United States Environmental Protection Agency

Region 7

Total Maximum Daily Load

For Total Suspended Solids,

Total Nitrogen and Total Phosphorus

Bear Creek (MO_0115U-01)

Adair County, Missouri

for Karen A. Flournoy
William A. Spratlin
Director
Water, Wetlands and Pesticides Division

12-23-10
Date

(This page intentionally left blank)

Total Maximum Daily Load (TMDL)
For Bear Creek
303(d) Listed Pollutant: Unknown

Name: Bear Creek

Location: Near the City of Kirksville in Adair County, Missouri

Hydrologic Unit Code (HUC): 07110005-0108

Water Body Identification (WBID): 0115U-01[1]

Missouri Stream Class: Unclassified

Designated Beneficial Uses: Missouri general criteria (10CSR 20-7.031) apply to unclassified streams. There are no designated beneficial uses assigned to unclassified streams.

Size of Segment: 8.9 miles[2]

Location of Segment: Section 8, T61N, 14W to Brook Drive near Kirksville, MO.

Size of Impaired Segment: 2 miles (length of MDNRs segment from 2008 303(d) List)

Location of Impaired Segment: From Section 8, T61N, 14W to Brook Drive near Kirksville, Missouri. The 2008 Missouri 303(d) List provides the following latitude and longitude for the upstream and downstream terminus of the impaired segment: Upstream (40.1585, -92.5644) and downstream (40.1436, -92.5374). The impaired length includes the entire unclassified headwater portion of Bear Creek.[3]

Identified Pollutant on 303(d) List: Unknown

Identified Source on 303(d) List: Unknown

TMDL Priority Ranking: Medium

---

[1] Bear Creek was listed on the 1994/1996 Missouri 303(d) List of impaired waters but was not assigned a WBID. In 1998, Bear Creek was not included on the 303(d) List. Bear Creek was listed on the 2002 303(d) List once again but was not assigned a WBID. In 2004/2006, Bear Creek was assigned a WBID of 0115U and in the 2008 303(d) List it was assigned its current WBID of 0115U-01.

[2] No mileage is associated with the 2008 Missouri 303(d) List; however, the stream length listed corresponds to the EPA approved 2008 Missouri 303(d) Listed segment.

[3] Bear Creek is an unclassified segment and there is no official location description in MO WQS Table H. However, the TMDL as described encompasses the entire reach referred to in the 2008 Missouri 303(d) List.

Table of Contents

List of Figures

List of Tables

List of Acronyms

Σ	Sum
µg	Micrograms
BI	Biotic Index
BOD	Biochemical Oxygen Demand
BOD_5	5 day Biochemical Oxygen Demand
CAFO	Concentrated Animal Feeding Operation
CBOD	Carbonaceous Biochemical Oxygen Demand
$CBOD_5$	5 day Carbonaceous Biochemical Oxygen Demand
$CBOD_{ult}$	Ultimate Carbonaceous Biochemical Oxygen Demand
CFR	Code of Federal Regulations
cfs	Cubic Feet per Second
cms	Cubic Meters per Second
CSR	Code of State Regulations
CWA	Clean Water Act
DO	Dissolved Oxygen
EDU	Ecological Drainage Unit
e.g.	For Example
EPA	United States Environmental Protection Agency
EPT	Ephemeroptera/ Plecoptera/Trichoptera
GIS	Geographic Information System
HUC	Hydrologic Unit Code
KJN and TKN	Total Kjeldahl Nitrogen
km	Kilometers
LA	Load Allocation
LC	Loading Capacity
m	Meters
m/s	Meters per Second
MDC	Missouri Department of Conservation
MDNR	Missouri Department of Natural Resources
mg	Milligram
mg/L	Milligrams per Liter
MGD	Million Gallons per Day
MO	Missouri
MoRAP	Missouri Resource Assessment Partnership
MOS	Margin of Safety
MS4	Municipal Separate Storm Sewer System
MSDIS	Missouri Spatial Data Information Service
MSOP	Missouri State Operating Permit
NASS	National Agricultural Statistics Service
NBOD	Nitrogenous Biochemical Oxygen Demand
$NBOD_{Ult}$	Ultimate Nitrogenous Biochemical Oxygen Demand
NCDC	National Climatic Data Center

List of Acronyms (continued)

NO_2	Nitrite
NO_3	Nitrate
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
O&G	Oil and Grease
^oC	Temperature in Degrees Celsius
pBIAS	Percent Bias
PCS	Permit Compliance System
PO_4	Phosphate
RMSE	Root Mean Squared Error
SCI	Stream Condition Index
SDI	Shannon Diversity Index
SOD	Sediment Oxygen Demand
SWPPP	Storm Water Pollution Prevention Plan
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
TR	Taxa Richness
TSS	Total Suspended Solids
US	United States
USDA	United States Department of Agriculture
WBID	Water Body Identification
WET	Whole Effluent Toxicity
WLA	Wasteload Allocation
WQS	Water Quality Standards
WWTP	Wastewater Treatment Plant

1 Introduction

The Bear Creek Total Maximum Daily Load (TMDL) is being established in accordance with Section 303(d) of the Clean Water Act (CWA). The water quality limited segment is included on the United States (U.S.) Environmental Protection Agency (EPA) approved 2008 Missouri 303(d) List and is identified as impaired due to unknown pollutants. This report addresses the Bear Creek impairment by establishing total suspended solids (TSS), total nitrogen (TN) and total phosphorus (TP) TMDLs in accordance with Section 303(d) of the CWA. EPA is establishing this TMDL to fulfill the requirements of the Consent Decree established as part of the *American Canoe Association, et al. v. EPA*, No. 98-1195-CV-W in consolidation with No. 98-4282-CV-W, February 27, 2001.

Section 303(d) of the CWA and Federal Chapter 40 of Code of Federal Regulations (CFR) Part 130 requires states to develop TMDLs for waters not meeting designated beneficial uses. The TMDL process quantitatively assesses the impairment factors so that states can establish water-quality based controls to reduce pollutants of concern and restore and protect the quality of their water resources. The purpose of a TMDL is to determine the maximum amount of a pollutant (the load) that a water body can assimilate without exceeding the water quality standards (WQS) for that pollutant. WQS are benchmarks used to assess the quality of rivers and lakes. The TMDL also establishes the pollutant loading capacity (LC) necessary to meet the Missouri WQS established for each water body based on the relationship between pollutant sources and instream water quality conditions. The TMDL consists of a wasteload allocation (WLA), load allocation (LA) and a margin of safety (MOS). The WLA is the portion of the allowable load that is allocated to point sources. The LA is the portion of the allowable load that is allocated to nonpoint sources. The MOS accounts for the uncertainty associated with linking pollutant load to the water quality impairment. This is often associated with model assumptions and data limitations.

The goal of the TMDL program is to restore impaired designated beneficial uses of water bodies. Thus, reduction strategies for point and nonpoint sources and implementation of source controls throughout the watershed will be necessary to restore the protection of warm water aquatic life use in Bear Creek. In addition to establishing a TMDL for Bear Creek, this report provides a summary of information, results and recommendations related to the impairment based on a broad analysis of watershed information and detailed analysis of water quality data, flow data and comparison to a reference stream condition in the same ecoregion or ecological drainage unit (EDU) in which Bear Creek is located.

Section 2 of this report provides background information on the Bear Creek watershed and Section 3 describes the water quality problems. Section 4 describes potential sources of concern and Section 5 presents the applicable WQS. Section 6 describes the modeling and technical approach used to develop the TMDL. Sections 7 to 11 present the LC, WLA, LA, MOS and seasonal variation. Sections 12 to 14 present the follow-up monitoring plan, reasonable assurances and public participation. A summary of the administrative record is presented in Section 15. Appendix A summarizes the available water quality data. Appendix B presents QUAL2K modeling conducted to support this TMDL. Methods and data used in load duration curve (LDC) modeling are presented in Appendix C – Appendix E.

2 Background

This section of the report provides information on Bear Creek and its watershed.

2.1 The Setting

Bear Creek is located in the Salt River Basin in northeast Missouri. Bear Creek originates in the southeastern portion of Kirksville, Missouri, flows southeast and ends at its confluence with the North Fork Salt River in Shelby County, Missouri. The Bear Creek watershed covers an area of approximately 126 square miles with a river distance of approximately 45 miles. The North Fork Salt River flows southeast and is a tributary to Mark Twain Lake which then drains to the Salt River and eventually joins the Mississippi River near the city of Louisiana, Missouri.

The EPA-approved 2008 303(d) List of impaired waters does not provide an impairment length for Bear Creek. Based on discussions with EPA and Missouri Department of Natural Resources' (MDNR) staff, the Bear Creek impaired segment originates at Brook Drive near Kirksville and continues south approximately 8.9 miles, ending approximately 0.2 miles south of State Highway KK (Figure 2). The approximate length of this segment (8.9 miles) was calculated from a geographic information systems (GIS) data layer of impaired streams (MSDIS, 2009). This TMDL addresses the 2008 303(d) Listed impaired segment in its entirety. The watershed area draining to the impaired stream segment is approximately 27 square miles. The elevation of the watershed ranges from approximately 980 – 860 feet above mean sea level (USDA, 2001) and the average stream gradient is approximately 5.4 feet/mile or 0.91 percent (MDC, 2009). The channel width ranges from 11 to 22 feet wide in the impaired segment based on monitoring at eight locations.

The Bear Creek impaired segment is currently listed as impaired due to exceedances of Missouri's general water quality criteria for protection of aquatic life and natural biological aquatic communities (10 CSR 20-7.031). Missouri's general water quality criteria consist of eight narrative criteria that must be met for all waters of the state. Historic water quality and aquatic life monitoring in Bear Creek has found unnaturally low diversity of fish species in upstream segments of the Creek (MDC, 2001). The water quality limited segment is included on the EPA-approved 2008 Missouri 303(d) List and is identified as impaired due to unknown pollutants and sources. Nutrients and oxygen consuming substances from both point and nonpoint sources are considered to be the likely contributors to the impairment and as such will be the focus of this TMDL effort.

2.2 Physiographic Location, Geology and Soils

The Bear Creek watershed is located within the Northern Plains; a region within the Dissected Till Plains. In Missouri, the Dissected Till Plains portion of the Northern Plains region lies in the portion of the state north of the Missouri River. The Dissected Till Plains are characterized by moderately dissected, glaciated, flat-to-rolling terrain that slopes gently toward the Missouri and Mississippi River valleys.

The Bear Creek watershed is within the Northeast Groundwater Province which often suggests good groundwater quality due to alluvial deposits that consist of sand and gravel underlying the floodplains of streams and rivers (MDNR, 2009). The Bear Creek watershed is located in the Middle Pennsylvanian-Middle Series-Desmonian Stage. Three predominant rock types occur in the Bear Creek watershed: shale, limestone and sandstone (Stoeser *et. al.*, 2005). These geologic and physiographic features affect the Bear Creek hydrology and background water quality.

A soils hydrologic group relates to the rate at which surface water enters the soil profile, which in turn affects the amount of water that enters the stream as direct runoff. Table 1 and Figure 1 provide a summary of soil types in the impaired Bear Creek watershed. The dominant soil type C, covers approximately 70 percent of the watershed. Group C includes sandy clay loam soils that have a moderately fine to fine structure. These soils have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water. Approximately 21 percent of soils in the impaired watershed are categorized as Group D. Group D soils include clay loam, silty clay loam, sandy clay, silty clay or clay. This hydrologic soil group has the highest runoff potential. It has very low infiltration rates when thoroughly wetted and consist chiefly of clay soils, soils with a permanently high water table, soils with a claypan or clay layer at or near the surface and shallow soils over nearly impervious material (Purdue Research Foundation, 2009). The remaining soil types within the Bear Creek watershed can be found in Table 1.

Table 1. Bear Creek Watershed Soils Summary (NRCS, 2009)

Soil Type	Hydrologic Soil Group	Acres	Percent
Leonard silty clay loam	D	1,392	8.0
Adco silt loam	D	2,200	12.6
(Subtotal D soil group)	**D**	**3,592**	**20.6**
Winnegan loam	C	192	1.1
Purdin clay loam	C	1,616	9.3
Gara loam	C	1,181	6.8
Gara fine sandy loam	C	1,749	10.1
Armstrong loam	C	6,052	34.8
Armstrong clay loam	C	1,142	6.6
(Subtotal C soil group)	**C**	**11,932**	**68.6**
Vesser silt loam	C/D	1,505	8.6
Other[4]	C/D	373	2.2

[4] Other soil types that make up less than one percent of the total watershed area include: Bevier silty clay loam (Hydrologic Soil Group C), Dockery and Tice silt loam (Hydrologic Soil Group C), Gorin-Winnegan comples (Hydrologic Soil Group C) and Putnam silt loam (Hydrologic Soil Group C).

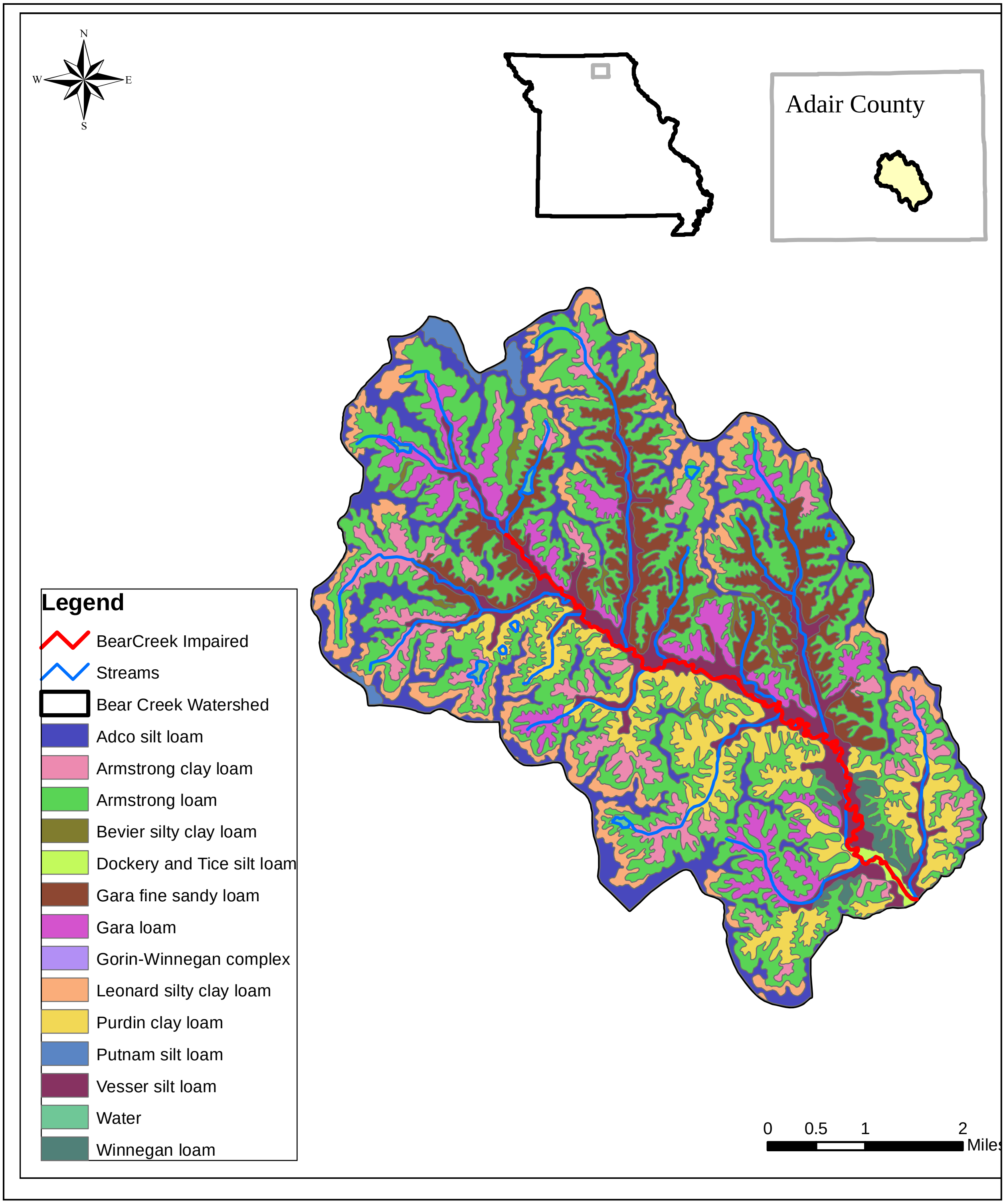

Figure 1. Bear Creek Watershed Soils

2.3 Rainfall and Climate

Two weather stations are located in Adair County within one-half mile of the Bear Creek watershed (Figure 2). Both stations record daily precipitation, maximum and minimum temperature, snowfall and snow depth. Figure 3 provides a summary of rainfall and temperature data for Station 234544 (Kirksville, MO) based on 30 year totals (1971 – 2000) (NOAA, 2009). The annual average precipitation and temperature over the thirty year period is 37.1 inches and 50.8º Fahrenheit, respectively. Climate data is an important input parameter for the QUAL2K water quality model. These nearby weather stations will provide useful information and data used for water quality modeling. The climate data is used for simulating stream temperature which impacts the growth of algae, decay of carbonaceous biochemical oxygen demand (CBOD), transformations of nutrients and solubility of DO.

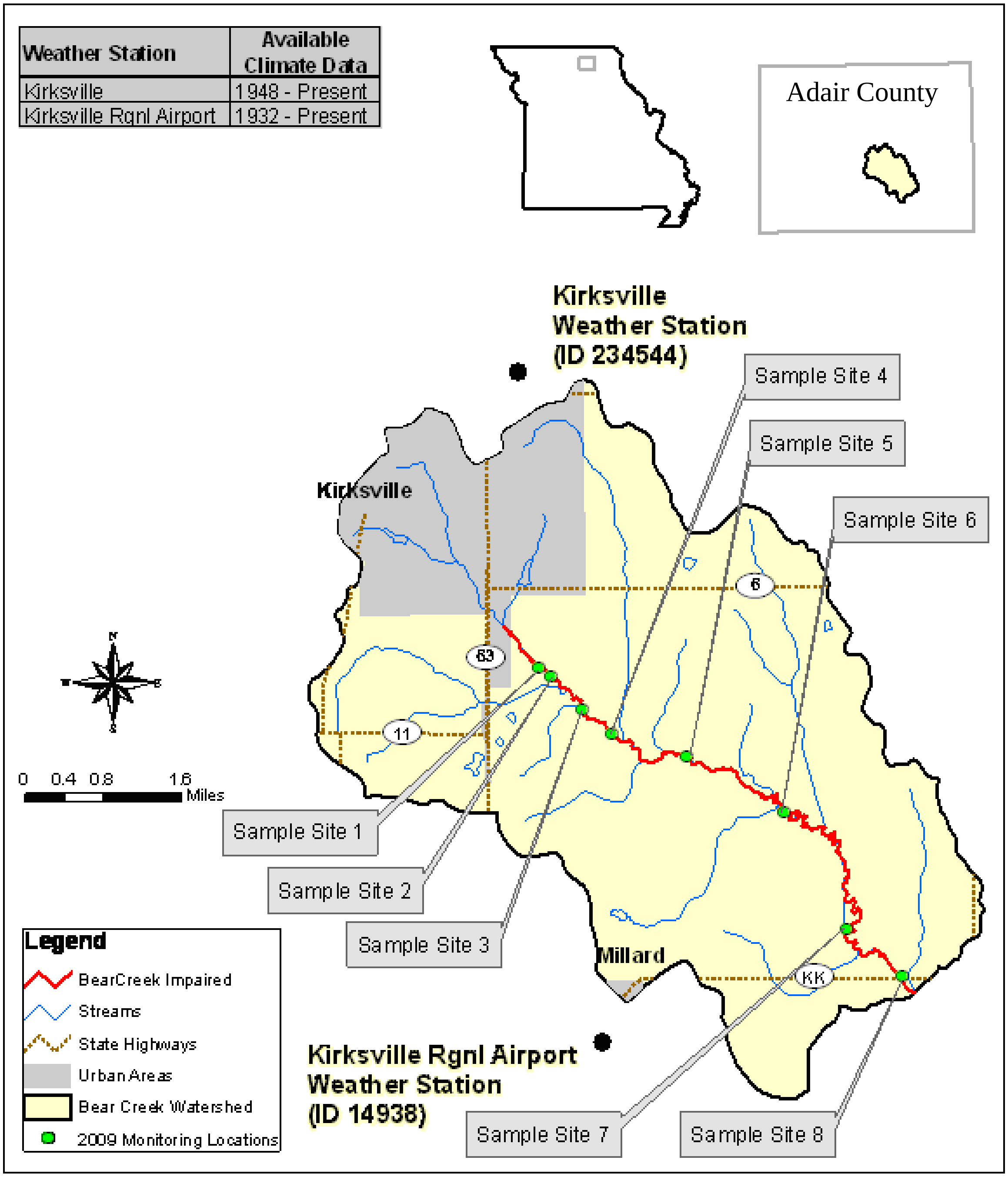

Figure 2. Location of Bear Creek Watershed with Weather Stations

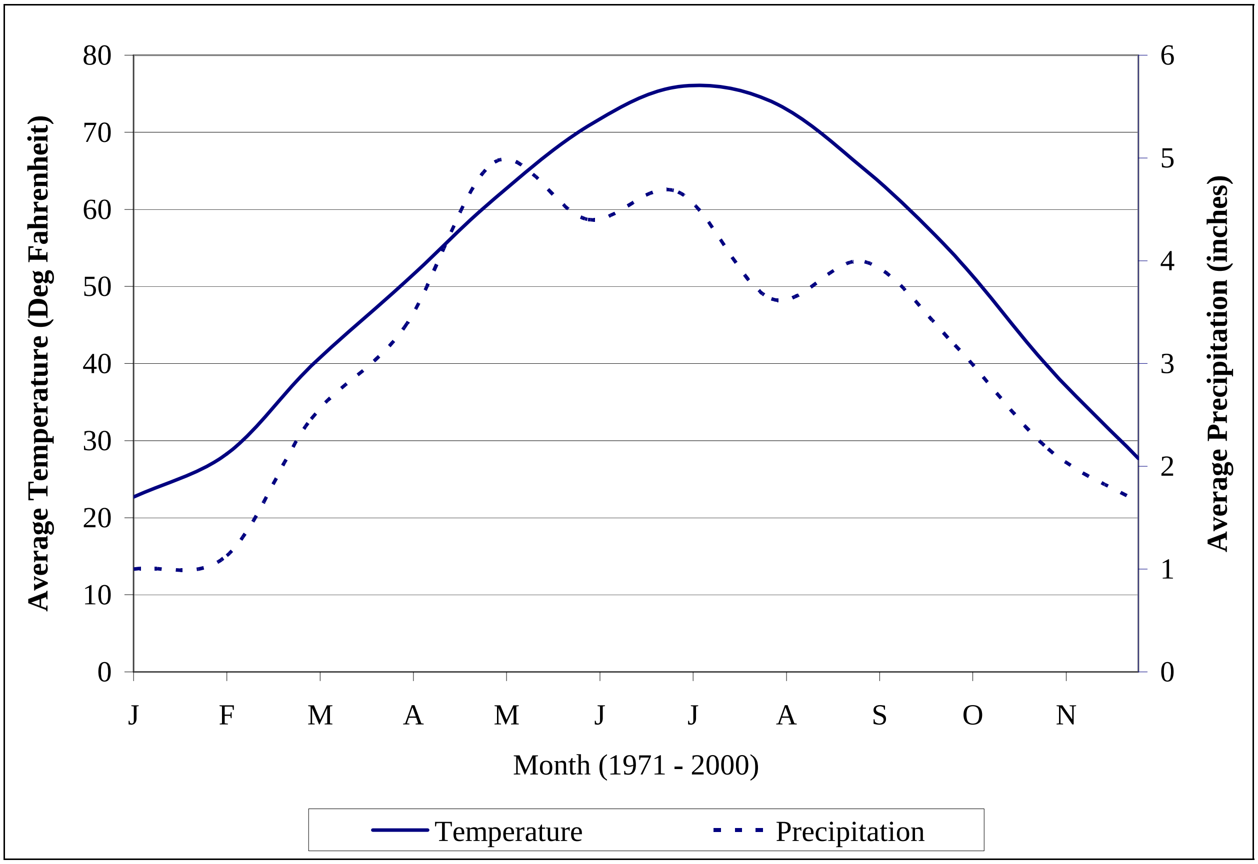

Figure 3. Thirty-year monthly temperature and precipitation averages at Station 234544 (Kirksville, MO) (NOAA, 2009)

2.4 Population

Population data for the Bear Creek watershed is not directly available. However, the US Census Bureau reports that the 2000 population for Kirksville and Millard were 16,988 and 75, respectively (US Census Bureau, 2000). The urban population of the watershed can be estimated by multiplying the percent of urban area (Kirksville and Millard municipal boundaries) that are within the watershed by the individual population of each urban area. Based on these assumptions the urban population of the Bear Creek watershed is approximately 7,459.

