	0.047	181	84	1.7
356	186	28	2.000	5.7	2.8	0.057	5.7	2.9	0.057	181	91	1.8
385	201	26	2.000	6.2	3.4	0.068	7.6	4.1	0.083	180	98	2.0
419	219	24	2.000	6.3	3.7	0.075	5.9	3.5	0.070	181	107	2.1
456	238	22	2.000	7.0	4.5	0.090	5.5	3.5	0.071	197	126	2.5
496	259	20	2.000	5.9	4.1	0.083	5.0	3.5	0.069	198	139	2.8
537	280	18	2.000	6.1	4.6	0.093	6.1	4.6	0.092	171	129	2.6
596	311	16	2.000	6.1	5.1	0.10	5.3	4.4	0.088	178	150	3.0
663	346	14	2.000	7.4	6.9	0.14	6.6	6.2	0.12	180	168	3.4
754	394	12	2.000	6.7	7.1	0.14	7.0	7.4	0.15	177	188	3.8
882	461	10	1.500	5.3	6.6	0.10	5.6	7.0	0.10	168	208	3.1
963	503	9	1.000	5.7	7.7	0.08	6.1	8.2	0.08	172	233	2.3
1,040	543	8	1.000	5.2	7.6	0.08	6.3	9.3	0.09	158	231	2.3
1,158	605	7	1.000	5.3	8.7	0.09	6.1	10	0.10	159	260	2.6
1,270	663	6	1.000	5.3	9.4	0.09	6.2	11	0.11	160	285	2.9
1,447	756	5	1.000	5.1	10	0.10	6.2	13	0.13	160	325	3.3
1,650	862	4	1.000	5.0	12	0.12	6.2	14	0.14	160	371	3.7
2,006	1,048	3	1.000	4.2	12	0.12	5.6	16	0.16	157	443	4.4
2,842	1,484	2	1.000	3.8	15	0.15	6.1	24	0.24	134	534	5.3
5,005	2,614	1	0.750	5.0	35	0.27	5.6	39	0.29	158	1,114	8.4
7,210	3,765	0.5	0.450	5.3	54	0.24	5.3	54	0.24	165	1,678	7.6
10,424	5,443	0.1	0.245	5.5	80	0.20	5.3	77	0.19	170	2,488	6.1
24,655	12,874	0.01	0.055	5.5	189	0.10	5.3	183	0.10	170	5,885	3.2
				Total area under exist. load curve for chloride (tons/day) =		3.25	Total area under exist. load curve for sulfate (tons/day) =		3.38	Total area under exist. load curve for TDS (tons/day) =		98.27