The rural population of the watershed can be estimated based on the proportion of the watershed compared to Adair County. Adair County covers an area of 569.32 square miles and has a population of 24,977. The rural population in Adair County is approximately 7,914 people (total county population minus Kirksville and Millard population) and the rural county area is 557.28 square miles (total county area minus county urban area). The Bear Creek watershed rural population was estimated to be 320 persons; calculated by dividing the rural watershed area (22.5 square miles) by the Adair County rural area (557.28 square miles) and multiplying the product by the Adair County rural population (7,914). The total estimated population of the Bear Creek watershed is approximately 7,779. An overall population density for the Bear Creek watershed was calculated to be 288 persons per square mile (7,779 persons divided by 27 square miles).

2.5 Land Use and Land Cover

The land use and land cover of the Bear Creek watershed is shown in Figure 4 and summarized in Table 2 (MoRAP, 2005). The primary land uses/land covers are grassland (56.3 percent), cropland (14.6 percent) and forest (10.4 percent). Other land uses include low intensity urban, herbaceous, impervious, wetland, open water, high intensity urban and barren or sparsely vegetated areas with percentages as found in Table 2.

Table 2. Land Use/Land Cover in the Bear Creek Impaired Watershed (MoRAP, 2005)

Land Use/Land Cover	Watershed Area		Percent of Watershed Area
	Acres	Square Miles	
Impervious[5]	508	0.79	2.9
High Intensity Urban[6]	99	0.15	0.6
Low Intensity Urban[7]	1,201	1.88	6.9
Barren or Sparsely Vegetated	28	0.04	0.2
Cropland	2,534	3.96	14.6
Grassland	9,794	15.30	56.3
Forest	1,802	2.82	10.4
Herbaceous[8]	755	1.18	4.3
Wetland	451	0.71	2.6
Open Water	230	0.36	1.3
Total	**17,402**	**27.19**	**100**

Note: MoRAP = Missouri Resource Assessment Partnership

5 Impervious land use includes non-vegetated, impervious surfaces including areas dominated by streets, parking lots and buildings (MoRAP, 2005).

6 High Intensity Urban land use includes vegetated urban environments with a high density of buildings (MoRAP, 2005).

7 Low Intensity Urban land use includes vegetated urban environments with a low density of buildings (MoRAP, 2005).

8 Herbaceous land use includes open woodland and woody shrubland (including young woodland) with less than 60 percent vegetated cover (MoRAP, 2005).

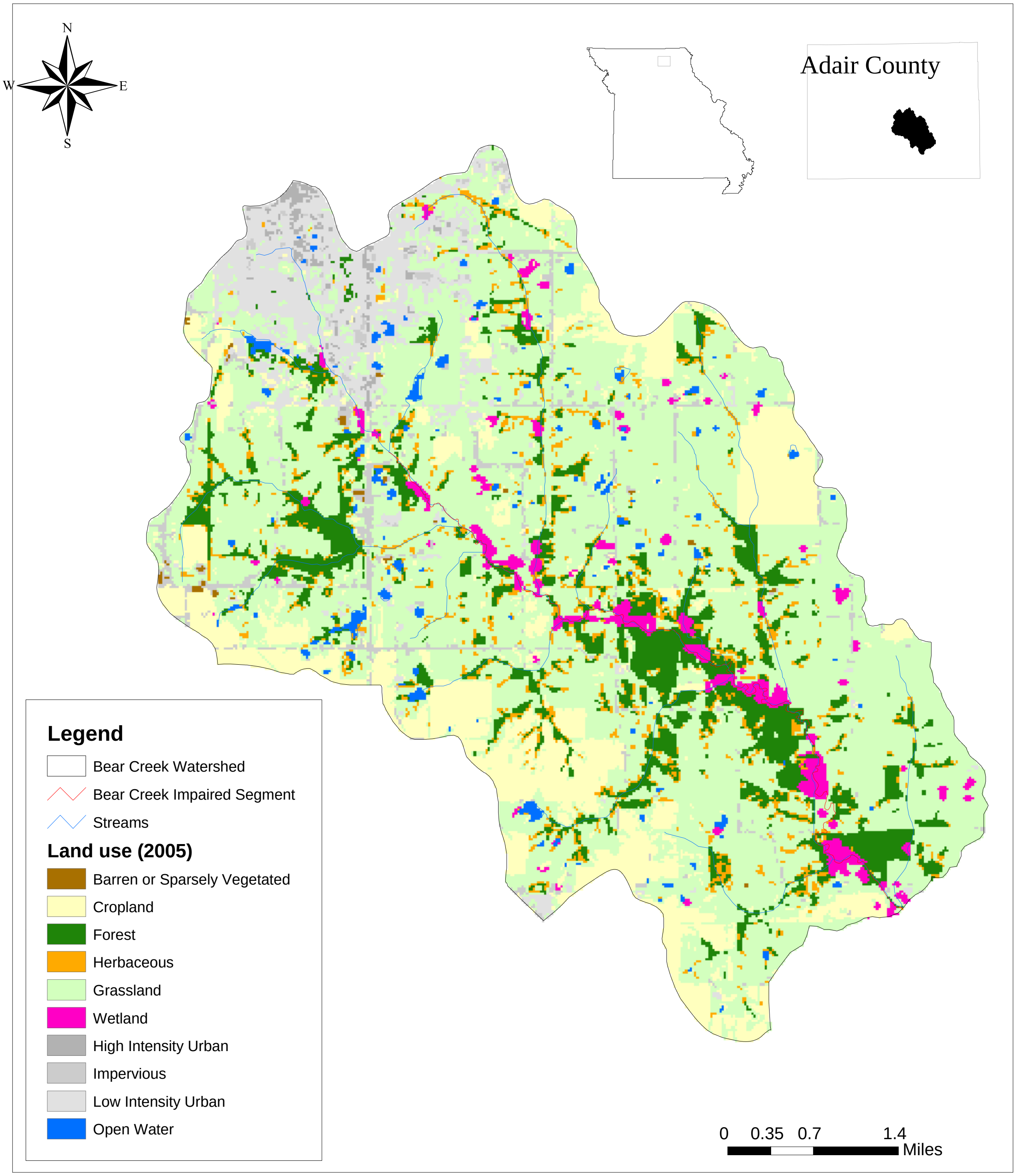

Figure 4. Land Use and Land Cover in the Impaired Bear Creek Watershed (MoRAP, 2005)

3 Defining the Problem

Bear Creek is impaired due to exceedances of Missouri's general water quality criteria for protection of aquatic life and biological aquatic communities (10 Code of State Regulations [CSR] 20-7.031(3)). Historic water quality data collected in August 1978, August 1995 and August 2002 show dissolved oxygen (DO) concentrations below 5 milligrams per liter (mg/L) in 18 of 36 samples collected at various locations in Bear Creek (Table 3 and Appendix A). The WQS for all classified Missouri streams except cold water fisheries require a daily minimum of 5 mg/L DO (10 CSR 20-7.031 Table A [CSR, 2009]). Bear Creek is a warm water stream, but is not a classified water body with the warm water fishery designated use; however, the 5 mg/L minimum criterion represents an appropriate threshold by which aquatic health can be evaluated.

Table 3. Summary of Historical DO Data for Bear Creek

Survey Date	Number of Samples	Minimum (mg/L)	Average (mg/L)	Maximum (mg/L)	Percentage of Samples < 5 mg/L
August 1978	16	2.4	4.9	9.9	56
August 1995	10	1.9	5.6	10	40
August 2002	10	3.2	4.9	7.6	50

Source: The Missouri Department of Natural Resources (MDNR)

3.1 Dissolved Oxygen and Aquatic Life

The amount of DO in water is one of the most commonly used indicators of river and stream health. Fish, mussels, macroinvertebrate and all other aquatic life utilize DO to create energy and metabolize food. Under extended hypoxic (low DO) or anoxic (no DO) conditions, many higher forms of life are driven off or die.

DO in streams is affected by several factors including water temperature, the amount of decaying matter (i.e. organic sediment) in the stream, turbulence at the air-water interface and the amount of photosynthesis occurring in plants within the stream. Excessive nitrogen and phosphorus loading to water bodies can also contribute to DO problems because they can accelerate algal growth.

Algae growth in streams is most frequently assessed based on the amount of chlorophyll-*a* in the water or attached to the stream bottom. Algal growth is affected by numerous biotic and abiotic factors including light availability, flow and water velocity, nutrients (particularly nitrogen and phosphorus), grazing and other influences. Algae consume DO during respiration and have the potential to depress DO concentrations in the stream. The breakdown of dead, decaying algae also removes oxygen from water. The most common approach to reducing excessive algal growth involves controls on activities that contribute nitrogen and phosphorus to the water body.

Organic sediment can also contribute to fluctuating DO concentrations. High levels of organic sediment can contribute to deposits along stream beds which smother aquatic invertebrates and fish eggs and cause offensive odors and unsightliness. Decaying matter (also known as organic sediment) can come from wastewater effluent as well as agricultural and urban runoff and is typically measured instream as biochemical oxygen demand (BOD). Decaying matter can also accumulate on the bottom of a stream and cause sediment oxygen demand (SOD). SOD is a combination of all of the oxygen-consuming processes that occur at or just below the sediment/water interface. SOD is partly due to biological processes and partly due to chemical processes. Most of the SOD at the surface of the sediment is due to the biological decomposition of organic material and the bacterially facilitated nitrification of ammonia (NH_3), while SOD found several centimeters into the sediment is often dominated by the chemical oxidation of species such as iron, manganese and sulfide (Wang, 1980; Walker and Snodgrass, 1986).

3.1.1 Total Nitrogen and Total Phosphorus

An overabundance of nutrients, in particular nitrogen and phosphorus, is a serious threat to aquatic ecosystems. Excess nutrients support rapid algal growth, also referred to as algal blooms, which will cause significant changes to the water body. This phenomenon is called eutrophication. Eutrophication is the natural aging of lakes or streams caused by nutrient enrichment. Cultural eutrophication is the accelerated aging of the natural condition caused by human activities. Nutrient-related water quality issues include the following:

- Proliferation of nuisance algae and the resulting unsightly and harmful bottom deposits;
- Turbidity due to suspended algae and the resulting green color;
- Organic enrichment when algal blooms die off, which perpetuates the cycle of excessive plant growth; and
- Low DO caused by extreme swings in oxygen production by over abundant plant life and oxygen depletion resulting from the decomposition of algae and other plants which can have a negative impact on aquatic organisms.

Missouri does not have numeric criteria for total nitrogen (TN) and total phosphorus (TP) in freshwater streams; therefore, targets and LCs are based on EPA-recommended Ecoregion 40 criteria and water quality observations at locations throughout the ecoregion (EPA, 2000). Reference conditions for TN and TP in level III Ecoregion 40 streams are as follows: TN = 0.855 mg/L and TP = 0.092 mg/L. For this TMDL, recommended TN and TP ecoregion criteria are used directly in developing LCs for TN and TP. A detailed discussion of the method used to develop the TN and TP targets is provided in Appendix D of this report.

3.2 Water Quality and Aquatic Life Conditions in Bear Creek

In 2001, a fishery study conducted by the Missouri Department of Conservation (MDC) in Bear Creek and North Fork Salt River (a Bear Creek reference reach) found there to be reduced numbers of riffle fish species in Bear Creek (MDC, 2001). This finding prompted MDNR to include Bear Creek on the 2002 Missouri 303(d) List of impaired waters.

In July and August 2009, two 48-hour WLA studies were conducted on Bear Creek during summer ambient low-flow conditions. Each of the 48-hour studies consisted of the collection of one early morning (e.g., 05:00-07:30) and one early afternoon (e.g., 12:00-14:30) grab sample at each of seven sampling locations (Figure 5), over a consecutive two-day period.

The first WLA study was conducted July 14 and July 15, 2009 while the second WLA study was conducted on August 25 and August 26, 2009. A detailed summary of monitoring activities conducted during these periods is provided in a separate report (EPA, 2009). Results from the monitoring are provided in Table 4 through Table 8 and are discussed in this section.

In both of the 48-hour sampling events, temperature and DO generally displayed lower values in the early morning and higher values in the afternoon. At all locations throughout both sampling events pH readings ranged from 6.52 to 8.46. These values are consistent with those typically expected for a surface water body. Ammonia (NH_3) was only detected in one sample at one location at a level slightly above the laboratory reporting limit. Concentrations of nitrite+nitrate (NO_2+NO_3), total kjeldahl nitrogen (TKN), TN (calculated by adding the NO_2+NO_3 and the TKN concentrations), TP and CBOD during both of the 48-hour WLA sampling events were lowest at sample location #1 upstream of the Kirksville Wastewater Treatment Plant (WWTP). Concentrations of these analytes were highest at the two locations (sample locations #2 and #4) immediately below the Kirksville WWTP and concentrations decreased with an increase in distance downstream. Total suspended solids (TSS) data was only collected only during the August WLA event and concentrations were relatively consistent across sample locations.

During the 2009 sampling events, macroinvertebrate samples were collected using a multi-habitat (pool, large woody debris and rootmat) sampling approach. Four metrics were calculated for each of the three habitat types within a stream reach. These included: taxa richness (TR), Ephemeroptera/Plecoptera/Trichoptera taxa index (EPT), biotic index (BI) and Shannon diversity index (SDI). An underlying assumption in interpreting metric values based on the macroinvertebrate community is that a healthy macroinvertebrate community is a reflection of healthy stream conditions. The calculated metric values for Bear Creek do not provide clear indications of good versus poor macroinvertebrate community/stream health for a given reach(es). Of the seven stream reaches sampled, calculated TR, EPT, BI and SDI metric values for the most downstream location (#8) on Bear Creek indicate that, for the pool habitat, this reach has the greatest overall community/stream health (i.e., community health, water quality, few pollutant tolerant species, community richness and evenness). Specifically, the pool sample collected at reach #8 had the best (i.e., highest) SDI value of all pool samples collected on Bear Creek. The pool sample collected at reach #8 had the second best (i.e., highest) TR and EPT values and the third best (i.e., lowest) BI value of all pool samples collected. Likewise, reach #6 had the greatest overall community/stream health for the large woody debris habitat and stream reach #2 (immediately downstream of the Kirksville WWTP outfall) had the greatest overall community/stream health for the rootmat habitat. Stream reach #6 had the highest habitat score and reach #2 had the lowest habitat score of the seven stream reaches assessed. Despite the lack of habitat at stream reach #2, the metric values for macroinvertebrates collected from the rootmat habitat here indicate good community health.

TR, EPT, BI and SDI metrics were used to determine stream condition index (SCI) values for the Bear Creek reaches. The SCI is Missouri's adopted method to measure aquatic biological integrity by comparing a study stream to at least ten reference streams in the same ecoregion as the study stream. Macroinvertebrate samples were collected at seven reaches that correspond to the sampling locations shown in Figure 5. Reach #2 had the lowest SCI score

(12). Reaches #4, #5 and #6 each had a score of 14. The SCI scores were highest (16) at stream reaches #1, #7, #8 and the duplicate sample at stream reach #6. These SCI scores indicate that stream reaches #2, #4 and #5 are partially supporting, stream reach #6 is partially to fully supporting and stream reaches #1, #7 and #8 are fully supporting of the aquatic life use, when compared against reference streams in the same ecoregion.

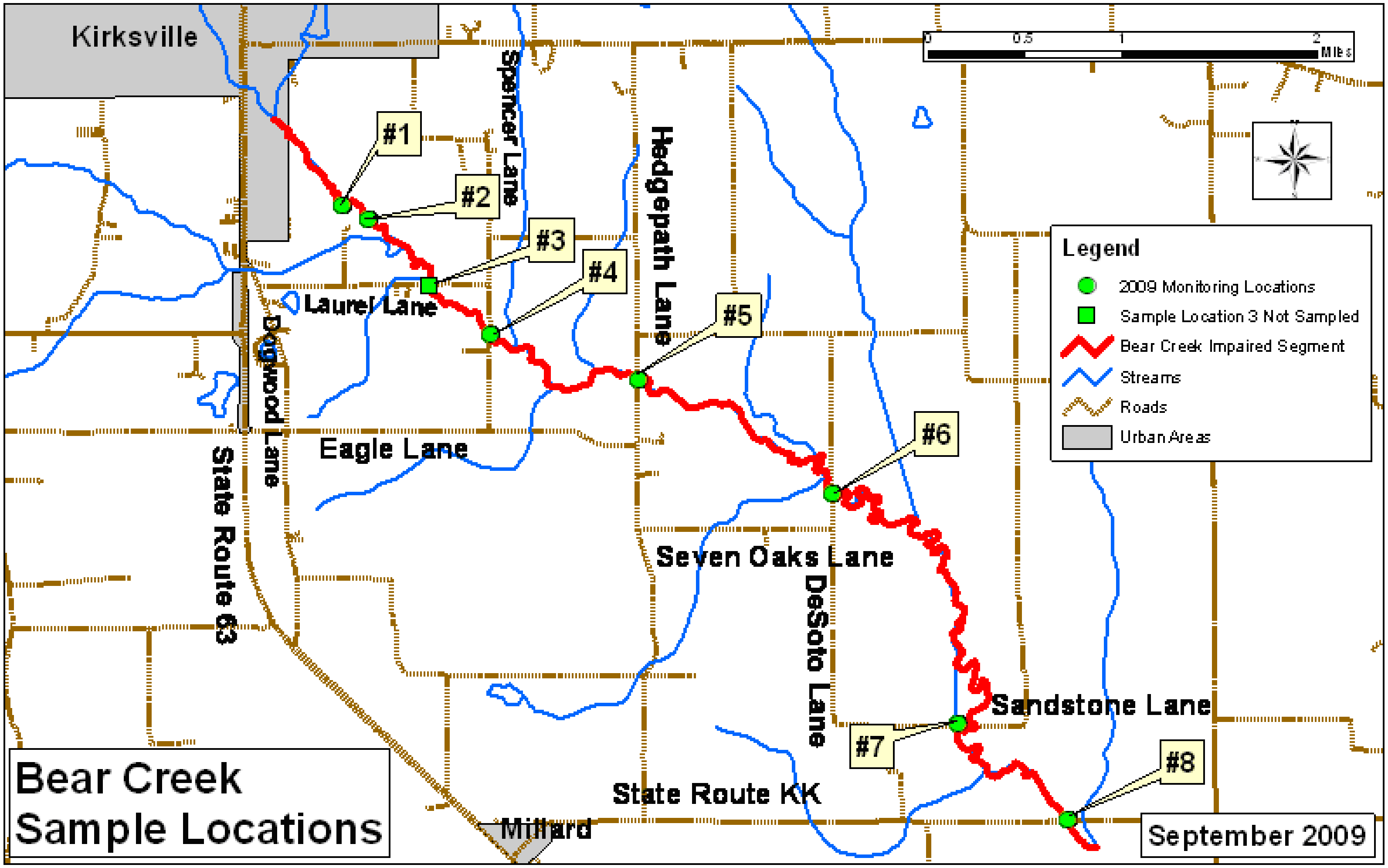

Figure 5. July 2009 and August 2009 Bear Creek sampling site locations

Given the relationship between DO and biological activity, feeding and reproduction it is likely that low DO conditions in Bear Creek contribute to a decline in fish species and benthic invertebrate health. Potential contributors to low DO in Bear Creek include the following:

- Excessive loads of decayable matter, as measured by BOD and/or CBOD
- Too much algae in the stream as a result of excessive nutrient loading
- High consumption of oxygen from decaying matter on the streambed

The Kirksville WWTP is a known contributor of nutrients and CBOD to the stream; however, low DO concentrations in portions of Bear Creek upstream of the Kirksville WWTP suggest there are additional sources. Section 4 of this report provides a summary and assessment of potential sources of nutrients and oxygen demanding substances in the watershed.

The upstream impairments may be due to low flows, excessive algal growth and/or natural or nonpoint source loads of BOD, CBOD and nutrients. Excessive algal growth has a direct impact on diurnal, or daily, DO fluctuations. Higher DO in stream during the daylight hours are due to algal photosynthesis processes and lower DO concentrations during the night are due to plant respiration. These diurnal swings in DO could cause instream DO to fall below Missouri's WQS minimum DO criterion. In addition to the direct effect of low DO on aquatic life, the magnitude of the diurnal swing could have a stressing effect on aquatic life if it is large.

Table 4. Summary of Bear Creek Water Quality Data Collected on July 14, 2009

Sample Location	Time	Flow (cms)	Velocity (m/sec)	$CBOD_5$ (mg/L)	NH_3 Nitrogen, (mg/L)	TKN Nitrogen, (mg/L)	NO_2+NO_3 Nitrogen, (mg/L)	DO (mg/L)	pH	Temp. (°C)	TP (mg/L)	CL (mg/L)
1	6:15 AM	0.002	0.002	ND	< 0.5	0.771	0.166	3.8	7.72	21.79	0.06	89.90
1	12:55 PM	0.191	0.118	2.3	< 0.5	0.9365	0.202	5.92	7.46	21.97	0.10	71.05
2	6:50 AM	0.078	0.110	ND	< 0.5	3.0245	8.815	6.16	7.66	22.41	7.50	165.00
2	1:50 PM	0.380	0.244	6.3	< 0.5	2.5015	5.180	6.68	7.74	23.2	4.60	122.00
4	5:40 AM	0.069	0.077	ND	< 0.5	2.669	9.380	5.07	7.56	21.93	7.70	171.00
4	12:25 PM	0.156	0.120	6.9	< 0.5	2.784	7.420	5.59	7.62	21.9	7.30	157.00
5	5:13 AM	0.107	0.029	ND	< 0.5	2.162	7.830	3.33	7.43	22.97	5.50	138.00
5	12:00 PM	0.121	0.035	6	< 0.5	2.205	8.610	4.65	7.56	22.1	6.70	154.00
6	6:15 AM	0.063	0.023	ND	< 0.5	1.752	7.180	4.2	7.68	22.43	4.50	126.00
6	1:15 PM	0.053	0.020	4.1	< 0.5	1.56	5.310	5.1	7.79	22.51	3.70	107.00
7	5:45 AM	0.080	0.042	ND	< 0.5	2.102	6.660	5.52	7.91	22.54	5.65	132.50
7	12:40 PM	0.079	0.039	3.3	< 0.5	1.941	5.820	9.13	8.03	22.49	5.50	129.00
8	5:05 AM	0.078	0.019	ND	< 0.5	1.555	6.370	5.05	7.94	22.56	4.20	147.00
8	12:02 PM	0.131	0.028	3.2	< 0.5	1.594	6.100	7.63	8.15	22.4	5.30	143.20

Notes: cms = cubic meters per second; m/sec = meters per second; $CBOD_5$ = Carbonaceous Biochemical Oxygen Demand (5 days); TKN = Total Kjeldahl Nitrogen; NO_2+NO_3 = Nitrite + Nitrate; DO = Dissolved Oxygen; Temp. = Temperature in degrees Celsius; TP = Total Phosphorus; CL = Chloride; ND = No Data. Method Detection Limits: $CBOD_5$ = 0.2 mg/L, NH_3 = 0.5 mg/L, TKN = 0.1 mg/L, NO_2 + NO_3 = 0.01 mg/L, TP = 0.003 mg/L, CL = 1.0 mg/L

Table 5. Summary of Bear Creek Water Quality Data Collected on July 15, 2009

Sample Location	Time	Flow (cms)	Velocity (m/sec)	$CBOD_5$ (mg/L)	NH_3 Nitrogen, (mg/L)	TKN Nitrogen, (mg/L)	NO_2+NO_3 Nitrogen, (mg/L)	DO (mg/L)	pH	Temp. (°C)	TP (mg/L)	CL (mg/L)
1	6:15 AM	0.006	0.005	ND	< 0.5	0.844	0.3	3.98	6.52	23.31	0.102	39.47
1	12:55 PM	0.013	0.011	1.6	< 0.5	0.64	0.281	2.27	7.58	24.22	0.072	38.67
2	6:50 AM	0.075	0.101	ND	< 0.5	2.105	11.73	6.15	7.68	23.32	5.2	100.00
2	1:50 PM	0.098	0.126	4.7	< 0.5	2.755	8.67	7.02	7.8	25.48	4.7	117.00
4	5:40 AM	0.086	0.082	ND	< 0.5	2.7505	9.24	5.77	7.54	23.1	4.35	104.00
4	12:25 PM	0.108	0.093	5.5	< 0.5	2.371	7.955	5.22	7.61	24.5	4.4	95.00
5	5:13 AM	0.130	0.034	ND	< 0.5	1.918	8.31	5.43	7.31	23.4	4.7	92.00
5	12:00 PM	0.109	0.031	4.9	0.55	2.243	5.81	3.13	7.61	24.58	3.2	98.00
6	6:15 AM	0.089	0.030	ND	< 0.5	2.019	8.34	4.4	7.54	23.39	6.5	141.00
6	1:15 PM	0.073	0.026	3.8	< 0.5	1.512	6.02	7.54	7.75	25.14	4.4	123.00
7	5:45 AM	0.118	0.056	ND	< 0.5	1.54	6.59	6.09	7.74	23.61	5.1	130.00
7	12:40 PM	0.091	0.044	4.1	< 0.5	1.6575	7.42	10.77	8.17	25.66	5.2	147.00
8	5:05 AM	0.169	0.035	ND	< 0.5	1.425	5.625	6.07	7.76	23.48	3.6	108.55
8	12:02 PM	0.130	0.028	3.0	< 0.5	1.489	6.22	9.97	8.46	26.19	3.8	137.10

Notes: See Table 4

Table 6. Summary of Bear Creek Water Quality Data Collected on August 25, 2009

Sample Location	Time	Flow (cms)	Velocity (m/sec)	$CBOD_5$ (mg/L)	NH_3 Nitrogen, (mg/L)	TKN Nitrogen, (mg/L)	NO_2+NO_3 Nitrogen, (mg/L)	DO (mg/L)	pH	Temp. (°C)	TP (mg/L)	CL (mg/L)
1	8:05 AM	0.034	0.029	0.9	< 0.5	0.553	0.173	7.8	7.67	19.2	0.06	25.46
1	14:35 PM	ND	ND	1.4	< 0.5	0.671	0.184	7.8	7.14	20.5	0.05	25.33
2	7:30 AM	0.094	0.085	7.4	< 0.5	2.125	10.050	9.2	7.72	21.1	5.45	134.65
2	13:20 PM	ND	ND	7.55	< 0.5	2.4525	11.400	6.4	7.79	23.5	6.25	137.70
4	6:50 AM	0.081	0.108	6.6	< 0.5	2.102	10.400	7.2	7.66	20.1	5.90	142.00
4	12:45 PM	ND	ND	6.4	< 0.5	2.192	9.500	6.1	7.6	22.2	5.40	122.90
5	5:45 AM	0.134	0.034	5.45	< 0.5	2.08	9.300	7	7.63	20.7	5.00	134.30
5	12:10 PM	ND	ND	5.2	< 0.5	2.1635	ND	8.42	7.35	21.2	5.40	129.70
6	7:15 AM	ND	ND	3.1	< 0.5	1.481	7.000	9.66	7.54	19.6	2.90	87.90
6	13:30 PM	0.129	0.048	3.75	< 0.5	1.507	7.567	8.99	7.54	21.7	3.73	101.60
7	6:40 AM	ND	ND	2.6	< 0.5	1.274	6.800	11.63	7.65	19.3	2.60	87.20
7	12:50 PM	0.155	0.076	2.5	< 0.5	1.138	7.700	10.34	7.82	22.1	2.60	84.90
8	5:35 AM	ND	ND	2.5	< 0.5	1.198	5.700	11.96	7.51	19	1.90	69.50
8	12:05 PM	0.157	0.054	2.2	< 0.5	1.241	7.750	7.8	7.96	22.3	2.30	80.00

Notes: See Table 4

Table 7. Summary of Bear Creek Water Quality Data Collected on August 26, 2009

Sample Location	Time	Flow (cms)	Velocity (m/sec)	$CBOD_5$ (mg/L)	NH_3 Nitrogen, (mg/L)	TKN Nitrogen, (mg/L)	NO_2+NO_3 Nitrogen, (mg/L)	DO (mg/L)	pH	Temp. (°C)	TP (mg/L)	CL (mg/L)
1	6:55 AM	ND	ND	1.05	< 0.5	0.762	0.152	6	7.61	21.3	0.05	28.40
1	14:45 PM	0.023	0.018	1.1	< 0.5	0.516	0.187	6.4	7.21	21.6	0.05	35.32
2	6:25 AM	ND	ND	6.2	< 0.5	2.29	8.700	7.3	7.64	22.4	5.90	125.10
2	14:15 PM	0.155	0.117	6.3	< 0.5	2.373	8.900	9	7.75	23.9	7.10	150.20
4	6:00 AM	ND	ND	5.8	< 0.5	3.248	11.100	5.8	7.55	21.9	5.80	125.40
4	12:35 PM	0.148	0.113	5.4	< 0.5	1.998	9.600	6.5	7.51	22.8	5.60	124.10
5	5:25 AM	ND	ND	4.4	< 0.5	2.083	10.450	5.3	7.51	22.5	5.55	128.60
5	12:00 PM	0.185	0.049	4.8	< 0.5	2.479	9.800	6.1	7.24	22.2	5.30	129.00
6	6:40 AM	0.161	0.060	3.9	< 0.5	1.907	8.700	7.84	7.5	21.3	4.60	124.70
6	13:05 PM	ND	ND	4	< 0.5	1.743	9.000	8.33	7.54	22.4	4.70	121.90
7	6:00 AM	0.168	0.080	2.5	< 0.5	1.759	7.200	8.6	7.61	21.2	3.20	102.20
7	12:35 PM	ND	ND	3	< 0.5	1.674	7.800	9.35	7.74	22.3	4.30	121.60
8	5:29 AM	0.184	0.071	2.2	< 0.5	1.519	6.800	8.5	7.56	21.1	2.60	85.80
8	12:02 PM	ND	ND	2.3	< 0.5	1.588	7.200	10.03	7.79	22.3	3.00	97.00

Notes: See Table 4

4 Source Inventory

A source assessment is used to identify and characterize the known and suspected pollutant sources contributing to the impairment in Bear Creek. For the purpose of this report, sources have been divided into two broad categories; point sources and nonpoint sources. Point sources can be defined as sources, either constant or time transient, which occur at a fixed location in a watershed. Nonpoint sources are generally accepted to be diffuse sources not entering a water body at a specific location. Nutrients and oxygen consuming substances from both point and nonpoint sources are considered to be the most likely potential contributors to impairment in Bear Creek and as such will be the focus of this TMDL effort. Historic water quality data used to identify and assess sources is presented in Appendix A of this document.

4.1 Point Sources

The term "point source" refers to any discernible, confined and discrete conveyance, such as a pipe, ditch, channel, tunnel or conduit, by which pollutants are transported to a water body. For the purposes of TMDL development, point sources are defined as sources regulated through the National Pollutant Discharge Elimination System (NPDES) program. Missouri has its own program for administering the NPDES program, referred to as the Missouri State Operating Permit (MSOP) system. The NPDES and MSOP programs are the same and for the purposes of this document the term "NPDES" will be used. The following NPDES-regulated entities are included in this source category:

- Municipal and industrial wastewater treatment plants (e.g. WWTPs),
- Concentrated animal feeding operations (CAFOs),
- Storm water runoff from Municipal Separate Storm Sewer Systems (MS4s) and

- General permitted facilities (including storm water runoff from construction and industrial sites).

General permits (as opposed to site specific permits) are issued to activities that are similar enough to be covered by a single set of requirements. Storm water permits are issued to activities that discharge only in response to precipitation events. Point sources in the Bear Creek watershed were identified by consulting EPA's Permit Compliance System (PCS) website[9] and MDNR's GIS inventory[10] of NPDES permitted facilities covered under storm water or general permits.

Point sources in the Bear Creek watershed are listed in Table 8 and shown in Figure 6. Of those listed, two are site specific permits, one is a general permit and the remaining seven are storm water permits. Only three permittees are required to monitor and report effluent or storm water concentrations.

The city of Kirksville WWTP (MO0049506) is located in Kirksville, Missouri. The current operating permit became effective February 2006 and expires February 2011. The facility was designed to accommodate a population of 34,000 people with a design flow of 3.16 million gallons per day (MGD) and sludge production of 1,162 dry tons sludge/year. The facility maintains two outfalls: outfall #001 is the primary discharge while outfall #002 is a discharge from a flow equalization basin.

The Burk Subdivision WWTP (MO0107557) is located in Kirksville, Missouri. The current operating permit became effective November 2006 and expires November 2011. The facility was designed to accommodate a population of 125 people with a design flow of 11,100 gallons per day and sludge production of 1.875 dry tons sludge/year. The facility maintains one outfall, outfall #001 which is the primary discharge. Relative to stream flows and other dischargers this WWTP is small and likely has minimal impact on DO and nutrients during low flow periods.

The MFA Oil Company (MOG350241) is a general permit located in Kirksville, Missouri. The current operating permit became effective September 2007 and expires June 2012. The permit is for storm water discharges from facilitates with above ground storage capacity of pre-consumer or post-consumer petroleum products, ethanol or biodiesel totaling more than 20,000 gallons, but less than 250,000 gallons. Since the permit is for storm water discharges it will likely have a minimal impact on DO concentrations in the stream as the majority of DO exceedances were present during low flow conditions. However, it is possible that the permit may have an impact on organic sediment and SOD.

[9] www.epa.gov/enviro/html/pcs/index.html
[10] http://msdis.missouri.edu/datasearch/ThemeList.jsp; GIS layers updated May 2009 and June 2009 (EPA, 2009a)

Table 8. Permitted Facilities in the Bear Creek Watershed

Facility ID	Facility Name[1]	Receiving Stream	Classification/ Description	Reporting Requirements[2]	Design Flow (MGD)[3]	Permit Expiration Date
MO0049506	Kirksville WWTP	Unnamed Tributary to Bear Creek	Municipal WWTP	pH, Unionized NH_3, Total NH_3, TSS, flow, BOD_5, Temperature, O&G, (monthly effluent reporting); WET (annual reporting)	3.16	2011
MO0107557	Burk Subdivision WWTP[3]	Tributaries to Bear Creek	Private WWTP	pH, Unionized NH_3, TSS, Flow, BOD_5, Temperature (quarterly reporting)	0.011	2011
MOG350241	MFA Oil Company	Tributary to Bear Creek	Bulk terminal petroleum station	pH, Flow, O&G, Total Recoverable Oil, ethyl benzene, ethanol (annual, storm water sampling)	General Permit	2012
MOR040078	City of Kirksville	Bear Creek and Tributaries to Bear Creek	MS4	Annual report	Storm Water Permit	2013
MOR80C258	Kirksville UPS	Tributary to Bear Creek	Motor freight transportation	None	Storm Water Permit	2012
MOR10C224	Kirksville Country Club D	Tributary to Bear Creek	Heavy construction	None	Storm Water Permit	2012
MOR10B825	The Coves at Kirksville	Tributary to Bear Creek	Heavy construction	None	Storm Water Permit	2012
MOR104486	Hamilton Meadows Plat 2	Tributary to Bear Creek	Heavy construction	None	Storm Water Permit	2012
MOR10A726	City of Kirksville	Tributary to Bear Creek	Heavy construction	None	Storm Water Permit	2012
MOR10C512	Rockhold Dam and Reservoir	Unnamed tributary to Bear Creek	Heavy Construction	None	Storm Water Permit	2012
MOR10D033	Northeast Pump Station	Unnamed tributary to Steer Creek	Land Disturbance	None	Storm Water Permit	2012
MOR10D162	Dollar General	Unnamed tributary to Bear Creek	Land Disturbance	None	Storm Water Permit	2012
MOR10D439	Pine Brook Subdivision	Unnamed tributary to Bear Creek	Land Disturbance	None	Storm Water Permit	2012

[1] WWTP = Wastewater Treatment Plant
[2] Where NH_3 = Ammonia, BOD5 = 5 day Biochemical Oxygen Demand, TSS = Total Suspended Solids, O&G = Oil and Grease and WET = Whole Effluent Toxicity.
[3] Storm water and general permits identified do not have a design flow.

The city of Kirksville (MOR040078) MS4 permit requires the city to submit an annual report regarding their storm water program; however, there are no specific monitoring requirements at this time. Therefore, there are no data to indicate that the outfall locations for this MS4 permit currently contribute to the impaired water body segment. Upon approval of this TMDL, the MS4 permit may be reopened and modified to include assessment monitoring and pollution control requirements sufficient to characterize and reduce impacts from these discharges.

The Kirksville UPS facility (MOR80C258) is classified as motor freight transportation which authorizes firms engaged in motor freight transportation, warehousing and US Postal Service maintenance facilities to discharge storm water runoff to waters of the state of Missouri with major requirements that discharges are not to cause a exceedance of the state WQS. The primary requirement of the permit is to develop and implement a Storm Water Pollution Prevention Plan (SWPPP). Since the permit is for storm water discharges it will likely have a minimal impact on DO concentrations in the stream during low flow conditions. However, they may contribute organic material to Bear Creek during high flow periods which settle and affects DO via sediment oxygen demand (SOD).

Storm water permits MOR10C224 (Kirksville Country Club D),[11] MOR10B825 (The Coves at Kirksville), MOR104486 (Hamilton Meadows Plat 2), MOR10A726 (City of Kirksville) and MOR10C512 (Rockhold Dam and Reservoir) are classified as heavy construction which is designated as land disturbance including construction or land disturbance greater than one acre. This type of permit authorizes discharge of storm water runoff to waters of the state of Missouri with major requirements that discharges are not to cause a exceedance of the state WQS (10 CSR 20-7.031) and the development and implementation of a SWPPP. Since the permit is for storm water discharges it will likely have a minimal impact on DO concentrations in the stream as the majority of DO exceedances were present during low flow conditions. However, they may contribute organic material to Bear Creek during high flow periods which settle and affects DO via SOD.

Illicit straight pipe discharges of household waste are also potential point sources of the pollutants of concern in rural areas. These sources are discharged directly into streams or land areas and are different than illicitly connected sewers. There is no specific information on the number of illicit straight pipe discharges of household wastes in the Bear Creek watershed. Leaking or illicitly connected sewers can also be a significant source of pollutant loads within urban areas.

[11] MDNR terminated storm water permit MOR10C224 (Kirksville Country Club D) on April 26, 2010.

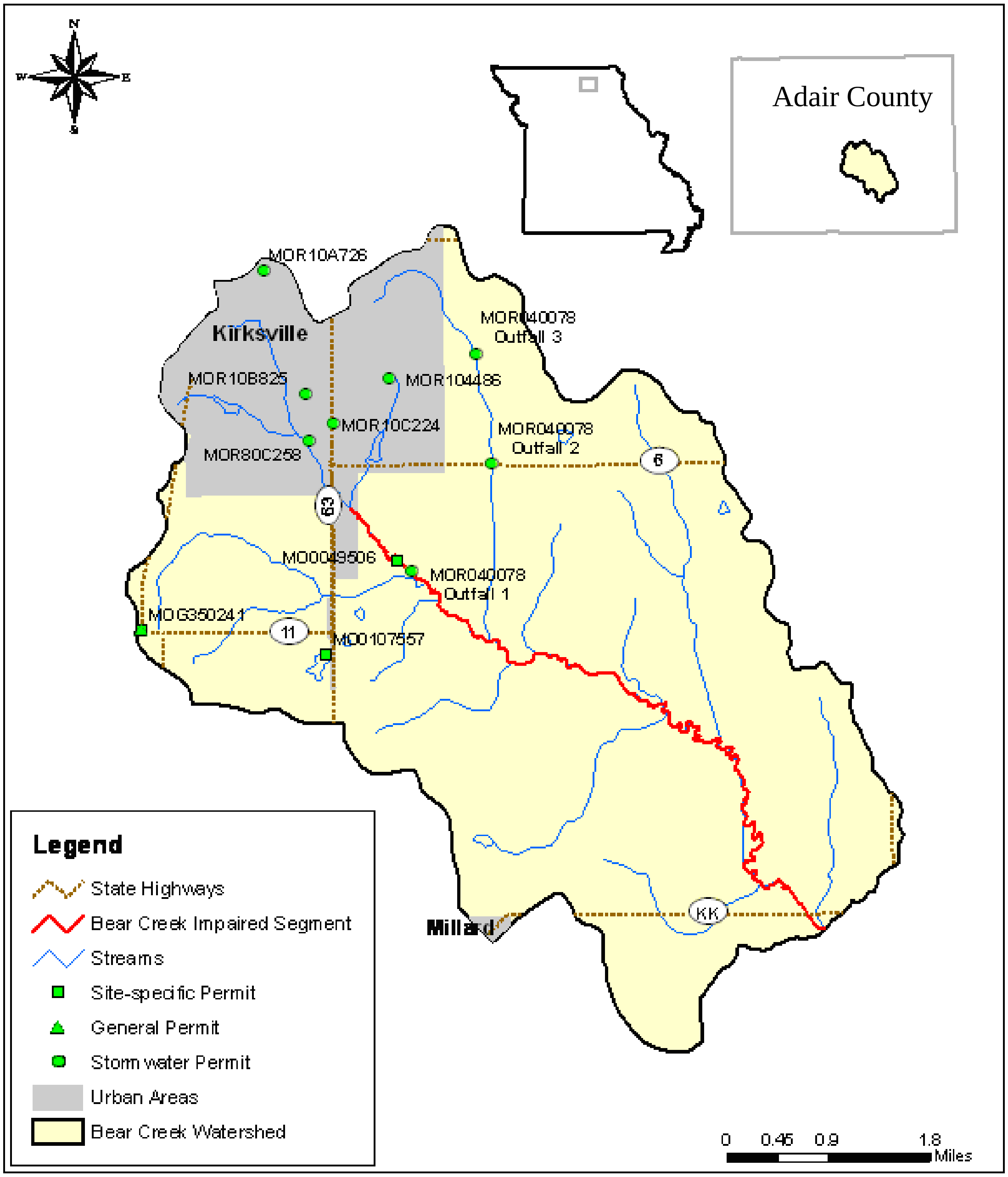

Figure 6. Location of Permitted Facilities in the Bear Creek Watershed

4.1.1 Runoff from MS4 Urban Areas

The city of Kirksville is required to have and comply with an NPDES permit for its storm water drainage system, known as a MS4. The permit requires the city of Kirksville to administer a storm water management program. The storm water program works to minimize the negative water quality impacts of the MS4. The permit contains specific required activities and programs that must be implemented to comply with the permit. The MS4 permit for the city of Kirksville was issued in 2008 and will expire in 2013.

4.2 Nonpoint Sources

Nonpoint sources include all other categories of pollutant sources not classified as point sources. Potential nonpoint sources contributing to low DO problems in the Bear Creek watershed include runoff from agricultural areas, runoff from urban areas, onsite wastewater treatment systems and various sources associated with riparian habitat conditions. Additional discussion of nonpoint sources is provided in the following sections.

Based on the information before us, the decision to apply the discharges associated with unpermitted sources to the LA, as opposed to the WLA for purposes of this TMDL, is acceptable. The decision to allocate these sources to the LA does not reflect any determination by EPA as to whether these discharges are, in fact, unpermitted point source discharges within this watershed. In addition, by approving these TMDLs with some sources treated as LAs, EPA is not determining that these discharges are exempt from NPDES permitting requirements. If sources of the allocated pollutant in this TMDL are found to be, or become, NPDES-regulated discharges, their loads must be considered as part of the calculated sum of the WLA in this TMDL. WLA in addition to that allocated here is not available.

4.2.1 Runoff from Agricultural Areas

Lands used for agricultural purposes can be sources of nutrients and oxygen-consuming substances, such as organic material and chemicals (pesticides and fertilizers). Accumulation of nitrogen and phosphorus on cropland occurs from decomposition of residual crop material, fertilization with chemical and manure fertilizers, atmospheric deposition, wildlife excreta and irrigation water. The 2005 land use and land cover data indicates there are 2,534 cropland acres in the watershed, which comprises 14.6 percent of the entire watershed area (Table 2). In contrast, less than two percent of the riparian buffer is classified as cropland (Table 9).

County-wide data from the National Agricultural Statistics Service (NASS) (USDA, 2007) were combined with the land cover data for the Bear Creek watershed to estimate that there are approximately 2,115 cattle in the watershed[12]. The cattle are most likely located on the approximate 15.3 square miles of grassland/pastureland in the watershed. Runoff from these areas can be potential sources of nutrients and oxygen-consuming substances. Animals grazing in pasture areas deposit manure directly upon the land surface and even though a pasture may be relatively large and animal densities low, the manure will often be concentrated near the feeding and watering areas in the field. These areas can quickly become barren of plant cover, increasing the possibility of erosion and contaminated runoff during a storm event. In addition, when pasture land is not fenced off from the stream, cattle or other livestock may contribute nutrients to the stream while walking in or adjacent to the water body. Although there are no CAFOs in the watershed, the density of cattle in the Bear Creek watershed (138 cattle per square mile or 2,115 cattle in the entire watershed) suggests they are a potential source of pollutants.