FILE: R:\PROJECTS\3013-380\TECH\ADEQ_WQ_DATA\CROOKED_CREEK\WHI0066 CROOKED CREEK WITH TMDL CALCS FEB 28.XLSX

Figure F.1 Flow duration curve for Crooked Creek Reach 11010003-049

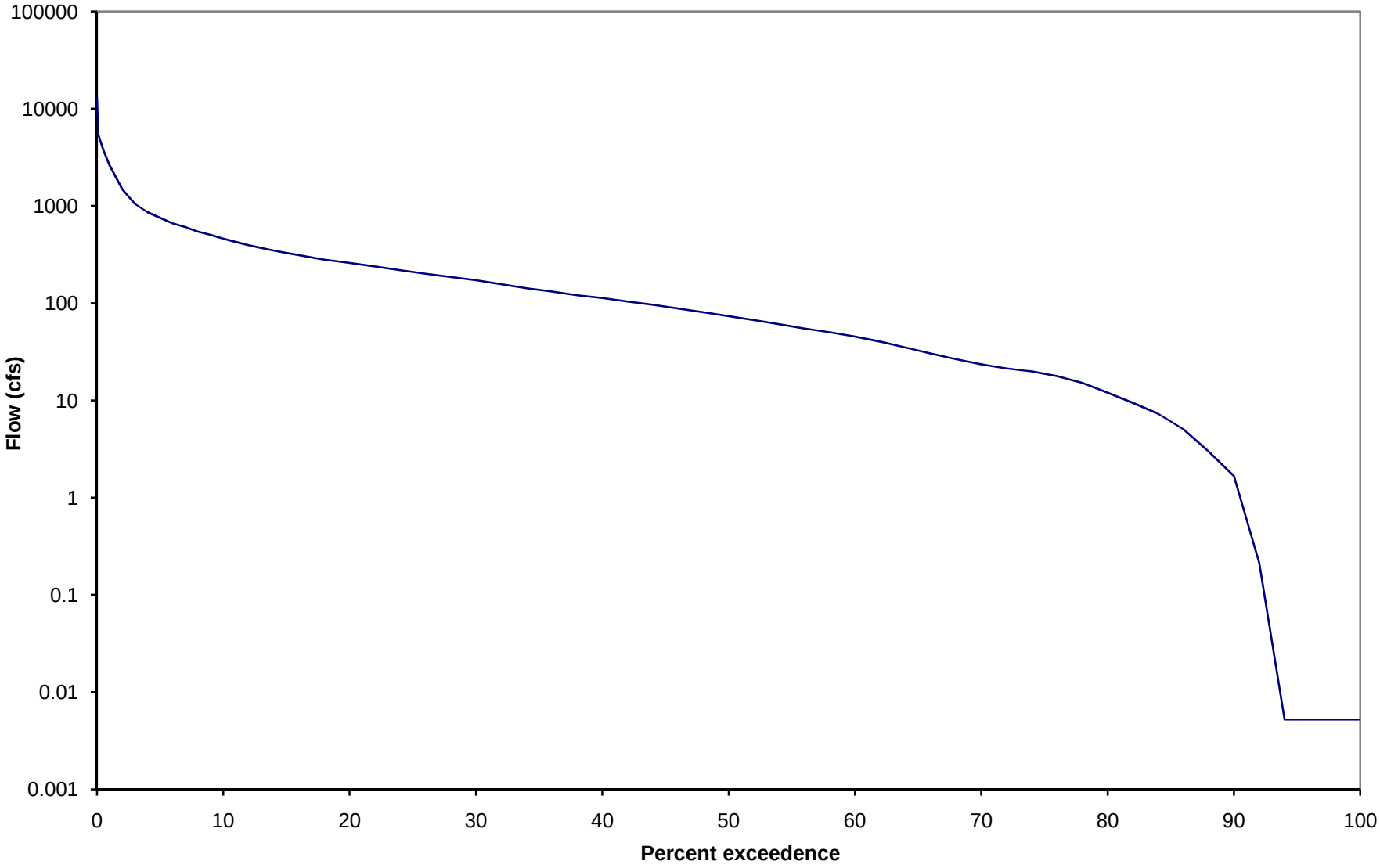

Figure F.2 Chloride Load Duration Curve for Crooked Creek Reach 11010003-049