[12] According to the National Agricultural Statistic Service there are approximately 37,193 head of cattle in Adair County (USDA, 2007). According to the 2005 MoRAP, there are 269 square miles of grasslands in Adair County (MoRAP, 2005). These two values result in a cattle density of approximately 138 cattle per square mile of grasslands. This density was multiplied by the number of grassland square miles in the Bear Creek watershed to estimate the number of cattle in the watershed.

The National Agricultural Statistic Service reported there were 1,144 hogs and pigs, 1,264 horses and ponies, 920 sheep and lambs and 629 layers in Adair County in 2007 (USDA, 2007). Insufficient information was available to calculate population densities for these animals in the Bear Creek watershed.

Any permitted CAFOs identified in this TMDL are part of the assigned WLA. At this time, animal feeding operations (AFOs) and unpermitted CAFOs are considered under the LA because we do not currently have enough detailed information to know whether these facilities are required to obtain NPDES permits. This TMDL does not reflect a determination by EPA that such facility does not meet the definition of a CAFO nor that the facility does not need to obtain a permit. To the contrary, a CAFO that discharges or proposes to discharge has a duty to obtain a permit. If it is determined that any such operation is an AFO or CAFO that discharges, any future WLA assigned to the facility must not result in an exceedance of the sum of the WLAs in this TMDL as approved.

Any CAFO that does not obtain a NPDES permit must operate as a no discharge operation. Any discharge from an unpermitted CAFO is a violation of Section 301. It is EPA's position that all CAFOs should obtain a NPDES permit because it provides clarity of compliance requirements, authorization to discharge when the discharges are the result of large precipitation events (e.g., in excess of 25-year and 24-hour frequency/duration) or are from a man-made conveyance.

4.2.2 Runoff from non-MS4 Urban Areas

Storm water runoff from impervious surfaces, high intensity urban areas and low intensity urban areas can also be a source of pollutants. Nutrients, organic matter and sediments from urban storm water runoff can contribute to degraded water quality and impact aquatic life. Excessive nutrients from fertilizers, pet waste and urban wildlife can contribute to nuisance algae and macrophyte growth, which may contribute to low DO concentrations. Phosphorus loads from residential areas can be comparable to or higher than loading rates from agricultural areas (Reckhow et al., 1980; Athayde et al., 1983). Organic matter in storm water runoff may originate from failing septic tanks, leaking sewers, yard waste, animal waste and natural organic material. Decomposition of this material consumes oxygen and may reduce DO concentrations in aquatic environments. Storm runoff from urban areas such as parking lots and buildings is also warmer than runoff from grassy and woodland areas, which can lead to higher temperatures that lower the DO saturation capacity of the stream. Excessive discharge of suspended solids from urban areas can also lead to streambed siltation problems and contribute SOD to streams.

Since approximately 10.4 percent of the Bear Creek watershed is classified as either high intensity urban, low intensity urban or impervious (including portions of Kirksville and Millard), urban storm water runoff is considered a potentially significant source of the pollutants that can lead to reduced DO levels.

4.2.3 Onsite Wastewater Treatment Systems

Onsite wastewater treatment systems (e.g., septic systems) that are properly designed and maintained should not serve as a source of contamination to surface waters. However, onsite wastewater treatment systems do fail for a variety of reasons. When these systems fail hydraulically (surface breakouts) or hydrogeologically (inadequate soil filtration) there can be adverse effects to surface waters (Horsley and Witten, 1996). Failing septic systems release nutrients and pathogens that can reach nearby streams through both runoff and groundwater flows.

The exact number of onsite wastewater treatment systems in the Bear Creek watershed is unknown. However, the National Environmental Service Center (NESC) reports that in 1998 there were 3,937 septic systems with an average population per septic system of 2.53 and a septic failure rate of 0.39 percent in the North Fork Salt watershed (HUC 07110005) (EPA, 2009b). As discussed in Section 2.3, the estimated rural population of the Bear Creek watershed is approximately 320 persons. Based on this population and an average density of 2.53 persons per septic system approximately 126 systems are estimated to be in the watershed. Based on a failure rate of 0.39 percent, there is one failing septic system within the Bear Creek watershed (EPA, 2009). EPA reports that the statewide failure rate of onsite wastewater systems in Missouri is between 30 percent and 50 percent (EPA, 2002). Failing onsite wastewater treatment systems could be a significant source of pollutants if the failure rate is closer to the EPA estimates than the NESC estimates. However, since no site specific studies have indicated that localized failure of onsite wastewater treatment systems are a problem in the Bear Creek watershed this source should not be considered a significant source of pollutants.

4.2.4 Riparian Habitat Conditions

Riparian[13] habitat conditions can have a strong influence on instream DO. Therefore, a stream with good riparian habitat is better able to moderate the impacts of high nutrient loads than a stream with poor habitat. Wooded riparian buffers are a vital functional component of stream ecosystems and are instrumental in the detention, removal and assimilation of nutrients from or by the water column. Wooded riparian buffers can also provide shading that reduces stream temperatures and increases the DO saturation capacity of the stream.

Riparian buffers are also sources of natural background material that contributes organic matter to the stream. For example, leaf fall from vegetation near the water's edge, aquatic plants and drainage from organically rich areas like swamps are all natural sources of material that add nutrients and organic matter.

As indicated in Table 9, about two-thirds of the land in the Bear Creek riparian buffer is classified as grassland and wetland (MoRAP, 2005). Grassland provides limited riparian habitat and very little shading compared to wooded areas and, as previously mentioned, can be subject to erosion and nutrient loading associated with livestock activity. Wetlands can play a critical role in regulating the movement of water within watersheds (Mitsch and Gosselink, 1993). Wetlands store precipitation and surface water and then slowly release the water into surface water, ground water and the atmosphere (Mitsch and Gosselink, 1993). Wetlands may be a sink or a source, of nutrients and TSS. They may become a permanent sink if the compounds become buried in the substrate or are released into the atmosphere; or they may retain them only during the growing season or under flooded conditions (Mitsch and Gosselink, 1993). In their natural state, wetlands can provide habitat and food sources for hundreds of plant and animal species and

[13] A riparian corridor (or zone or area) is the linear strip of land running adjacent to a stream bank.

some contribute to water quality (Evans, et al., 1996). Contrary to popular belief, not all wetlands contribute equally to water quality. While some wetlands impede drainage flow from developed land, filtering out pollutants and greatly improving the quality of the water entering streams, others provide no significant water-quality benefits (Evans, et al., 1996).

Low intensity urban and impervious areas are less than one percent of the riparian corridor and are likely insignificant contributors to DO conditions in the creek.

Table 9. Percentage Land Use/Land Cover within Riparian Buffer, 30-Meter (MoRAP, 2005)

Land Use/Land Cover	Percent of Bear Creek Riparian Area (%)
Cropland	1.4
Forest	26.7
Herbaceous[14]	5.0
Grassland	31.7
Impervious	0.4
Low Intensity Urban	0.1
Open Water	0.1
Wetland	34.6

5 Applicable Water Quality Standards and Numeric Water Quality Targets

Section 303(d) of the CWA and Chapter 40 of the CFR Part 130 require states to develop TMDLs for waters not meeting WQS. The TMDL process quantitatively assesses the impairment factors so that states can establish water-quality based controls to reduce pollutants of concern from both point and nonpoint sources and to restore and protect the quality of their water resources.

Under the CWA, every state must adopt WQS to protect, maintain and improve the quality of the nation's surface waters (US Code Title 33, Chapter 26, Subchapter III [US Code, 2009]). These standards represent a level of water quality that will support the CWA's goal of "fishable/swimmable" waters. Missouri's Surface WQS (10 CSR 20-7.031) consist of three components: designated uses, criteria (general and numeric) and an antidegradation policy.

Beneficial or designated uses for Missouri streams are found in the WQS at 10 CSR 20-7.031(1)(C), (1)(F) and Table H (CSR, 2009). Criteria for designated uses are found at 10 CSR 20-7.031, Tables A and B (CSR, 2009)). Missouri's antidegradation policy is outlined at 10 CSR 20-7.031(2) (CSR, 2009).

Historic water quality and aquatic life monitoring studies indicate that low diversity of fish species occurs in the upstream segments of Bear Creek. Nutrients and oxygen consuming

[14] Herbaceous land use includes open woodland and woody shrubland (including young woodland) with less than 60percent vegetated cover (MoRAP, 2005).

substances from both point and nonpoint sources are considered to be potential contributors to the impairment and as such are the focus of this TMDL. Missouri's general water quality criteria consist of eight narrative criteria that must be met for all waters of the state.

5.1 Designated Beneficial Uses

The designated beneficial uses and stream classifications for Missouri are found in the WQS at 10 CSR 20-7.031(1)(C), (1)(F) and Table H available from the Missouri Secretary of State (CSR, 2009). The impaired portion of Bear Creek is in the unclassified headwaters of the stream, so there are no assigned beneficial uses from Table H.

5.2 Criteria

Water quality studies conducted by MDNR during 2001 and 2002 identified low fish diversity in upstream portions of Bear Creek near the Kirksville WWTP outfall (MDNR data provided to URS on April 23, 2009). Since this segment is unclassified, numeric criteria do not apply; however, the general or narrative criteria are applicable. In the 2008 Missouri 303(d) List, Bear Creek is listed as impaired due to unknown pollutants.

All water bodies in Missouri are protected by the general WQS contained in 10 CSR20-7.031(3). The narrative criteria that are not being met in Bear Creek are criteria (3)(D) and (G) from 10 CSR 20-7.031. These are:

- "Waters shall be free from substances or conditions in sufficient amounts to result in toxicity to human, animal or aquatic life," and
- "Waters shall be free from physical, chemical or hydrologic changes that would impair the natural biological community"

Historical water quality studies have found low DO concentrations (<5 mg/L) in Bear Creek. DO less than 5 mg/L is not in compliance with numeric water quality criteria for classified streams and is not protective of aquatic life in unclassified waters where aquatic life exists. A modeling approach is used in this study to characterize the sources contributing to low DO through evaluating nutrient dynamics, algal production and DO during critical, low-flow periods. Missouri's 5 mg/L DO minimum criterion for warm water fisheries is used as the target for quantifying impairment of the above criterion and allowable pollutant loading in Bear Creek.

There are many quantitative indicators of sediment, such as TSS, turbidity and bedload sediment, which are appropriate to describe sediment in rivers and streams (EPA, 2006). A concentration of TSS was selected to represent the numeric target for this TMDL because it enables the use of the highest quality available data and is included in monitoring data. A detailed discussion of the method used to develop the TSS target is provided in Appendix C.

5.2.1 Total Nitrogen and Total Phosphorus

An overabundance of nutrients, in particular nitrogen and phosphorus, is a serious threat to aquatic ecosystems. Excess nutrients support rapid algal growth, also referred to as algal blooms, which will cause significant changes to the water body. This phenomenon is called eutrophication. Eutrophication is the natural aging of lakes or streams caused by nutrient enrichment. Cultural eutrophication is the accelerated aging of the natural condition caused by human activities. Nutrient related water quality issues include the following:

- Proliferation of nuisance algae and the resulting unsightly and harmful bottom deposits;
- Turbidity due to suspended algae and the resulting green color;
- Organic enrichment when algal blooms die off, which perpetuates the cycle of excessive plant growth;
- Low DO caused by extreme swings in oxygen production by over abundant plant life; and oxygen depletion resulting from the decomposition of algae and other plants which can have a negative impact on aquatic organisms.

Missouri does not have a numeric criterion for TN and TP in freshwater streams; therefore targets and LCs are based on EPA-recommended Ecoregion 40 criteria and water quality observations at locations throughout the ecoregion (EPA, 2000). Reference conditions for TN and TP in level III Ecoregion 40 streams are as follows: TN = 0.855 mg/L and TP = 0.092 mg/L. For this TMDL, recommended TN and TP ecoregion criteria are used directly in developing LCs for TN and TP. A detailed discussion of the method used to develop the TN and TP targets is provided in Appendix D of this report.

5.3 Antidegradation Policy

Missouri's WQS include EPA's "three-tiered" approach to antidegradation and can be found at 10 CSR 20-7.031(2) (CSR, 2009). The three tiers are described in this section.

> Tier 1 – Protects existing instream uses and a level of water quality necessary to maintain and protect those uses. Tier 1 provides the absolute floor of water quality for all waters of the United States (US). Existing instream water uses are those uses that were attained on or after November 28, 1975, the date of EPA's first WQS Regulation.
>
> Tier 2 – Protects and maintains the existing level of water quality where it is better than applicable water quality criteria. Before water quality in Tier 2 waters can be lowered, there must be an antidegradation review consisting of: 1) a finding that it is necessary to accommodate important economic and social development in the area where the waters are located; 2) full satisfaction of all intergovernmental coordination and public participation provisions; and 3) assurance that the highest statutory and regulatory requirements for point sources and best management practices for nonpoint sources are achieved. Furthermore, water quality may not be lowered to less than the level necessary to fully protect the "fishable/swimmable" uses and other existing or designated uses.
>
> Tier 3 – Protects the quality of outstanding national and state resource waters, such as waters of national and state parks, wildlife refuges and exceptional recreational or ecological significance. There may be no new or increased discharges to these waters and no new or increased discharges to tributaries of these waters that would result in lower water quality.

6 Modeling Approach

The amount of DO in water is one of the most commonly used indicators of river and stream health. Under extended hypoxic (low DO) or anoxic (no DO) conditions, many higher forms of life are driven off or die. Fish, mussels, macroinvertebrates and all other aquatic life utilize DO to create energy and metabolize food. DO in streams is affected by several factors including water temperature, the amount of decaying matter (i.e. organic sediment) in the stream, turbulence at the air-water interface and the amount of photosynthesis occurring in plants within the stream. Excessive nitrogen and phosphorus loading to water bodies can also contribute to DO problems because they can accelerate algal growth.

Algal growth in streams is most frequently assessed based on the amount of chlorophyll-a in the water. Algal growth is affected by numerous biotic and abiotic factors including light availability, flow and water velocity, nutrients (particularly nitrogen and phosphorus), grazing and other influences. Algae contribute DO during photosynthesis and consume DO during respiration. This typically results in a net gain of DO during the day and net loss of DO during the night. The breakdown of dead, decaying algae also removes oxygen from water. The most common approach to reducing excessive algal growth involves controls on activities that contribute phosphorus to the water body.

DO in streams is determined by the factors of photosynthetic productivity, respiration (autotrophic and heterotrophic), reaeration and temperature. These factors are influenced by natural and anthropogenic conditions within a watershed. Generally, reaeration is based on the physical properties of the stream and on the capacity of water to hold DO. This capacity is mainly determined by water temperature, with colder water having a higher saturation concentration for DO. In a review of variables and their importance in DO modeling, Nijboer and Verdonschot (2004) categorized the impact of a number of variables on oxygen depletion. For this TMDL, the effects of temperature and the physical aspects of the stream itself were discounted. Even though the hydrologic regime of historic alluvial streams was modified by changes in land cover and channelization, manipulation of these parameters does not address a pollutant and so is not the goal of a TMDL. Pollutants which result in oxygen concentrations below saturation are:

- fine particle size of bottom sediment
- high nutrient levels (nitrogen and phosphorus)
- suspended particles of organic matter (i.e., turbidity)

Because the influence of these three pollutants on DO varies to a large extent based on anthropogenic factors, they are appropriate targets for a TMDL written to address an impairment of low DO.

An essential component of developing a TMDL is establishing a relationship between the source loadings and the resulting water quality. For this TMDL, two modeling approaches are used. The load duration curve (LDC) method is used to develop TMDLs for TSS, TN and TP under all flow conditions and the QUAL2K model is used to assess DO under critical low flow conditions. The relationship between the source loadings of CBOD, nutrients (NH_3, TN and TP) and algal dynamics on DO is generated by the water quality model QUAL2K (Chapra et al., 2008) under steady-state low flow conditions.

Since fine particle sized sediment and turbidity are derived from similar loading conditions of terrestrial and stream bank erosion, this TMDL establishes an allocation for TSS (see Appendix C for discussion of development of TSS targets). This target was derived based on a reference approach by targeting the 25th percentile of TSS measurements (US Geological Survey [USGS], non-filterable residue) in the geographic region in which Bear Creek is located. To address nutrient levels, the EPA nutrient ecoregion reference concentrations were used. For the ecoregion where Bear Creek is located, the reference concentration for TN is 0.855 mg/L and the reference concentration for TP is 0.092 mg/L (EPA, 2000). This TMDL will not specifically target chlorophyll-*a* as a WLA, but will use a linkage between nutrient concentrations and chlorophyll response to achieve the ecoregion reference concentrations.

6.1 Load Duration Curves

The sediment target for this TMDL was derived using a reference approach by targeting the 25th percentile of TSS measurements (USGS, non-filterable residue) in the geographical region in which Bear Creek is located (see Appendix C for a list of sites and data). In this approach, the target for pollutant loading is the 25th percentile of the current EDU condition calculated from all data available within the EDU in which the water body is located. Therefore, the 25th percentile is targeted as the TMDL LDC.

To develop LDCs for TN and TP, a method similar to that used for TSS was employed. First, TN and TP measurements were collected from USGS sites in the vicinity of the impaired stream. These data were adjusted such that the median of the measured data was equal to the ecoregion reference concentration. This was accomplished by subtracting the difference of the data median and the reference concentration. Where this would result in a negative concentration, the data point in question was replaced with the minimum concentration seen in the measured data. This resulted in a modeled data set which retained much of the original variability seen in the measured data. This modeled data was then regressed as instantaneous load versus flow. The resultant regression equation was used to develop the LDC.

To develop the TMDL expression of maximum daily loads, the background discharge at the stream outlet was modified from the traditional approach using synthetic flow estimation. Since the design flow from permitted facilities would overwhelm the background natural low flow, the sum of permitted volumes was added to the derived stream discharge at all percentiles of flow to take into account the increases in flow volume as well as pollutant load. The TMDL curves in the LDCs flatten at low flow because at these lower flows the TMDL target is dominated by the point source flow.

6.2 QUAL2K

QUAL2K and its predecessor models have been used extensively for permitting of wastewater treatment discharges and TMDL development across the country. QUAL2K is supported by EPA and is well accepted within the scientific community because of its proven ability to simulate the processes important to DO conditions within streams. Critical conditions are considered when the LC is calculated. DO levels that threaten the integrity of aquatic communities generally occur during low flow periods, so these periods are considered the critical condition. Therefore, in order to ensure attainment of applicable WQS, all water quality criteria must be met end of pipe for permitted facilities. QUAL2K is suitable for simulating the hydraulics and water quality conditions of a small river. It is a one-dimensional model with the assumption of a completely mixed system for each computational cell. QUAL2K assumes that the major pollutant transport mechanisms, advection and dispersion, are significant only along the longitudinal direction of flow. The model allows for multiple waste discharges, water withdrawals, tributary flows and incremental inflows and outflows. The processes employed in QUAL2K address nutrient cycles, algal growth and DO dynamics. QUAL2K links plant respiration and photosynthesis as well as other oxygen demanding substances such as CBOD, the nitrification process (which uses oxygen to break down organic nitrogen to NH_3 and then to NO_2+NO_3) and sediment demands of organic substances to instream oxygen levels.

Flow and water quality data collected on July 15, 2009 were used to calibrate the QUAL2K model for Bear Creek and data collected on August 25 and August 26, 2009 were used to validate the model. Once the QUAL2K model was set up and calibrated, a series of scenarios were run to evaluate the pollutant load reductions needed to achieve the minimum DO criterion. These results are summarized in Section 7 and a detailed discussion of the QUAL2K modeling is included in Appendix B.

7 Calculation of Loading Capacity

LC is defined as the greatest amount of a pollutant that a water body can assimilate without violating WQS. This load is then divided among the point source (WLA) and nonpoint source (LA) contributions to the stream, with an allowance for an explicit MOS if desired. The MOS accounts for uncertainty in the relationship between pollutant loads and the quality of the receiving water body. If the MOS is implicit, no numeric allowance is necessary. Conceptually, this definition is represented by the equation:

$$LC = \Sigma \text{ WLAs} + \Sigma \text{ LAs} + MOS \qquad \textbf{Equation 1}$$

Where:

LC = Loading Capacity

WLA = Waste Load Allocations (point source)

LA = Load Allocations (nonpoint source)

MOS = Margin of Safety (may be implicit and factored into a conservative WLA or LA or explicit)

The objective of the TMDL is to estimate allowable pollutant loads and to allocate these loads to known pollutant sources within the watershed so appropriate control measures can be implemented and the WQS achieved. The WLA and LA are calculated by multiplying the appropriate flow in cubic feet per second (cfs) by the appropriate pollutant concentration in milligrams per liter (mg/L). A conversion factor of 5.395 is used to convert to pounds per day (lbs/day).

The QUAL2K model was calibrated using data collected on July 15, 2009 and validated using data collected on August 25-26, 2009. The July 15, 2009 model was used for the TMDL model runs. Of the three days modeled it has the lowest flows and lowest observed DO and represented a more critical condition. The following steps were taken during the modeling process:

Step 1: Application of the Model to Existing Conditions

- This application forms the current condition that is used to evaluate the magnitude of load reductions that are needed to meet WQS. Nonpoint source loads are set equal to the calibrated conditions.

Step 2: Application of the Model to Existing Conditions with Point Sources at Permit Limits

- This application forms the baseline condition that will be reduced to meet the allowable load. For example, the Kirksville WWTP was set at its permit limits using the permitted flow and mean daily concentration allowed for in the permit. For pollutants not included in the permit, the observed data were used.

Step 3: Develop and Test Allocation Scenarios

- Working from the baseline condition and considering the primary pollutant sources, sample allocation scenarios are developed and applied. For example, if existing BOD or nutrient effluent limits for the Kirksville WWTP in Step 2 are not protective of the instream WQS, the QUAL2K model is iteratively run at reduced BOD and nutrient concentrations until compliance with the WQS is met. The difference between the baseline condition and BOD and nutrient WLAs required to achieve the standard is the percent reduction needed at the facility.

The TMDL, summarized in Table 10, is based on 7Q10[15] flows of 0.01 cfs and the environmental conditions (air temperature, dew point temperature and cloud cover) that were present on July 15, 2009. Headwater and nutrient concentrations were set equal to ecoregion criteria. The results of the modeling analysis indicate that to meet a minimum allowed DO concentration of 5 mg/L at all locations downstream of the Kirksville WWTP an NH_3 concentration of 0.855 mg/L and $CBOD_{ult}$ concentration of 18.5 mg/L is needed. This is equivalent to a 79 percent reduction of BOD_5 when compared to the permitted monthly average concentration and a 78 percent reduction when compared to the permitted monthly average NH_3 concentration. The Burk subdivision WWTP has a very small permitted flow (11,100 gallons per day) and has very little impact on DO; thus, no reductions to its CBOD or NH_3 loads were made for the TMDL. In addition to these load reductions, a 60 percent reduction in SOD is needed to achieve a minimum DO of 5 mg/L throughout the stream and effluent aeration to 8.0 mg/L (or greater) is required. BOD_5 reductions (through reduction in ammonia, organic nitrogen and CBOD reductions) are deemed necessary to achieve the SOD reduction because most of the SOD at the surface of the sediment is likely due to the biological decomposition of particulate

[15] 7Q10 flows of 0.01 cfs is an assumption used by MDNR for unclassified streams in Missouri that have not had a site specific low flow analysis completed (personal communication with John Hoke, 2009).

organic material (including algae) discharged by the Kirksville WWTP and settling downstream of the outfall.

To meet the targeted nutrient and TSS critical condition targets outlined in this TMDL, the sum of the WLAs was calculated by using nutrient ecoregion reference concentrations and 25th percentile TSS concentrations and the sum of the design flows of all permitted facilities in the watershed (with the exception of the MS4). For Bear Creek, the sum of the design flows is the Kirskville WWTP design flow considering all other design flows are insignificant in comparison. The LDCs for the targeted pollutants are depicted in Figure 7, Figure 8 and Figure 9, where the TMDL line represents the total LC of all point and nonpoint sources of pollutants. The pollutant allocations under a range of flow conditions are presented in Table 11, Table 12 and Table 13.

Table 10. Low Flow TMDL Summary for Bear Creek

Pollutant	Baseline Conditions (based on monthly average permit limits and design flow)			TMDL Condition			WLA Percent Reduction	LA Percent Reduction
	Point Sources	Nonpoint Sources	Total	Point Sources (WLA)	Nonpoint Sources (LA)	Total		
Flow (cfs)	4.898	0.002	0.141	0.139	0.002	0.141	0	0
BOD_5 (lb/day)	795.6	0.51	796.1	170.2	0.82	171.0	79	0
$CBOD_{ult}$ (lb/day)	No limit	1.78	Not applicable	492.2	1.9	494.1	Not applicable	0
$NBOD_{ult}$ (lb/day)	No limit	1.00	Not applicable	103.4	0.97	104.4	Not applicable	3
Ammonia (lb/day)	102.9	0.14	103.0	22.6	0.0	22.6	78	100
TSS (lb/day)	798	407	1,205	798	14	812	0	See LDC
TN (lb/day)	No limit	0.17	Not applicable	22.63	0.28	22.9	Not applicable	See LDC
TP (lb/day)	No limit	0.03	Not applicable	2.44	0.03	2.47	Not applicable	See LDC

Note: The WLA and LA specified in Table 10 results in DO of 5.0 mg/L when SOD is decreased by 60 percent, the effluent is aerated to at least 8.0 mg/L DO and background nutrient conditions are equivalent to EPA ecoregion criteria (TN = 0.855 mg/L and TP = 0.092 mg/L). Percent reduction cannot be calculated for $CBOD_{ult}$, $NBOD_{ult}$, TN and TP because the WWTPs do not have permit limits for these constituents. Point and nonpoint baseline conditions for flow, BOD_5, $NBOD_{ult}$, NH_3, TN and TP are based on QUAL2K modeling results. Baseline point source limits for TSS were determined using permitted flows and TSS limits. Baseline nonpoint source condition for TSS is based on an average of two measurements taken under low flow conditions in Bear Creek (at the 85% percentile exceedance flow). Point and nonpoint source TMDL limits for BOD_5, $NBOD_{ult}$ and NH_3 were obtained from QUAL2K model results. Point and nonpoint source TMDL limits for TN and TP were obtained using LDCs that are based on ecoregion criteria and design flows. Point source TMDL limits for TSS are based on the monthly average of 30 mg/L TSS because this value is below the ecoregion criteria, 44 mg/L TSS.

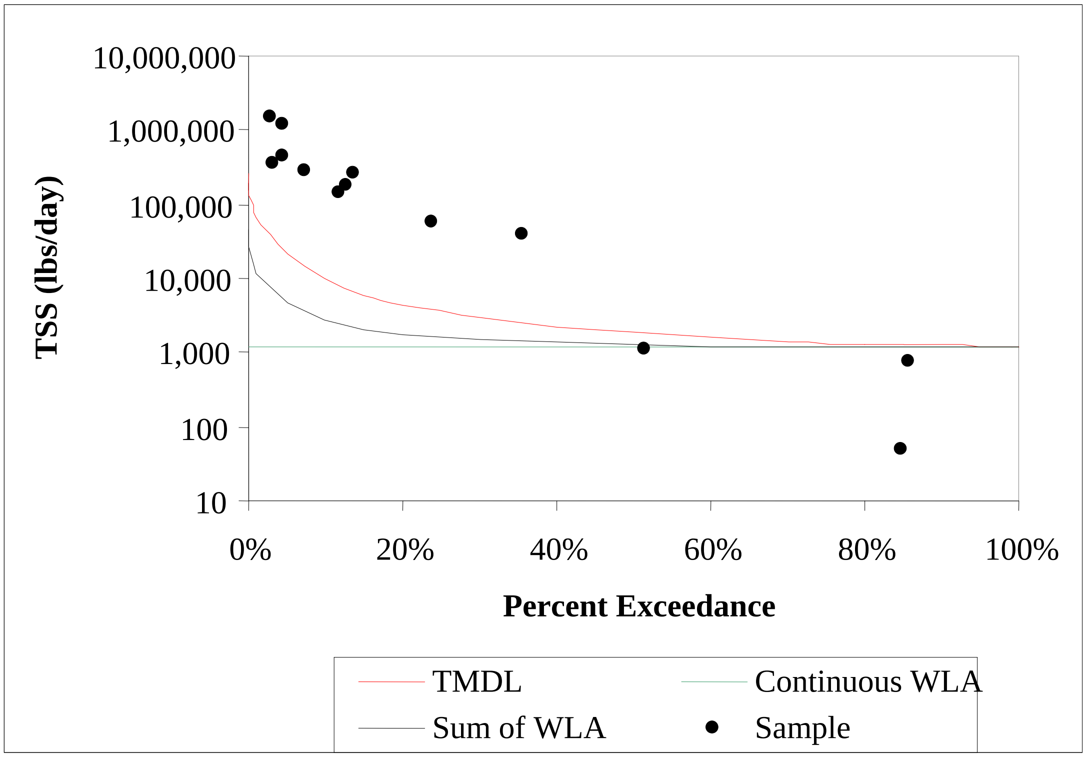

Figure 7. TSS LDC for Bear Creek near Kirksville, MO

Table 11. TSS TMDL Under a Range of Flow Conditions in Bear Creek

Percent Flow Exceedance	Estimated Flow (cfs)	TMDL (lbs/day)	MOS[1] (lbs/day)	LA (lbs/day)	WLA Kirksville WWTP (lbs/day)	WLA (other permits) (lbs/day)	WLA MS4 Storm water (lbs/day)
95%	5.1	846	--	42	791	4	9
90%	5.2	874	--	66	791	4	13
70%	5.9	1,029	--	194	791	4	40
50%	7.8	1,483	--	572	791	4	116
30%	12.5	2,595	--	1,495	791	4	305
10%	42.1	9,614	--	7,327	791	4	1,492
5%	88.7	20,684	--	16,524	791	4	3,365

[1] The TSS MOS is implicit.

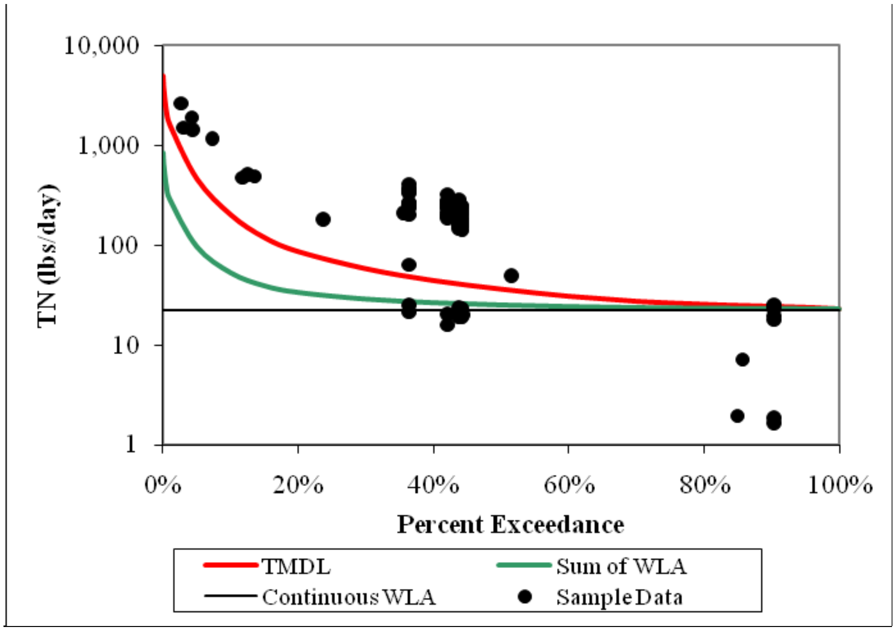

Figure 8. TN LDC for Bear Creek near Kirksville, MO

Table 12. TN TMDL Under a Range of Flow Conditions in Bear Creek

Percent Flow Exceedance	Estimated Flow (cfs)	TMDL (lbs/day)	MOS[1] (lbs/day)	LA (lbs/day)	WLA Kirksville WWTP (lbs/day)	WLA (other permits) (lbs/day)	WLA MS4 Storm water (lbs/day)
95%	5.1	23.6	--	0.7	22.6	0.1	0.2
90%	5.2	24.2	--	1.2	22.6	0.1	0.3
70%	5.9	27.2	--	3.7	22.6	0.1	0.8
50%	7.8	36.0	--	11.0	22.6	0.1	2.3
30%	12.5	57.6	--	29.0	22.6	0.1	5.9
10%	42.1	200.2	--	147.6	22.6	0.1	29.9
5%	88.7	459.6	--	363.4	22.6	0.1	73.5

[1] The TN MOS is implicit.

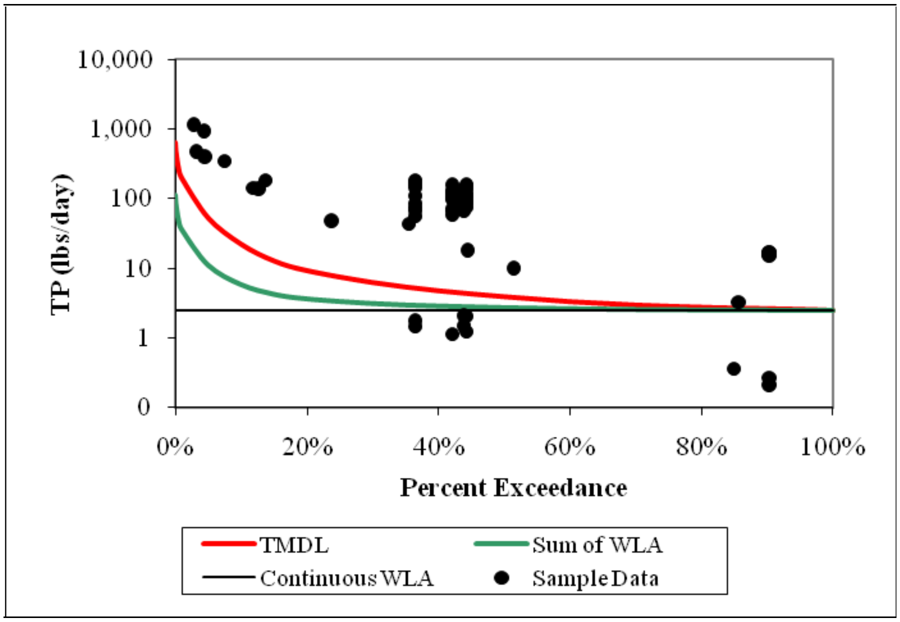

Figure 9. TP LDC for Bear Creek near Kirksville, MO

Table 13. TP TMDL Under a Range of Flow Conditions in Bear Creek

Percent Flow Exceedance	Estimated Flow (cfs)	TMDL (lbs/day)	MOS[1] (lbs/day)	LA (lbs/day)	WLA Kirksville WWTP (lbs/day)	WLA (other permits) (lbs/day)	WLA MS4 Storm water (lbs/day)
95%	5.1	2.54	--	0.08	2.43	0.01	0.02
90%	5.2	2.60	--	0.13	2.43	0.01	0.03
70%	5.9	2.92	--	0.40	2.43	0.01	0.08
50%	7.8	3.87	--	1.19	2.43	0.01	0.24
30%	12.5	6.20	--	3.12	2.43	0.01	0.64
10%	42.1	22.20	--	16.44	2.43	0.01	3.32
5%	88.7	53.28	--	42.32	2.43	0.01	8.52

[1] The TP MOS is implicit.

8 Waste Load Allocation (Point Source Loads)

The WLA is the portion of the LC that is allocated to existing or future point sources of pollutants. The sum of design flows of all site specific permitted dischargers with NPDES Permits (Table 8) in the Bear Creek watershed, excluding permitted storm water flows, is 4.906 cfs (3.171 MGD).

The city of Kirksville MS4 WLA is set based on the percentage of the watershed covered under the MS4 permit. The watershed area associated with the impaired segment of Bear Creek is 27.2 square miles and the city of Kirksville MS4 area within this watershed is 4.6 square miles (based on the 2000 census layer of the city boundary). This results in the city of Kirksville MS4 receiving a WLA equivalent to 16.9 percent of the diffuse load to the stream. The MS4 WLA increases at higher storm flows as available diffuse flow increases. An area of approximately 0.05 square miles of the Village of Millard is also within the watershed; however, this area is not covered under an MS4 permit and is addressed under the LA portion of this TMDL.

New WLAs for the city of Kirksville WWTP were calculated through the modeling process and are shown in Table 10. Existing permit limits and model simulated effluent concentrations are provided in Table 14. The WLA for $CBOD_5$ and NH_3 were derived from the QUAL2K modeling that resulted in meeting WQS. The WLAs for TN, TP and TSS were derived from the LDCs at low flow, when inputs are set at the facility design flow of 4.898 cfs (3.16 MGD). The other permitted facilities in the watershed discharge insignificant volumes of effluent compared to the Kirksville WWTP and are unlikely to discharge during the critical low flow periods. Their WLAs therefore remain equal to existing permit limits, which are summarized in Table 8 for the facilities with individual site specific permits.

Table 14. WLAs for the Kirksville WWTP (MO0049506) in Bear Creek Watershed

Effluent Parameter	Design Flow (MGD)	Existing Permit Limit		WLA at Design Flow		Percent Reduction
		Concentration (mg/L)	Load (lbs/day)	Concentration (mg/L)	Load (lbs/day)	
$CBOD_5$	3.16	No existing limit	No limit	4.96	131.2	Not applicable
$NBOD_5$	3.16	No existing limit	No limit	1.44	38.1	Not applicable
NH_3	3.16	Daily Maximum = 7.8[16] - 9.0[17] Monthly Average = 3.9[18] – 4.5[19]	103.3	0.855	22.6	78
TSS	3.16	Weekly Average = 45 Monthly Average = 30	791.3	30	791.3	0
TN	3.16	No existing limit	No limit	0.855	22.6	Not applicable
TP	3.16	No existing limit	No limit	0.092	2.4	Not applicable

Notes: $CBOD_5$ is calculated using simulated BOD_5 divided by 1.29, based on 1998 EPA modeling guidance for NH3 toxicity and DO modeling. $NBOD_5$ is the difference between BOD_5 and $CBOD_5$. TN target loading for point sources was based on 855 µg/L, Ecoregion 40 TN value. TP target loading for point sources was based on 92 µg/L, Ecoregion 40 TP value.

[16] Represents limits from May 1 – October 31
[17] Represents limits from November 1 – April 30
[18] Represents limits from May 1 – October 31
[19] Represents limits from November 1 – April 30

9 Load Allocation (Nonpoint Source Loads)

The LA includes all existing and future nonpoint sources and natural background contributions of the pollutants of concern (40 CFR § 130.2(g)). The LAs for the Bear Creek TMDL are for all nonpoint sources of TSS, TN and TP which could include loads from agricultural lands, runoff from urban areas, livestock and failing onsite wastewater treatment systems. The LA also includes runoff from the village of Millard, Missouri. The LAs for TSS, TN and TP are provided in Table 11, Table 12 and Table 13, respectively, and were calculated based on the total of all headwater and lateral inflow loads used in the QUAL2K model for the allocation scenario model run and LDCs. The LAs are intended to allow the DO target to be met at all locations within the stream.

10 Margin of Safety

A MOS is required in the TMDL calculation to account for uncertainties in scientific and technical understanding of water quality in natural systems. The MOS is intended to account for such uncertainties in a conservative manner. Based on EPA guidance, the MOS can be achieved through one of two approaches:

1) Explicit - Reserve a numeric portion of the LC as a separate term in the TMDL.
2) Implicit - Incorporate the MOS as part of the critical conditions for the WLA and LA calculations by making conservative assumptions in the analysis.

An implicit MOS was incorporated into the TMDL by using conservative assumptions. The conservative assumptions include:

- Performing the QUAL2K simulation under 7Q10 low flow conditions;
- Using the entire design flow during simulations;
- Calibration of the water quality models focused on matching measured low DO

For TSS, TN and TP, an implicit MOS was incorporated into the TMDL based on conservative assumptions used in the development of the TMDL LDCs. Among the conservative approaches used, the TMDL calculated WLAs for TSS by targeting the 25th percentile of TSS concentrations in the geographic region in which Bear Creek is located. Another conservative approach was to establish WLAs for the city of Kirksville WWTP under critical low flow conditions when discharge from this facility will dominate the stream flow. The TN and TP targets for this TMDL are also conservative factors in the analysis because they are based on the 25th percentile of all TN and TP data in from the Subecoregion 40 of Aggregate Nutrient Ecoregion IX. These targets were derived by EPA to represent conditions of surface waters that are minimally impacted by human activities and protective of aquatic life and recreational uses (EPA, 2000). The 25th percentile is considered a surrogate for establishing a reference population for minimally impacted systems (EPA 2000).

11 Seasonal Variation and Critical Conditions

A TMDL must consider seasonal variation in the derivation of the allocations. DO levels that threaten the integrity of aquatic communities generally occur during low flow periods and warm temperatures, so these periods are considered the critical condition for the DO target. Annual low-flow conditions in Missouri typically occur between July 1 and September 15. This TMDL addresses seasonal variation and critical conditions for low DO by identifying a LC that would be protective during the 7-day average flow of the 10-year return frequency (7Q10) dry-weather low flow period.

DO in streams is affected by several factors including water temperature, the amount of decaying matter (i.e. organic sediment) in the stream, turbulence at the air-water interface and the amount of photosynthesis occurring in plants within the stream. Organic sediments and SOD can also contribute to fluctuating DO concentrations in the water column. The effects of high nutrient and BOD concentrations on DO swings and low DO conditions (discussed in Section 5.2) are typically amplified under circumstances in which flow is low and water temperature is relatively high (for example, summer months). As noted previously, the TMDL is protective of critical conditions and therefore considers seasonal variation and sensitivity of DO in the analysis.

The TMDL LDCs for TSS, TN and TP represents flow under all seasonal conditions. The advantage of LDC approach is that all flow conditions are considered and the constraints associated with using a single-flow critical condition are avoided. Because the WLA, LA and TMDL are applicable at all flow conditions, they are also applicable and protective over all seasons.

12 Monitoring Plan for TMDLs Developed under Phased Approach

No future monitoring has been scheduled Bear Creek at this time. In general, future stream monitoring is scheduled and conducted by MDNR approximately three years after the approval of the TMDL or in a reasonable time frame following the completion of permit compliance schedules and/or the application of new effluent limits. Any volunteer or permittee water quality monitoring that occurs in Bear Creek will be used for evaluating the present stream condition to see if the state's WQS established by the TMDL are being met. MDNR will routinely examine physical habitat, water quality, invertebrate and fish community data collected by the Missouri Department of Conservation under its Resource Assessment and Monitoring (RAM) Program. This program randomly samples streams across Missouri on a 5- to 6-year rotating schedule.

As with all of Missouri's TMDLs, if continuing monitoring reveals that water quality standards are not being met, the TMDL will be reopened and re-evaluated accordingly.

13 Reasonable Assurances

MDNR has the authority to issue and enforce state operating permits. Inclusion of effluent limits into a state operating permit and requiring that effluent and instream monitoring be reported to MDNR should provide reasonable assurance that instream WQS will be met. Section 301(b)(1)(C) requires that point source permits have effluent limits as stringent as necessary to meet WQS. However, for WLAs to serve that purpose, they must themselves be stringent enough so that (in conjunction with the water body's other loadings) they meet WQS. This generally occurs when the TMDL's combined nonpoint source LAs and point source WLAs do not exceed the WQS-based LC and there is reasonable assurance that the TMDL's allocations can be achieved. Any discussion of reduction efforts relating to nonpoint sources would be found in the implementation section of the TMDL. EPA believes that point source permitting authority and nonpoint source measures discussed in the supplemental implementation plan (see Appendix F) provides reasonable assurances that the TMDL allocations can be achieved.

14 Public Participation

EPA regulations require that TMDLs be subject to public review (40 CFR 130.7). EPA is providing public notice of this draft TMDL for Bear Creek on the EPA, Region 7, TMDL website: http://www.epa.gov/region07/water/tmdl_public_notice.htm. The response to comments and final TMDL will be available at: http://www.epa.gov/region07/water/apprtmdl.htm#Missouri.

This water quality limited segment of Bear Creek in Adair County, Missouri, is included on the EPA-approved 2008 Missouri 303(d) List. This TMDL is being established by EPA to meet the requirements of the 2001 Consent Decree, *American Canoe Association, et al. v. EPA*, No. 98-1195-CV-W in consolidation with No. 98-4282-CV-W, February 27, 2001. EPA is developing this TMDL in cooperation with the state of Missouri and EPA is establishing this TMDL at this time to meet the *American Canoe* consent decree milestones. Missouri may submit and EPA may approve a revised or modified TMDL for this water at any time.

Before finalizing EPA established TMDLs (such as this TMDL), the public is notified that a comment period is open on the EPA Region 7 website for at least 30 days. EPA's public notices to comment on draft TMDLs are also distributed via mail and electronic mail to major stakeholders in the watershed or other potentially impacted parties. After the comment period closes, EPA reviews all comments, edits the TMDL as is appropriate, writes a Summary of Response to Comments and establishes the TMDL. For Missouri TMDLs, groups receiving the public notice announcement include a distribution list provided by MDNR, the Missouri Clean Water Commission, the Missouri Water Quality Coordinating Committee, stream team volunteers, state legislators, County Commissioners, the County Soil and Water Conservation District and potentially impacted cities, towns and facilities. EPA followed this public notice process for this TMDL. Links to active public notices for draft TMDLs, final (approved and established) TMDLs and Summary of Response to Comments are posted on the EPA website: http://www.epa.gov/region07/water/tmdl.htm.

The availability of the TMDL in draft form was published on EPA Region 7 Website for at least 30 days. The public notice period for the draft Bear Creek TMDL was from October 7 to November 15, 2010. EPA's public notice inviting comments on the draft TMDL was also distributed via mail and electronic mail to major stake-holders in the watershed and other potentially impacted parties. One public comment was received and the TMDL document was adjusted where appropriate.

15 Administrative Record and Supporting Documents

An administrative record on the Bear Creek TMDL has been assembled and is being kept on file with EPA.

16 References

Athayde, D., P. Shelley, E. Driscoll, D. Gaboury and G. Boyd, 1983. Results of the Nationwide Urban Runoff Program, Volume I.