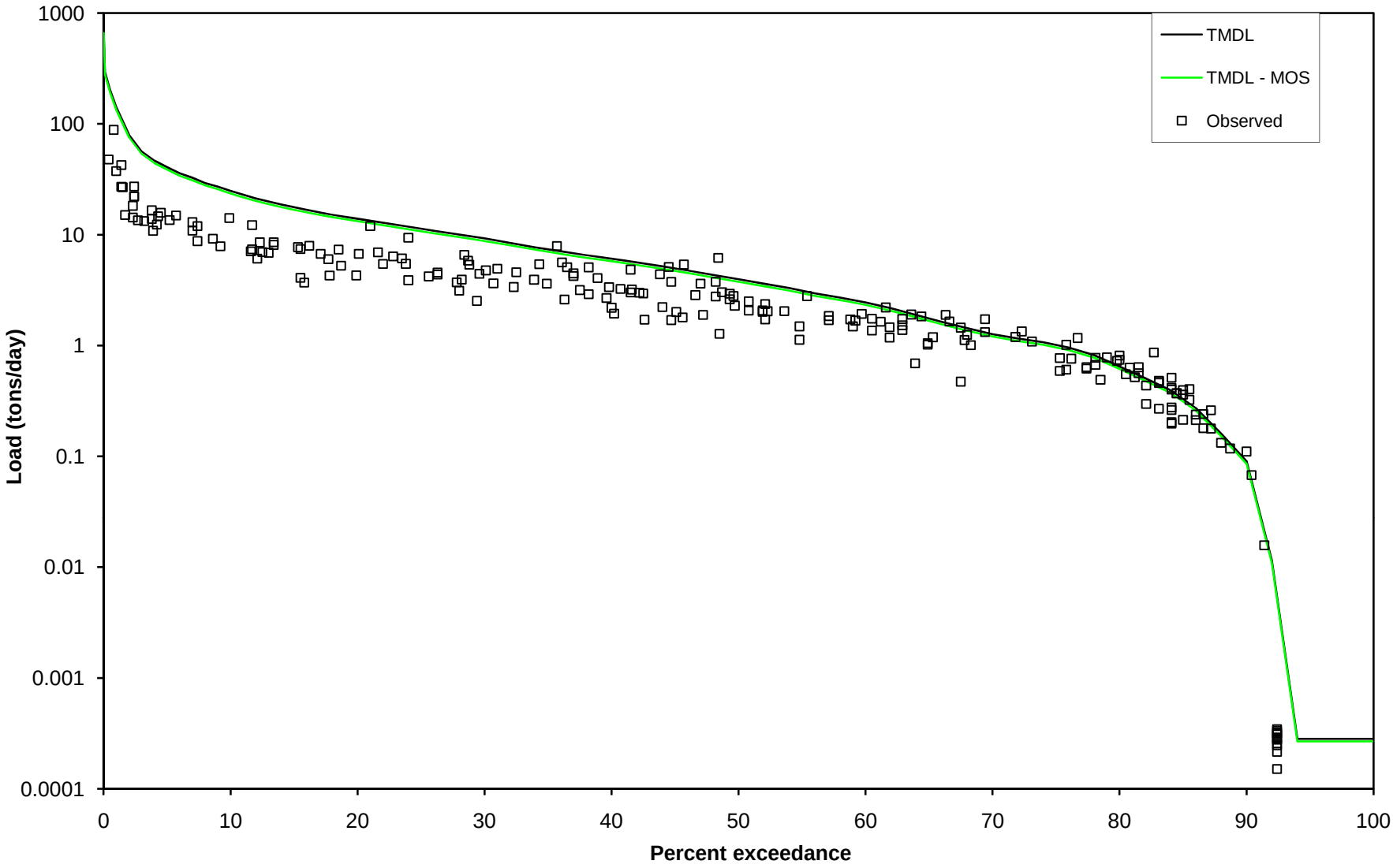

Figure F.3 Sulfate Load Duration Curve for Crooked Creek Reach 11010003-049

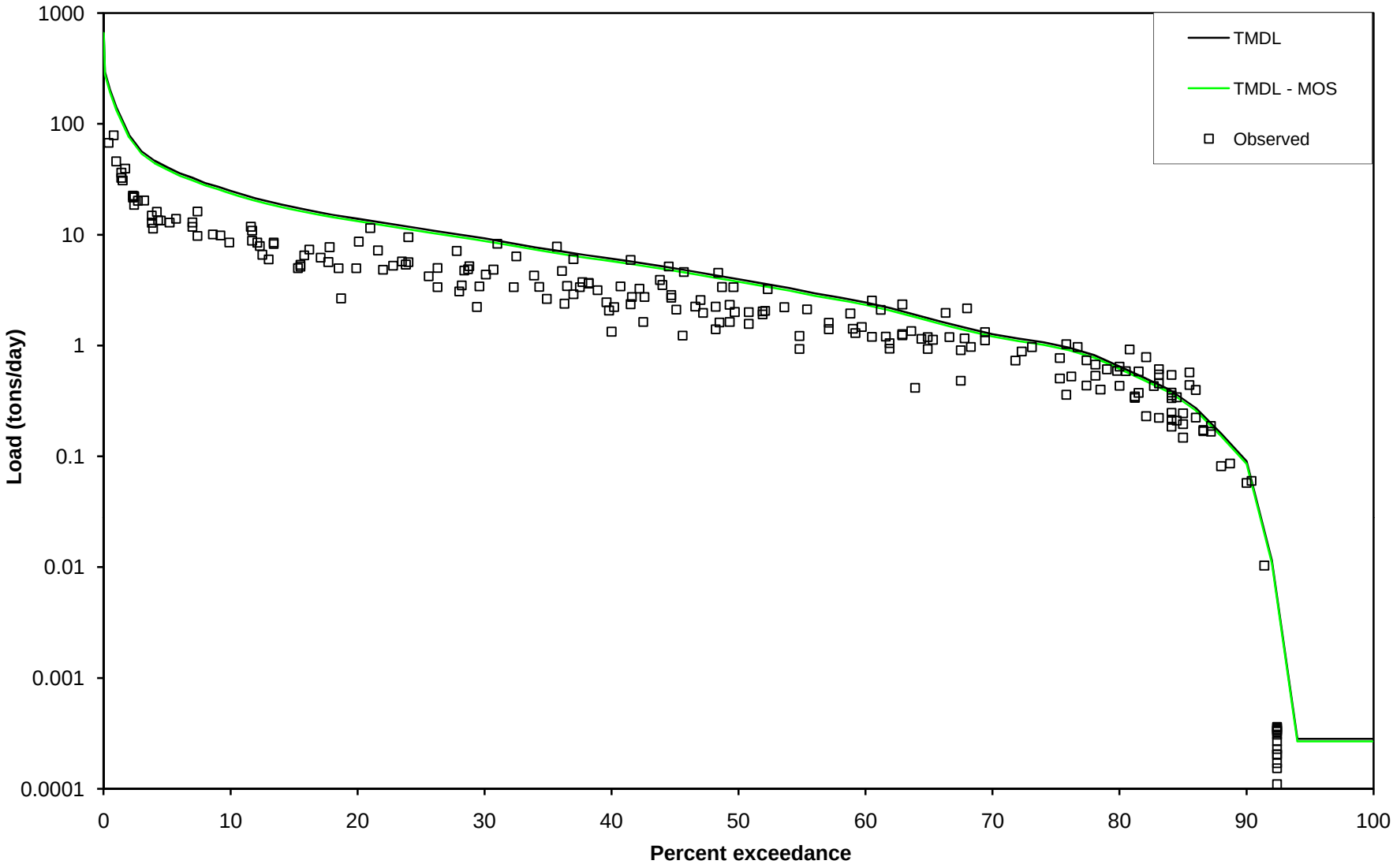

Figure F.4 TDS Load Duration Curve for Crooked Creek Reach 11010003-049