Chapra, Steve. 1997. Surface Water Quality Modeling. University of Colorado at Boulder. McGraw-Hill Companies, Inc.

Code of State Regulations (CSR), 2009. Missouri Secretary of State Web page. Title 10 – Missouri Department of Natural Resources. Division 20 – Clean Water Commission. Chapter 7 – Water Quality. 10 CSR 20-7.031 - Water Quality Standards. Accessed November 17, 2009. http://www.sos.mo.gov/adrules/csr/current/10csr/10c20-7.pdf

United States Environmental Protection Agency (EPA), 1997.Volunteer Stream Monitoring: A Methods Manual. EPA/841/B-97/003. US Environmental Protection Agency, Office of Wetlands Oceans and Watersheds. November 1997.

EPA, 2000. Ambient Water Quality Criteria Recommendations. Information Supporting the Development of State and Tribal Nutrient Criteria. Rivers and Streams in Nutrient Ecoregion IX. EPA 822-B-00-019. December 2000.

EPA, 2002. Onsite Wastewater Treatment System Manual. EPA/625/R-00/008. US Environmental Protection Agency, Office of Water, Washington, DC and Office of Research and Development, Cincinnati, OH. February 2002.

EPA, 2009a. Water Discharge Permits (PCS). Accessed July 17, 2009. http://www.epa.gov/enviro/html/pcs/index.html.

EPA, 2009b. United States Environmental Protection Agency Region 5 STEPL Online Database Cites National Environmental Service Center (NESC). 2002. Accessed July 28, 2009. http://bering.tetratech-ffx.com/website/stepl/viewer.htm

Evans, R., J.W. Gilliam and J.P. Lilly. 1996. Wetlands and Water Quality. Published by the North Carolina Cooperative Extension Service. Publication Number AG 473-7.

Horsley & Witten, Inc., 1996. Identification and Evaluation of Nutrient and Bacterial Loadings to Maquoit Bay, Brunswick and Freeport, Maine. Casco Bay Estuary Project.

John Hoke, 2009. Personal communication related to estimating low flows for Missouri streams.

Missouri Department of Conservation (MDC), 2001. Water Pollution Control Program Sampling of Bear Creek and North Fork Salt River.

MDC, 2009. Salt River Watershed Geomorphology. Accessed July 17, 2009. http://mdc.mo.gov/fish/watershed/salt/geology/

Missouri Department of Natural Resources (MDNR), 2009. Northeast Missouri Groundwater Providence. Accessed July 17, 2009. http://dnr.mo.gov/env/wrc/groundwater/education/provinces/nemissouriprovince.htm.

Missouri Resource Assessment Partnership (MoRAP), 2005. Land Use/Land Cover Data. Accessed April 26, 2007. http://www.msdis.missouri.edu

Mitsch, W. J. and J.G. Gosselink. 1993. Wetlands. Second Edition.

Missouri Spatial Data Information Service (MSDIS), 2009. GIS Layers Downloaded May 2009. http://msdis.missouri.edu/datasearch/ThemeList.jsp.

National Oceanic and Atmospheric Administration (NOAA), 2009. NCDC Climate Data Online. Accessed July 17, 2009. http://cdo.ncdc.noaa.gov/climatenormals/clim20/mo/234544.pdf.

Natural Resource Conservation Service (NRCS), Accessed July 17, 2009. http://soildatamart.nrcs.usda.gov/Survey.aspx?County=MO001.

Nijboer, R.C. and P.F.M. Verdonschot, 2004. Variable selection for modeling effects of eutrophication on stream and river ecosystems. Ecol. Model. 177, 17-39.

Purdue Research Foundation, 2009. Hydrologic Soil Groups. Accessed July 17, 2009. http://www.ecn.purdue.edu/runoff/documentation/hsg.html, Hydrologic Soil Groups.

Reckhow, K. H., M. N. Beaulac and J. R. Simpson, 1980. Modeling Phosphorus Loading and Lake Response Under Uncertainty: A Manual and Compilation of Export Coefficients. EPA-440/5-8-011, US Environmental Protection Agency, Washington, D.C.

Stoeser, Douglas B., Green, Gregory N., Morath, Laurie C., Heran, William D. , Wilson, Anna B. , Moore, David W. and Bradley S. Van Gosen, 2005, Preliminary Integrated Geologic Map Databases for the United States Central States: Montana, Wyoming, Colorado, New Mexico,

Kansas, Oklahoma, Texas, Missouri, Arkansas and Louisiana, - The State of Missouri: US Geological Survey Open-File Report 2005-1351, US Geological Survey, Denver, CO.
US Code. 2009. Title 33 of the US Code. Accessed February 19, 2009. http://www.gpoaccess.gov/uscode/

United States Census Bureau, 2000. 2000 Population Estimates. Accessed July 20, 2009. http://www.census.gov/

US Department of Agriculture (USDA), 2001 Natural Resource Conservation Service - National Cartography & Geospatial Center. 2001 USDA-NRCS-NCGC Digital Raster Graphic MrSID Mosaic.

USDA, 2007. National Agriculture Statistics Service. Accessed February 19, 2009. http://www.nass.usda.gov/

Walker, R.R. and Snodgrass, W.J., 1986. Model for sediment oxygen demand in lakes: Journal of Environmental Engineering, v. 112, no. 1, p. 25-43.

Wang, W., 1980. Fractionation of sediment oxygen demand: Water Research, v. 14, p. 603-612.

Appendices

Appendix A – Bear Creek Water Quality Data
Appendix B – Bear Creek QUAL2K Modeling
Appendix C – Development of TSS Targets Using Reference LDCs
Appendix D – Development of Nutrient Targets Using Ecoregion Nutrient Criteria with LDCs
Appendix E – Stream Flow and Water Quality Stations Used to Develop TMDLs in Bear Creek
Appendix F – Supplemental Implementation Plan

Appendix A – Bear Creek Water Quality Data

Table A-1. Historical Data

Org	Site	Site Name	Date	C	DO	pH	KJN	NH_3N	NO_3N	TN	PO4	TP	TSS	BOD_5	$CBOD_5$
MDNR	115/26.3	Bear Cr. 13.9 mi.bl. Kirksville WWTP	8/3/1978	20	5.6	7.6		0.4	3.3		4.45	4.72		6.4	
MDNR	115/26.3	Bear Cr. 13.9 mi.bl. Kirksville WWTP	8/3/1978	20	5.1	7.9									
MDNR	115/26.3	Bear Cr. 13.9 mi.bl. Kirksville WWTP	8/4/1978	19	4.5	7.8									
MDNR	115/26.3	Bear Cr. 13.9 mi.bl. Kirksville WWTP	8/4/1978	19	5.7	7.6		0.6	3.7		3.77	3.84		7	
MDNR	115/33/1.1	Bear Cr. 6 mi.bl. Kirksville WWTP	8/3/1978	21	2.4	7.7									
MDNR	115/33/1.1	Bear Cr. 6 mi.bl. Kirksville WWTP	8/3/1978	22	3.1	7.5		1.5	0.5		2.91	2.92		6.4	
MDNR	115/33/1.1	Bear Cr. 6 mi.bl. Kirksville WWTP	8/4/1978	17	3.5	7.7									
MDNR	115/33/1.1	Bear Cr. 6 mi.bl. Kirksville WWTP	8/4/1978	21	3.8	7.7		3	1.9		4.22	4.4		6	
MDNR	115/33/1.1	Bear Cr. 6 mi.bl. Kirksville WWTP	8/14/1995	26.5	10			0.02499	3.5						0.99
MDNR	115/33/1.1	Bear Cr. 6 mi.bl. Kirksville WWTP	8/15/1995	20.5	4.7			0.05	3.34						0.99
MDNR	115/33/7.3	Bear Cr. 0.1 mi.ab. Kirksville WWTP	8/3/1978	24	7.6	7.8		0.2	1		0.16	0.32		4.4	
MDNR	115/33/7.3	Bear Cr. 0.1 mi.ab. Kirksville WWTP	8/3/1978	18	5.7	7.3									
MDNR	115/33/7.3	Bear Cr. 0.1 mi.ab. Kirksville WWTP	8/4/1978	16	6.2	7.7									
MDNR	115/33/7.3	Bear Cr. 0.1 mi.ab. Kirksville WWTP	8/4/1978	23	9.9	7.7		0.1	0.8		0.13	0.32		3.5	
MDNR	115/33/7.3	Bear Cr. 0.1 mi.ab. Kirksville WWTP	8/14/1995	27.5	8.3			0.02499	0.26						0.99
MDNR	115/33/7.3	Bear Cr. 0.1 mi.ab. Kirksville WWTP	8/15/1995	21	1.9			0.1	0.1						0.99
MDNR	115/33/7.3	Bear Cr. 0.1 mi.ab. Kirksville WWTP	8/15/2002	22	4.2	7.4	0.78	0.02499	0.15	0.93		0.12			2.3
MDNR	115/33/7.3	Bear Cr. 0.1 mi.ab. Kirksville WWTP	8/15/2002	20	3.2	7.8	0.8	0.02499	0.25	1.05		0.15			0.99
MDNR	115/33/7.1	Bear Cr. 0.1 mi.bl. Kirksville WWTP	8/3/1978	21	3.7	7.6									
MDNR	115/33/7.1	Bear Cr. 0.1 mi.bl. Kirksville WWTP	8/3/1978	23	4.3	7.5		2.3	1.7		5.11	5.36		15.6	
MDNR	115/33/7.1	Bear Cr. 0.1 mi.bl. Kirksville WWTP	8/4/1978	22	4.4	7.8		3.9	2.9		5.96	6.56		18	

Org	Site	Site Name	Date	C	DO	pH	KJN	NH_3N	NO_3N	TN	PO4	TP	TSS	BOD_5	$CBOD_5$
MDNR	115/33/7.1	Bear Cr. 0.1 mi.bl. Kirksville WWTP	8/4/1978	20	3.1	7.6									
MDNR	115/33/6.5	Bear Cr. 0.7 mi.bl. Kirksville WWTP	8/14/1995	24	5.2			0.74	4.5						1.99
MDNR	115/33/6.5	Bear Cr. 0.7 mi.bl. Kirksville WWTP	8/15/1995	20	3.2			0.46	4.78						4
MDNR	115/33/6.5	Bear Cr. 0.7 mi.bl. Kirksville WWTP	8/15/2002	20	3.9	7.3	2.56	0.47	11.2	13.8		8.64			4.1
MDNR	115/33/6.5	Bear Cr. 0.7 mi.bl. Kirksville WWTP	8/15/2002	25	5.3	7.7	2.35	0.36	10.6	13		9.14			4.3
MDNR	115/33/6.1	Bear Cr. 1.1 mi.bl. Kirksville WWTP	8/15/2002	20	4.4	7.4	2.77	0.39	11.6	14.4		8.66			5.1
MDNR	115/33/6.1	Bear Cr. 1.1 mi.bl. Kirksville WWTP	8/15/2002	25	5.3	7.7	2.35	0.51	10.8	13.2		8.67			4.1
MDNR	115/33/5.1	Bear Cr. 2.1 mi.bl. Kirksville WWTP	8/14/1995	23.5	5.1			0.32	5.4						3
MDNR	115/33/5.1	Bear Cr. 2.1 mi.bl. Kirksville WWTP	8/15/1995	20.5	3.6			0.46	4.37						1.99
MDNR	115/33/5.1	Bear Cr. 2.1 mi.bl. Kirksville WWTP	8/15/2002	20	3.2	7.6	2.19	0.33	7.84	10		9.72			3.5
MDNR	115/33/5.1	Bear Cr. 2.1 mi.bl. Kirksville WWTP	8/15/2002	23	5.9	7.8	2.1	0.21	8.93	11		8.95			3.7
MEC	115/3.9	Bear Cr. 4 mi. NW of Hagers Grove	6/3/2000					0.12	1.48	3.09		1.41	329		
MEC	115/3.9	Bear Cr. 4 mi. NW of Hagers Grove	7/2/2000					0.01	4.01	1		0.9			
MEC	115/3.9	Bear Cr. 4 mi. NW of Hagers Grove	5/6/2002						1.3	3.63		1.79	2220		
MEC	115/3.9	Bear Cr. 4 mi. NW of Hagers Grove	4/7/2002						1.35	3.43		0.7	78		
MEC	115/3.9	Bear Cr. 4 mi. NW of Hagers Grove	5/7/2002						0.85	3.18		1.41	1780		
MEC	115/3.9	Bear Cr. 4 mi. NW of Hagers Grove	8/8/2002						0.02	0.81		0.15	21.2		
MEC	115/3.9	Bear Cr. 4 mi. NW of Hagers Grove	7/11/2002						0.01	3.14		0.84	1000		
MEC	115/3.9	Bear Cr. 4 mi. NW of Hagers Grove	6/12/2002						0.87	3.95		1.18	974		
MEC	115/3.9	Bear Cr. 4 mi. NW of Hagers Grove	4/19/2002						1.95	6.79		1.42	1303		
MEC	115/3.9	Bear Cr. 4 mi. NW of Hagers Grove	5/24/2002						0.71	3.75		1.41	2009		
MEC	115/3.9	Bear Cr. 4 mi. NW of Hagers Grove	5/25/2002						0.83	2.78		0.78	842		
MEC	115/3.9	Bear Cr. 4 mi. NW of Hagers Grove	4/26/2002						1.81	3.54		0.98	1254		
MEC	115/3.9	Bear Cr. 4 mi. NW of Hagers	5/28/2002						0.56	3.06		0.92	903		

Org	Site	Site Name	Date	C	DO	pH	KJN	NH_3N	NO_3N	TN	PO4	TP	TSS	BOD_5	$CBOD_5$
		Grove													
MEC	115/3.9	Bear Cr. 4 mi. NW of Hagers Grove	4/29/2002						1.01	2.14		0.68	491		
MDNR	115/33/7.2	Kirksville WWTP Effluent Outfall 001	8/3/1978			7.6		3.3	0.9		4.59	7.5	2	19	
MDNR	115/33/7.2	Kirksville WWTP Effluent Outfall 001	8/4/1978			7.5		4.4	1.8		5.9	9.5	7	16	
MDNR	115/33/7.2	Kirksville WWTP Effluent Outfall 001	8/14/1995	22	8			0.11	4.64						6
MDNR	115/33/7.2	Kirksville WWTP Effluent Outfall 001	8/15/1995	21	6.3			0.24	4.76						5
MDNR	115/33/7.2	Kirksville WWTP Effluent Outfall 001	8/15/2002	23	6.2	7.6	2.84	0.2	11.5	14.3		9.43			
MDNR	115/33/7.2	Kirksville WWTP Effluent Outfall 001	8/15/2002	24.1	7.6	7.6	2.6	0.16	11	13.6		9.45			6.5

Blank Cells indicate no data was collected for that parameter on that date.
C = temperature in degrees Celsius
DO = Dissolved Oxygen (mg/L)
KJN= Total Kjeldahl Nitrogen (mg/L) (KJN is the abbreviation used in MDNR's water quality database. Typically this is abbreviated as TKN)
NH_3N or NH_3 = Ammonia as Nitrogen (mg/L)
NO_2+NO_3 or NO_3N = Nitrite + Nitrate as Nitrogen (mg/L)
TN = Total Nitrogen (mg/L)
PO_4 = Phosphate (mg/L)
TP = Total Phosphorus (mg/L)
TSS = Total Suspended Solids (mg/L)
BOD = Biochemical Oxygen Demand (mg/L)
$CBOD_5$ = Carbonaceous Biochemical Oxygen Demand (5 days) (mg/L)
MDNR = Missouri Department of Natural Resources
MEC = Midwest Environmental Consultants
115/26.3 = Bear Creek (Water Body ID: 115) 26.3 miles from the mouth of the segment
115/33/1.1 = Bear Creek (Water Body ID: 115) 34.1 miles from the mouth of the segment
115/33/7.3= Bear Creek (Water Body ID: 115) 40.3 miles from the mouth of the segment
115/33/7.2= Bear Creek (Water Body ID: 115) 40.2 miles from the mouth of the segment
115/33/7.1= Bear Creek (Water Body ID: 115) 40.1 miles from the mouth of the segment
115/33/6.5= Bear Creek (Water Body ID: 115) 39.5 miles from the mouth of the segment
115/33/6.1= Bear Creek (Water Body ID: 115) 39.1 miles from the mouth of the segment
115/33/5.1= Bear Creek (Water Body ID: 115) 38.1 miles from the mouth of the segment
115/3.9= Bear Creek (Water Body ID: 115) 3.9 miles from the mouth of the segment

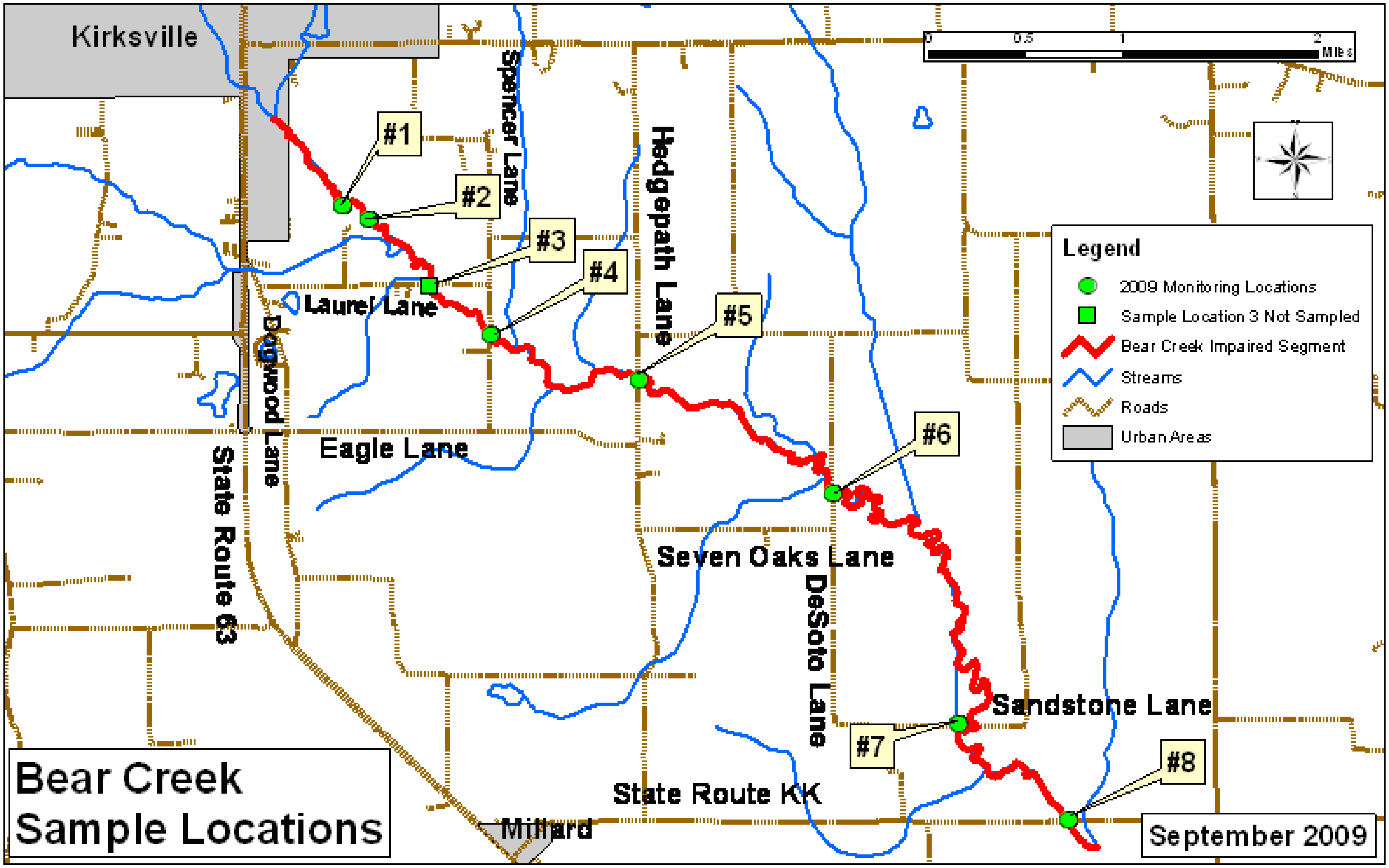

Figure A.1 Bear Creek Sampling Locations

Appendix B – Bear Creek QUAL2K Modeling

B.1 Overview of QUAL2K

The QUAL2K water quality model was selected for the development of the Bear Creek DO TMDL. QUAL2K is supported by the EPA and has been used extensively for TMDL development and point source permitting issues across the country, especially for issues related to DO concentrations. The QUAL2K model is suitable for simulating hydraulics and water quality conditions of small rivers and creeks. It is a one-dimensional uniform flow model with the assumption of a completely mixed system for each computational cell. QUAL2K assumes that the major pollutant transport mechanisms, advection and dispersion, are significant only along the longitudinal direction of flow. The model allows for multiple waste discharges, water withdrawals, nonpoint source loading, tributary flows and incremental inflows and outflows. The processes employed in QUAL2K can address nutrient cycles, algal growth, particulate settling, SOD and DO dynamics.

B.2 QUAL2K Model Setup

This section describes the process that was used to setup the QUAL2K models for the Bear Creek watershed.

B.2.1 Stream Segmentation

Figure B-1 and Figure B-2 provide a visual description of the Bear Creek QUAL2K model structure, including locations of monitoring stations, point sources, nonpoint sources and boundaries. The impaired water body segment is divided into 9 reaches; the lengths of each reach are provided in Table B-1. Reach lengths are based on the location of water quality monitoring stations, stream hydrology, NPDES discharges, shading estimates and point/nonpoint sources. Reaches are further segmented into elements as identified in Table B-1. A element length between 0.03 and 0.09 kilometers was used for all reaches.

As shown in Figure B-2, Bear Creek watershed includes ten tributaries. Each tributary was represented in the model as a unique point source (Figure B-1). Average daily flow for each simulated day and tributary was estimated using a drainage area ratio approach. Using measured flow at the seven monitoring locations, a flow/mi^2 was calculated for each of the seven stations. A watershed average was calculated based flow/mi^2 estimates at Sample Locations 1, 4, 5, 6, 7 and 8. Flow at Sample Location 2 was excluded from this analysis because flow/mi^2 estimates at this location were found, at times, to be less than the average daily Kirksville WWTP discharge located directly upstream from the station. This occurrence was likely the result of variability (throughout the day) in discharge from the Kirksville WWTP and measurement errors.

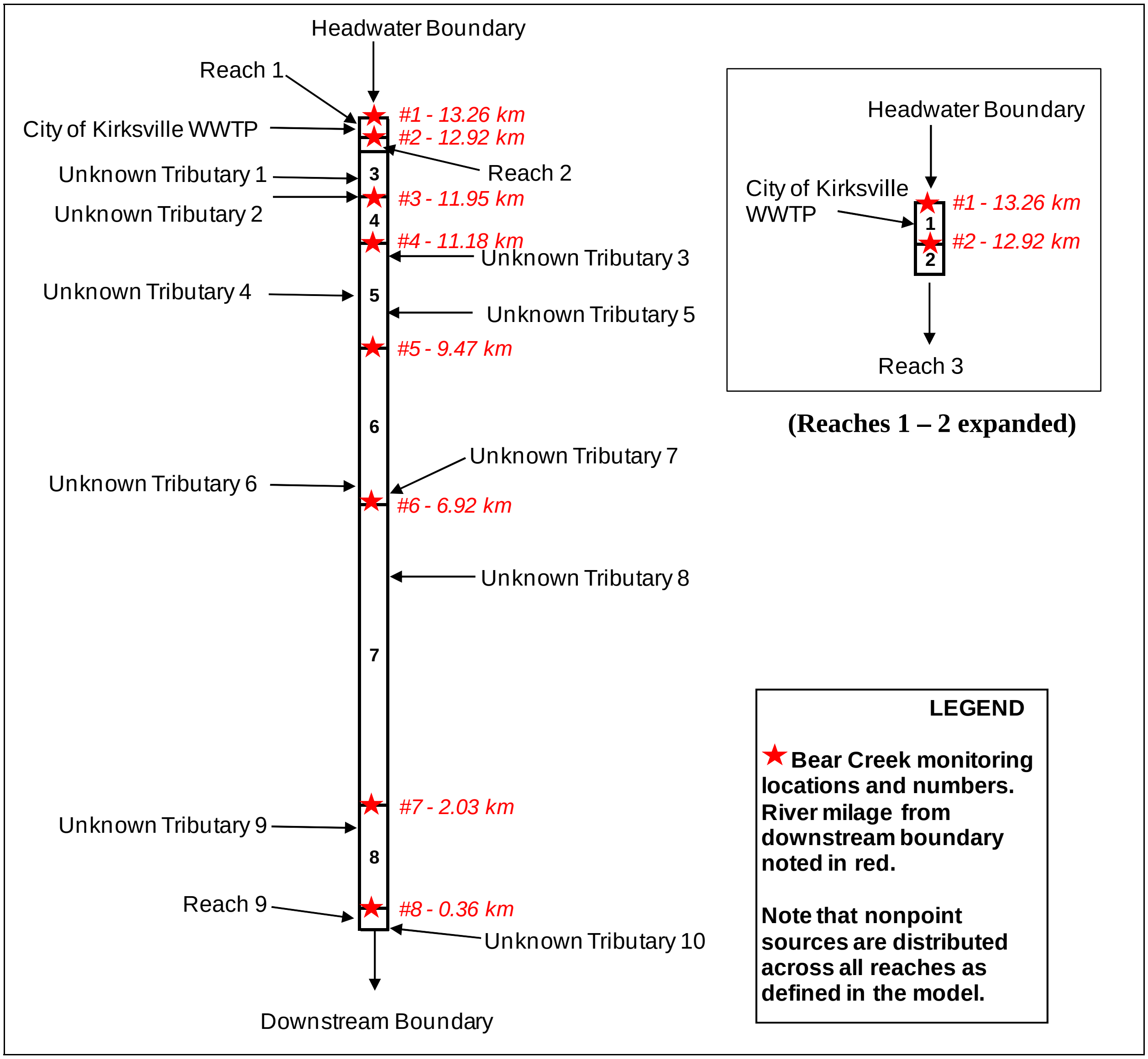

Figure B-1. Diagram of Bear Creek QUAL2K watershed model

Table B-1. Number of Reaches and Elements Associated with Each Reach in Bear Creek

Reach Number	Reach Length (kilometers)	Number of Elements	Element Length (kilometers)
1	0.34	4	0.09
2	0.24	5	0.05
3	0.74	8	0.09
4	0.77	12	0.06
5	1.71	21	0.08
6	2.55	30	0.09
7	4.89	50	0.10
8	1.67	33	0.05
9	0.36	12	0.03

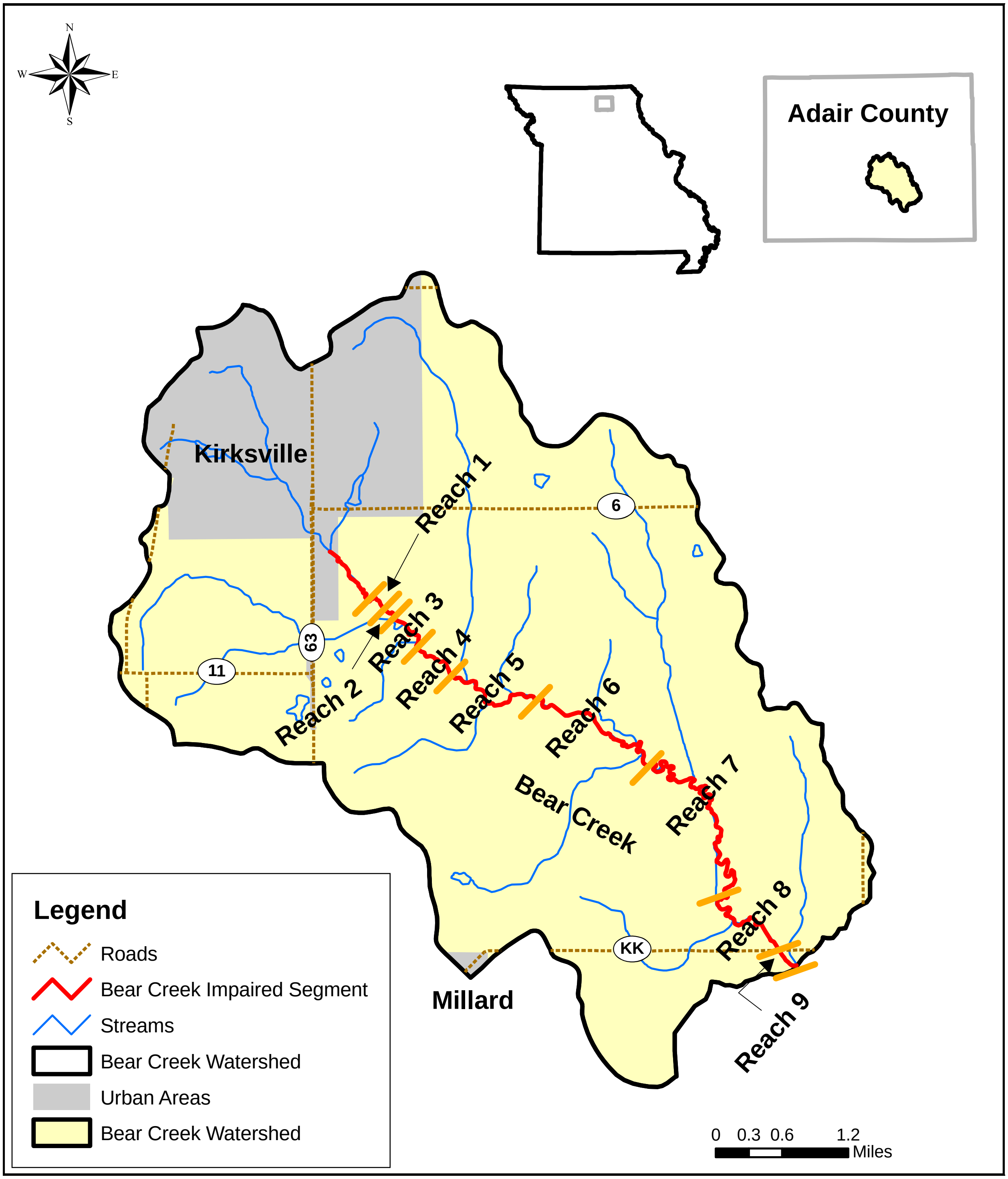

Figure B-2. Reaches in Bear Creek QUAL2K Model

B.2.2 Geometry, Elevation and Weather Data

Measurements of stream velocity, width and depth collected at seven locations in Bear Creek were used to calculate flow rates at each location. QUAL2K allows the user to calculate the flow balance using one of three approaches: weirs, rating curves and Manning equations. For the Bear Creek models, velocity and depth inputs were estimated using rating curves that were developed using Equations 3 and 4, as taken from the QUAL2K User's Manual (Chapra, 2008).

$$U = aQ^b$$ **Equation 3**

Where,

U = Velocity (m/s)
a = Empirical Coefficient
Q = Flow (m^3/s)
b = Empirical Coefficient

$$H = \alpha Q^\beta$$ **Equation 4**

Where,

H = Depth (m)
α = Empirical Coefficient
Q = Flow (m^3/s)
β = Empirical Coefficient

a, b, α and β are empirical coefficients that are determined from velocity-discharge and stage-discharge rating curves. Within QUAL2K the values of velocity and depth are used to estimate reach average cross-sectional area and width by:

$$A_c = \frac{Q}{U}$$ **Equation 5**

Where,

A_c = average cross-sectional area (m^2)
Q = flow (m^3/s)
U = velocity (m/s)

$$B = \frac{A_c}{H}$$ **Equation 6**

Where,

B = width (m)
A_c = average cross-sectional area (m^2)
H = depth (m)

The surface area and volume of the element can then be computed as:

$$A_s = B\Delta x$$ **Equation 7**

Where,

A_s = surface area (m^2)
B = width (m)
Δx = length of element

$$V = BH\Delta x$$ **Equation 8**

Where,

V = volume (m^3)
B = width (m)
H = depth (m)
Δx = length of element

The measured hydraulic characteristics collected during the spring and summer of 2009 are included in Table B-2 and the rating curves calculated from this data are included in Table B-3.

Table B-2. Measured width, average depth, area, velocity and flow used to develop rating curves for QUAL2K hydraulic inputs

Site	Date	Flow (cms)	Width (meters)	Average Depth (meters)	Area (square meters)	Velocity (m/s)
Bear 1	04/01/09	0.053	3.353	0.388	1.301	0.040
Bear 1	07/14/09	0.0021	3.353	0.29649	0.9941	0.0021
Bear 1	07/14/09	0.1914	3.429	0.47278	1.6212	0.1180
Bear 1	07/15/09	0.0063	3.581	0.34112	1.2217	0.0051
Bear 1	07/15/09	0.0134	3.536	0.33371	1.1799	0.0114
Bear 1	08/25/09	0.0335	3.353	0.34360	1.1520	0.0291
Bear 1	08/26/09	0.0232	3.612	0.36023	1.3011	0.0178
Bear 2	04/01/09	0.293	3.658	0.310	1.133	0.259
Bear 2	07/14/09	0.0778	2.134	0.33093	0.7061	0.1101
Bear 2	07/14/09	0.3804	3.353	0.46552	1.5608	0.2437
Bear 2	07/15/09	0.0752	1.905	0.39259	0.7479	0.1006
Bear 2	07/15/09	0.0985	2.210	0.35315	0.7804	0.1262
Bear 2	08/25/09	0.0941	3.581	0.30740	1.1009	0.0855
Bear 2	08/26/09	0.1554	3.353	0.39624	1.3285	0.1169
Bear 4	04/01/09	0.352	3.429	0.312	1.071	0.328
Bear 4	07/14/09	0.0685	2.819	0.31716	0.8942	0.0766
Bear 4	07/14/09	0.1561	3.429	0.38067	1.3053	0.1196
Bear 4	07/15/09	0.0856	3.124	0.33231	1.0382	0.0825
Bear 4	07/15/09	0.1078	3.505	0.32932	1.1543	0.0934
Bear 4	08/25/09	0.0813	3.429	0.21946	0.7525	0.1080
Bear 4	08/26/09	0.1482	3.566	0.36759	1.3109	0.1130
Bear 5	04/01/09	0.348	5.410	0.520	2.813	0.124
Bear 5	07/14/09	0.1068	7.315	0.49658	3.6326	0.0294
Bear 5	07/14/09	0.1209	7.315	0.47753	3.4932	0.0346
Bear 5	07/15/09	0.1305	7.772	0.49486	3.8463	0.0339

Site	Date	Flow (cms)	Width (meters)	Average Depth (meters)	Area (square meters)	Velocity (m/s)
Bear 5	07/15/09	0.1088	8.001	0.43950	3.5165	0.0309
Bear 5	08/25/09	0.1345	7.772	0.50502	3.9252	0.0343
Bear 5	08/26/09	0.1849	7.315	0.52071	3.8091	0.0485
Bear 6	07/14/09	0.0629	5.791	0.47565	2.7546	0.0228
Bear 6	07/14/09	0.0530	5.486	0.47583	2.6106	0.0203
Bear 6	07/15/09	0.0895	5.944	0.49863	2.9637	0.0302
Bear 6	07/15/09	0.0731	5.944	0.47127	2.8011	0.0261
Bear 6	08/25/09	0.1291	5.563	0.48226	2.6826	0.0481
Bear 6	08/26/09	0.1609	5.410	0.49370	2.6710	0.0603
Bear 6	04/01/09	0.426	6.096	0.573	3.493	0.122
Bear 7	04/01/09	0.551	6.706	0.441	2.954	0.187
Bear 7	07/14/09	0.0801	6.858	0.27500	1.8860	0.0425
Bear 7	07/14/09	0.0786	6.858	0.29600	2.0300	0.0387
Bear 7	07/15/09	0.1179	6.858	0.30616	2.0997	0.0561
Bear 7	07/15/09	0.0905	6.858	0.30006	2.0579	0.0440
Bear 7	08/25/09	0.1554	6.706	0.30446	2.0416	0.0761
Bear 7	08/26/09	0.1678	6.782	0.30754	2.0857	0.0805
Bear 8	04/01/09	0.632	6.858	0.347	2.378	0.266
Bear 8	07/14/09	0.0778	8.535	0.47952	4.0925	0.0190
Bear 8	07/14/09	0.1314	8.687	0.53153	4.6174	0.0285
Bear 8	07/15/09	0.1691	8.382	0.58411	4.8961	0.0345
Bear 8	07/15/09	0.1302	8.382	0.55973	4.6917	0.0278
Bear 8	08/25/09	0.1571	8.535	0.34236	2.9219	0.0538
Bear 8	08/26/09	0.1841	8.458	0.30453	2.5758	0.0715

Table B-3. Rating Curve QUAL2K Model Inputs

Model Reach	Sample Location	Velocity		Depth	
		Coefficient	Exponent	Coefficient	Coefficient
1	1	0.5687	0.911	0.5143	0.092
2	2	0.4571	0.6097	0.4289	0.0863
3	2	0.4571	0.6097	0.4289	0.0863
4	2	0.6459	0.8183	0.3928	0.0998
5	4	0.4078	1.1951	0.5849	0.0899
6	5	0.2787	0.8944	0.598	0.0858
7	6	0.3147	0.8012	0.4791	0.2117
8	7	0.4887	1.3182	0.3048	-0.2026
9	8	0.4887	1.3182	0.3048	-0.2026

Hourly air temperature, dew point temperature and wind speed were retrieved from the National Climatic Data Center (NCDC). Measurements at the Kirksville Regional Airport weather station (ID 14938) were used because of the close proximity of this station to the watershed. Table B-3 displays the hourly weather data used for July 15, 2009 and August 25-26, 2009 modeled periods.

Table B-3. Hourly Weather Data for July 15, 2009 and August 25-26, 2009 from the Kirksville Regional Airport Weather Station (ID 14938)

Date/Time	Air Temperature ºC	Dew point Temperature ºC	Wind speed (m/s)	Percent Cloud Cover
July 15, 2009				
12:00 AM	22.8	22.2	5.36	19
1:00 AM	22.8	21.7	4.47	0
2:00 AM	22.1	21.9	4.92	19
3:00 AM	22.2	21.7	2.24	19
4:00 AM	22.7	21.9	3.69	80
5:00 AM	22.1	21.0	1.19	54
6:00 AM	22.1	21.0	0.00	31
7:00 AM	22.4	21.9	0.00	58
8:00 AM	23.1	22.1	0.00	63
9:00 AM	24.8	22.4	3.13	22
10:00 AM	27.2	22.2	4.02	0
11:00 AM	27.8	21.1	2.68	0
12:00 PM	29.4	20.6	3.13	0
1:00 PM	28.9	18.9	2.24	0
2:00 PM	29.4	18.3	3.13	0
3:00 PM	29.4	18.9	3.13	0
4:00 PM	29.4	18.9	3.13	0
5:00 PM	28.9	18.3	4.47	0
6:00 PM	28.3	18.9	3.58	0
7:00 PM	27.2	18.3	3.13	0
8:00 PM	25.0	18.0	1.34	0
9:00 PM	20.6	18.3	2.24	0
10:00 PM	20.0	17.0	1.34	0
11:00 PM	20.6	16.7	1.34	0
August 25, 2009				
12:00 AM	16.7	15.0	3.58	0
1:00 AM	16.7	15.0	3.58	0
2:00 AM	16.7	15.0	3.13	0
3:00 AM	15.0	14.0	3.13	0
4:00 AM	13.9	13.3	2.68	0
5:00 AM	14.4	13.9	3.13	0
6:00 AM	15.6	15.0	3.13	0
7:00 AM	16.7	15.6	4.47	0
8:00 AM	17.8	16.1	3.13	19
9:00 AM	19.4	17.2	4.47	0
10:00 AM	20.6	16.7	5.36	0
11:00 AM	23.9	18.9	4.47	0

Date/Time	Air Temperature ºC	Dew point Temperature ºC	Wind speed (m/s)	Percent Cloud Cover
12:00 PM	25.6	20.0	5.36	0
1:00 PM	26.7	20.6	4.02	0
2:00 PM	28.3	21.1	3.58	0
3:00 PM	28.9	20.0	5.81	0
4:00 PM	28.9	20.6	4.02	0
5:00 PM	28.9	21.1	4.47	0
6:00 PM	28.3	20.0	4.02	0
7:00 PM	26.1	20.6	3.58	0
8:00 PM	22.8	20.0	1.34	0
9:00 PM	21.1	19.4	2.24	0
10:00 PM	20.6	18.9	2.24	0
11:00 PM	20.6	18.9	1.34	75
August 26, 2009				
12:00 AM	18.9	17.8	3.13	0
1:00 AM	19.4	17.8	2.68	44
2:00 AM	19.4	17.2	3.13	0
3:00 AM	20.0	17.0	3.58	0
4:00 AM	19.4	17.2	2.24	0
5:00 AM	18.9	17.2	0.00	0
6:00 AM	18.3	17.2	1.34	0
7:00 AM	20.0	18.0	2.68	0
8:00 AM	22.2	18.9	2.68	0
9:00 AM	23.9	19.4	2.68	0
10:00 AM	23.9	19.4	1.34	0
11:00 AM	24.4	20.6	2.24	19
12:00 PM	26.7	22.2	3.13	19
1:00 PM	26.7	22.2	2.68	19
2:00 PM	26.7	22.8	3.13	0
3:00 PM	26.0	23.0	2.68	75
4:00 PM	26.6	22.9	2.68	46
5:00 PM	27.2	22.8	3.13	0
6:00 PM	26.7	22.8	2.68	30
7:00 PM	25.6	23.3	2.24	0
8:00 PM	24.4	23.3	2.24	40
9:00 PM	23.9	22.9	2.01	0
10:00 PM	23.6	22.6	2.68	40
11:00 PM	24.0	23.0	2.68	40

B.2.3 Boundary Conditions

Water quality and stream channel information collected at the most upstream station were used to specify headwater boundary conditions for most parameters. The following constituents and parameters were based on data collected at the most upstream station (Sample Location #1): flow, $CBOD_5$, organic nitrogen, ammonium-nitrogen, organic phosphorus, inorganic phosphorus, pH and rating curve velocity and depth coefficient and exponent inputs. Hourly estimates for temperature and DO were initially calculated using a polynomial regression on daily measurements. Separate regressions were developed for DO and temperature on July 15, 2009, August 25, 2009 and August 26, 2009 by utilizing morning and afternoon samples for each day at Sample Location #1. Hourly air temperature inputs on August 25, 2009 and August 26, 2009 were adjusted to improved water temperature calibration during both days. This value was based on the morning measurement on July 15, 2009 at Sample Location #1. Hourly headwater inputs are provided in Table B-4.

Table B-4. Bear Creek QUAL2K Headwater Model Input Values for July 15, August 25 and August 26

Constituent	QUAL2K Headwater Model Input values		
	July 15, 2009	August 25, 2009	August 26, 2009
Flow (cms)	0.01	0.033	0.024
Temperature (Degree C)[1]	23.97 – 25.56	17.51 – 19.79	20.00
Dissolved Oxygen (mg/L)[1]	3.00	6.70 – 8.10	5.85 – 6.55
CBOD Ultimate (mg O_2/L)	5.00	4.75	3.50
Organic Nitrogen (µg N/L)	492.00	362.00	389.00
NH4-Nitrogen (µg N/L)	250.00	250.00	250.00
NO3-Nitrogen (µg N/L)	290.50	178.50	163.67
Organic Phosphorus (µg P/L)	81.00	46.75	45.35
Inorganic Phosphorus (µg P/L)	6.00	8.25	5.15
Alkalinity (mg $CaCO_3$/L)	100.00	100.00	100.00
pH	7.05	7.41	7.41

[1] Values for temperature and DO vary hourly

B.2.4 Point Sources

Point source inputs for the QUAL2K model were obtained from discharge monitoring reports provided by MDNR and are summarized in Table B-5. Two point sources were simulated in the model: the Kirksville WWTP, which discharges at kilometer 13.05 (between monitoring Sample Locations #1 and #2) and the Burk Subdivision WWTP, which discharges to a tributary that enters Bear Creek at kilometer 12.52 (between monitoring Sample Locations #3 and #4). A conservative approach was used in simulating flows and loads from the Burk Subdivision WWTP by including them in the model as a direct point source to Bear Creek at kilometer 12.52. Neither of the point sources report organic nitrogen, NO_3 and phosphorus. With the exception of NH_3, estimates for each nutrient fraction were included in the model for Kirksville WWTP, based on instream measurements downstream of the discharge. Model inputs for flow, CBOD, NH_3, DO and other parameters reported by the WWTP in discharge monitoring reports were based on daily records, when available.

Table B-5. Point Source Data Summary

Facility Name	Kirksville WWTP			Burk Subdivision WWTP		
Date:	**7/15/2009**	**8/25/2009**	**8/26/2009**	**7/15/2009**	**8/25/2009**	**8/26/2009**
Discharge Point (km)	13.05	13.05	13.05	12.52	12.52	12.52
Flow (cms)	0.0896	0.0959	0.1016	0.0001	0.0001	0.0001
CBOD Ultimate (mg/L)	42.00	33.60	28.35	29.75	29.75	29.75
NH_3 (µg/L)	620	520	520	2,900	2,900	2,900
Organic N (µg/L)	2,500 E	2,500 E	2,500 E	2,500 E	2,500 E	2,500 E
Nitrate+Nitrite N (µg/L)	10,400 E	14,000 E	14,000 E	10,400 E	14,000 E	14,000 E
Organic P (µg/L)	4,000 E	5,833 E	5,833 E	4,000 E	5,833 E	5,833 E
Inorganic P (µg/L)	1,800 E	2,500 E	2,500 E	1,800 E	2,500 E	2,500 E
DO (mg/L)	6.0	9.0	8.0	6.0	9.0	8.0

Notes:

1. Discharge location is based on the distance to the end of the stream;
2. E = Estimated value was estimated based on monitoring conducted on each day. All other values determined using DMR data.
3. NS = Data was not simulated for this parameters.
4. Organic N is set equal to TKN minus NH_3; Inorganic P estimated to be 70 percent of TP and Organic P estimated to be 30 percent of TP based on EPA, 1997.

B.2.5 Critical Conditions

The TMDL developed needs to reflect critical conditions of the stream. The critical flow for Bear Creek is the 7Q10 flow of 0.01 cfs (assigned by MDNR). This flow value and the environmental conditions of July 15, 2009 were used to represent critical conditions for Bear Creek. July 15, 2009 was selected for use when modeling critical conditions because observed temperature was the highest and DO was the lowest on this compared to the other days modeled. As presented in Table B-6, the July 15, 2009 sampling event included a DO measurement of 3.125 mg/L. Because of the DO and temperature data this date was adopted as the critical condition.

Table B-6. DO (mg/L) at Each Sampling Location

Sample Location	Stream Distance (km)	7/15/2009	8/25/2009	8/26/2009
1	13.26	3.13	7.40	6.20
2	12.92	6.59	8.50	8.15
4	11.18	5.50	6.80	6.15
5	9.47	4.28	6.55	5.70
6	6.92	5.97	9.04	8.09
7	2.03	8.43	10.31	8.98
8	0.36	8.02	11.15	9.27

Notes: Stream distance is measured from the downstream portion of the impaired segment which is approximately 0.2 miles south of State Highway KK (Figure B-2).

B.3 Model Calibration

This section of the appendix describes the process that was used to calibrate the QUAL2K model for the Bear Creek watershed and presents the calibration results.

B.3.1 Flow and Water Depth Simulations

The model was calibrated for flow, stream velocities and depths for the data collected on July 15, 2009. The project QAPP specified that model calibration would be based on data collected during July 14, 2009 and July 15, 2009. Unfortunately, the influence of precipitation and highly variable discharge at the Kirksville WWTP during July 14 resulted in variable and inconsistent flow measurements and the information was rendered unusable for simulating conditions in the creek.

QUAL2K provides the user with the option to simulate the following flows: boundary headwater flows, point source flows and nonpoint source diffuse flow. Flow can also be "lost" from the model through the simulation of losing reaches or water withdrawals. In the Bear Creek models, nonpoint sources are grouped with tributary flows that are included in the model as point sources. No other water gains or losses were added to the model. A total of ten tributaries are included. Measured flow was not available for the upstream boundary headwater; thus flows from the most upstream monitoring station were used as the boundary flow condition. Daily average reported discharges at two WWTPs were included as separate point sources.

Depths, widths and velocities for each reach were related to flow using the rating curve approach. Flow and its related parameters (velocity and depth) can be reasonably simulated using this approach. Stream velocity, depth and discharge are all critical to the water quality simulation because they influence reaeration, DO, biogeochemical reactions and deposition rates, growth of algal species and the influence of SOD in the stream. Calibration results for flow, depth and velocity are provided for July 15, 2009 in Figure B-3. A summary of all calibration statistics is provided in Table B-10.

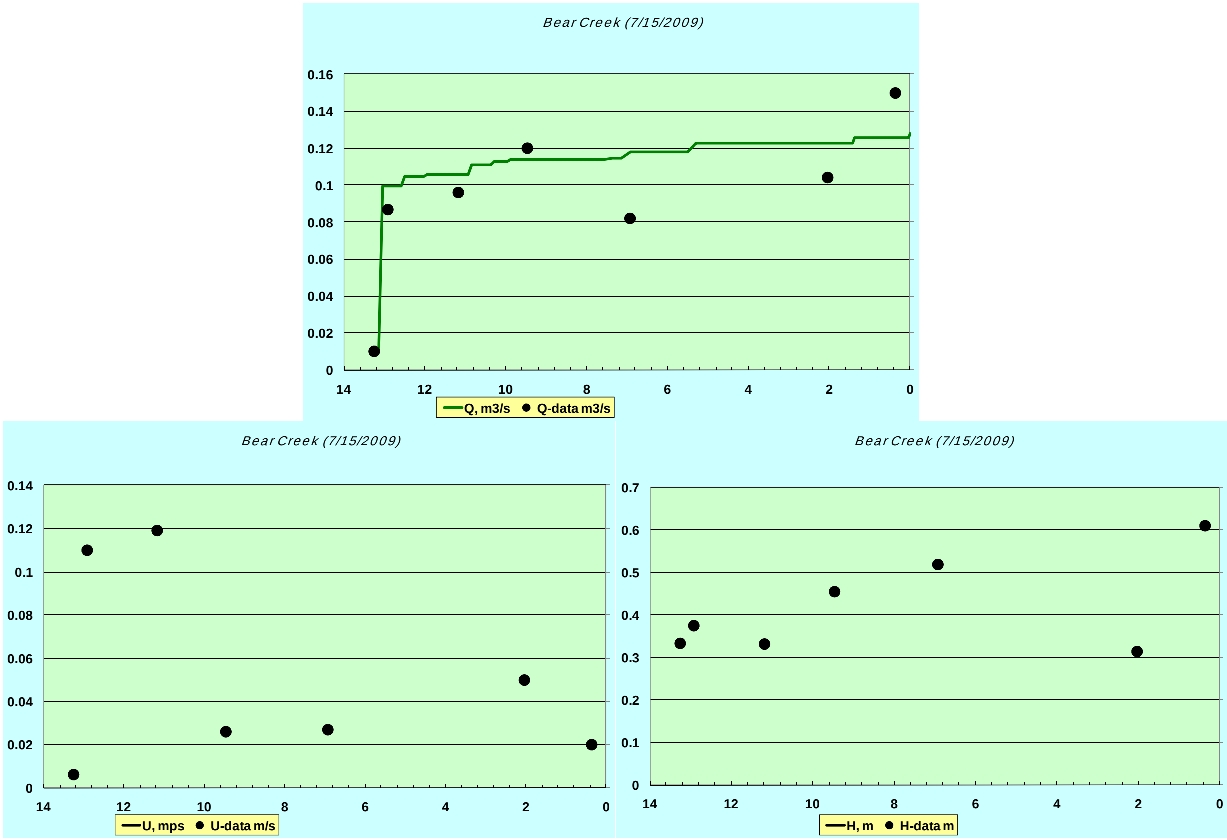

Figure B-3. Comparisons of Observed and Simulated Flow (Q), Velocity (U) and Depth (H) in Bear Creek for July 15, 2009 Calibration Period

B.3.2 Water Quality Calibration

Calibration consists of the process of adjusting model parameters and the initial estimates of boundary conditions to provide a suitable representation of observed conditions. Calibration is necessary because of the semiempirical nature of water quality models. Although these models are formulated from mass balance principles, most of the kinetic descriptions in the models are empirically derived. These empirical derivations contain a number of coefficients that are usually determined by calibration to data collected in the water body. In addition, there is uncertainty associated with the specification of boundary conditions, point source loads and tributary loads. The boundary conditions and tributary loads might need to be adjusted within the uncertainty bounds of available data to achieve model calibration. Water quality calibration for the Bear Creek QUAL2K model relied on comparison of model predictions to observations at seven stations on the mainstem of the system.

Water quality models are often evaluated through visual comparisons, in which the simulated results are plotted against the observed data for the same location and time and are visually evaluated to determine if the model is able to mimic the trend and overall magnitude of the observed conditions. If the model predictions follow the general trend and reproduce the overall magnitude of the observed data, the model is said to represent the dynamics of the system well. The merit of this method is that it is straightforward, taking full advantage of the strength of human intelligence in pattern identification. This method works particularly well when data are limited in quantity and contain significant uncertainty. The limitation of this method is that it relies on the subjective judgment of modelers and lacks quantitative measures to differentiate among sets of calibration result. Because of this, both a visual comparison and quantitative measures were used during the Bear Creek calibration.

BOD is an important calibration parameter because of its influence on DO concentrations. BOD typically consists of two parts: CBOD and nitrogenous biochemical oxygen demand (NBOD). CBOD is the result of the breakdown of organic carbon molecules such as cellulose and sugars into carbon dioxide and water. NBOD is the result of NH_3 oxidation, which is a conversion of NH_3 to NO_3 in the environment. The consumption of nitrogen usually occurs slower than that of CBOD. CBOD is the oxygen consumed by heterotrophic microbes that utilize the organic matter of the waste in their metabolism. Nitrifying bacteria grow slower than the heterotrophic bacteria, which is one of the reasons why NBOD occurs slower.

The parameter “fast reacting CBOD” was used to simulate CBOD in the models. CBOD5 measurements were adjusted by multiplying each value by the average $CBOD_5$:CBOD-ultimate ratio observed at all stations on July 15, 2009. The $CBOD_5$:CBOD-ultimate ratio was calculated to be 3.5. This approach to adjusting $CBOD_5$ model inputs was used for headwater, tributary and WWTP source loads.

The first order kinetic reaction rates for biogeochemical reactions are influenced from the various flow and chemical conditions in streams. Kinetic rates may be estimated from the observed data, stream distance and velocity. However, the estimated rates based on the field data are a function of different physical and chemical mechanisms such as mixing and turbulence, the particulate and dissolved chemical components ratio, physical settling, biochemical decompositions and sorption by biological slimes on river bottom. Thus, applying the derived reaction rate from the field data could overestimate oxygen consumption. In all Bear models, first order reaction rates were selected for the final calibration because they were found to produce the best match to the observed data.

SOD by benthic sediments and organisms can be a large fraction of oxygen consumption in the stream. Benthic sediments can be composed of inorganic minerals and organic material such as leaf litter, particulate and dissolved BOD, detritus from phytoplankton/periphyton and macrophytes. Reduced inorganic and organic materials can exert SOD by diffused oxygen into sediments or oxygen consumption in water column after the inorganic and organic materials are suspended from the sediments. In addition to physical and chemical characteristics of sediments, the impact that SOD has on water column DO can be affected by water depth, stream velocity and water temperature.

SOD is primarily a function of oxidation of dissolved ammonium, methane and decomposition of organic matter by bacteria. Additionally, dissolved hydrogen sulfide and reduced iron and manganese could consume DO once they diffuse into the aerobic sediment layers. The amount of organic matter can be related to SOD consumption.

Organic matter can be described by Redfield ratio, $C_{106}H_{263}O_{110}N_{16}P$. As this ratio suggests, the bacterial conversion (decomposition) of the organic matter can generate the rapidly reactive dissolved N and C species. These species eventually exert SOD from within sediments and at the interface between water column and sediments. SOD can be measured using the respiration chamber but the method can have high uncertainty and the data was not collected for Bear Creek. SOD values were estimated using the QUAL2K sediment diagenesis routines. Percent bottom SOD coverage was based on the percent fine material identified in the stream reach during the 2009 sampling events.

Benthic algae (periphyton) kinetics also have a marked effect on DO concentrations and diurnal swings (EPA, 1985). Periphyton dynamics were included in model calibration to account for the observed diurnal variation in DO. Algal growth, respiration, death and related nutrient kinetics were adjusted within typical literature values (EPA, 1985; Ambrose, 2006) to best match the observed DO variations and nutrient concentrations from the July sampling events.

The method for the oxygen reaeration selected was the "Internal" option (patterned after Covar 1976). This method selects the appropriate reaeration formula depending on site-specific depth (H) and velocity (U):

- If $H < 0.61$ m, use the Owens-Gibbs formula
- If $H > 0.61$ m and $H > 3.45U^{2.5}$, use the O'Connor-Dobbins formula
- Otherwise, use the Churchill formula

The final rates used for the Bear Creek calibration are presented in Table B-8. Figures B-4 through B-8 present the results of the model calibrations, including temperature, DO, CBOD, TKN, ammonium, NO_3, TN and TP. A visual inspection of the plots indicates that the model predictions follow the general trend and reproduce the overall magnitude of the observed data well. Simulated TP does not match measured values below kilometer 9.47 (Sample Location #5). Measured data suggest there to be a nonpoint source influence between Sample Locations #5 and #6 on this day. Elevated phosphorus at this location was not evident during August 25, 2009 and August 26, 2009; and therefore, the model was not adjusted to include the phosphorus source.

The quantitative calibration metrics that were used to assess the calibration include the evaluation of average error, residual error, root mean squared error (RSME), coefficient of determination (R^2), relative error and percent bias. Table B-9 reports the statistical measure and equation for each quantitative calibration metrics used to evaluate the calibration. Table B-10 presents statistical results for calibration and validation model runs for flow, DO, TN, NO_3, TKN and TP.

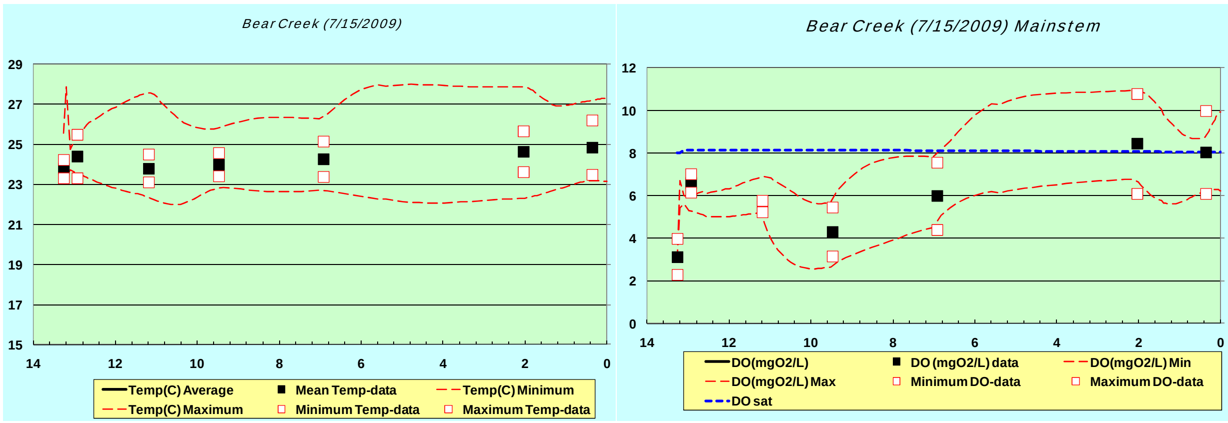

Figure B-4. Temperature and DO Calibration in Bear Creek

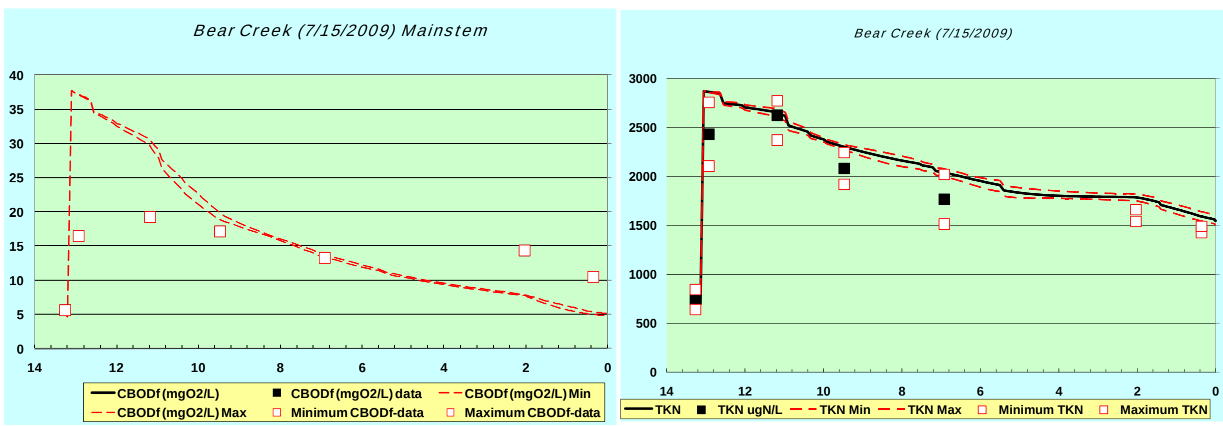

Figure B-5. CBOD and TKN Calibration in Bear Creek

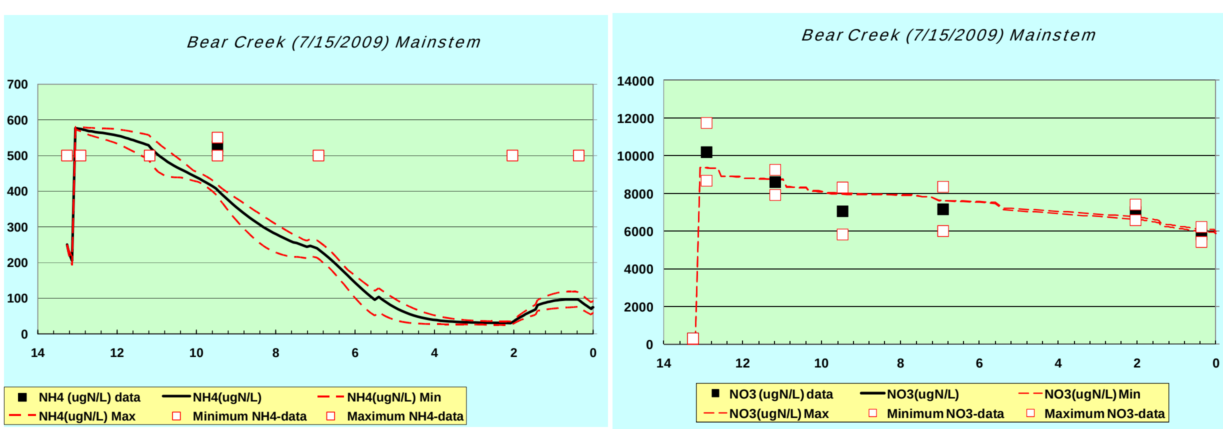

Figure B-6. Ammonium and Nitrate Calibration in Bear Creek (with the exception of a measurement at monitoring location 4, all measured ammonia was below the detection limit of 500 µg/L)

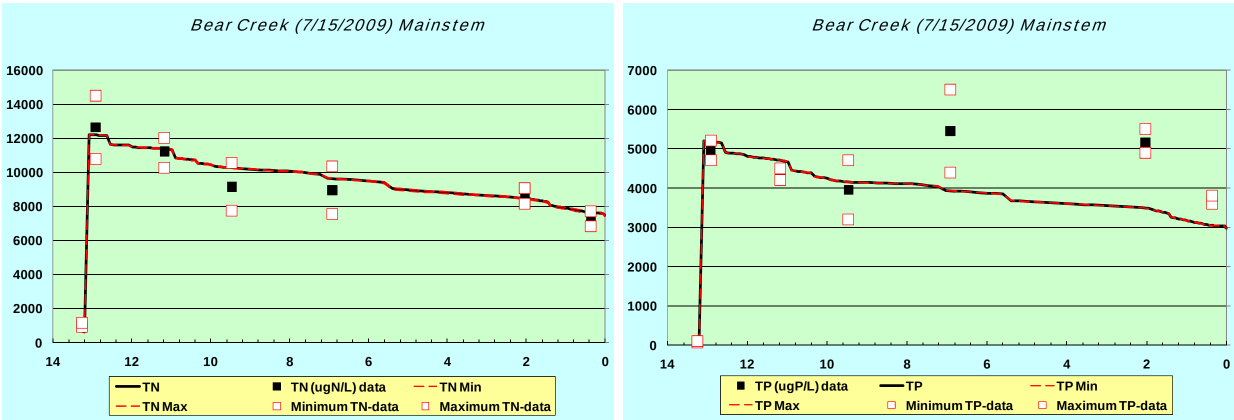

Figure B-7. Total Nitrogen and Phosphorus Calibration in Bear Creek

Table B-8. Rates used for the Bear Creek QUAL2K calibration

Parameter	***Value***	***Units***	***Symbol***
Stoichiometry:			
Carbon	40	gC	gC
Nitrogen	7.2	gN	gN
Phosphorus	1	gP	gP
Dry weight	100	gD	gD
Chlorophyll	1	gA	gA
Inorganic suspended solids:			
Settling velocity	1.304	m/d	v_i
Oxygen:			
Reaeration model	Internal		
User reaeration coefficient α	0		α
User reaeration coefficient β	0		β
User reaeration coefficient γ	0		γ
Temp correction	1.024		θ_a
Reaeration wind effect	None		
O2 for carbon oxidation	2.69	gO_2/gC	r_{oc}
O2 for NH4 nitrification	4.57	gO_2/gN	r_{on}
Oxygen inhib model CBOD oxidation	Exponential		
Oxygen inhib parameter CBOD oxidation	0.60	L/mgO2	K_{socf}
Oxygen inhib model nitrification	Exponential		
Oxygen inhib parameter nitrification	0.60	L/mgO2	K_{sona}
Oxygen enhance model denitrification	Exponential		
Oxygen enhance parameter denitrification	0.60	L/mgO2	K_{sodn}
Oxygen inhib model phyto resp	Exponential		
Oxygen inhib parameter phyto resp	0.60	L/mgO2	K_{sop}
Oxygen enhance model bot alg resp	Exponential		
Oxygen enhance parameter bot alg resp	0.60	L/mgO2	K_{sob}

Parameter	***Value***	***Units***	***Symbol***
Slow CBOD:			
Hydrolysis rate	0	/d	k_{hc}
Temp correction	1.047		θ_{hc}
Oxidation rate	0	/d	k_{dcs}
Temp correction	1.047		$_{dcs}$
Fast CBOD:			
Oxidation rate	0.34	/d	k_{dc}
Temp correction	1.047		θ_{dc}
Organic N:			
Hydrolysis	0.07	/d	k_{hn}
Temp correction	1.07		θ_{hn}
Settling velocity	0.08	m/d	v_{on}
Ammonium:			
Nitrification	0.1	/d	k_{na}
Temp correction	1.07		θ_{na}
Nitrate:			
Denitrification	0.1	/d	k_{dn}
Temp correction	1.07		θ_{dn}
Sed denitrification transfer coeff	0	m/d	v_{di}
Temp correction	1.07		θ_{di}
Organic P:			
Hydrolysis	0.06	/d	k_{hp}
Temp correction	1.07		θ_{hp}
Settling velocity	0.08	m/d	v_{op}
Inorganic P:			
Settling velocity	0.12	m/d	v_{ip}
Inorganic P sorption coefficient	0.073	L/mgD	K_{dpi}
Sed P oxygen attenuation half sat constant	1.831	mgO_2/L	k_{spi}
Phytoplankton:			
Max Growth rate	3	/d	k_{gp}
Temp correction	1.07		θ_{gp}
Respiration rate	0.05	/d	k_{rp}
Temp correction	1.07		θ_{rp}
Excretion rate	0.04	/d	k_{ep}
Temp correction	1.07		θ_{dp}
Death rate	0.01	/d	k_{dp}
Temp correction	1.047		θ_{dp}
External Nitrogen half sat constant	100	ugN/L	k_{sPp}
External Phosphorus half sat constant	40	ugP/L	k_{sNp}
Inorganic carbon half sat constant	1.30E-05	moles/L	k_{sCp}

Parameter	***Value***	***Units***	***Symbol***
Light model	Half saturation		
Light constant	15	langleys/d	K_{Lp}
Ammonia preference	25	ugN/L	k_{hnxp}
Subsistence quota for nitrogen	0.72	mgN/mgA	q_{0Np}
Subsistence quota for phosphorus	0.1	mgP/mgA	q_{0Pp}
Maximum uptake rate for nitrogen	72	mgN/mgA/d	ρ_{mNp}
Maximum uptake rate for phosphorus	5	mgP/mgA/d	ρ_{mPp}
Internal nitrogen half sat constant	0.9	mgN/mgA	K_{qNp}
Internal phosphorus half sat constant	0.13	mgP/mgA	K_{qPp}
Settling velocity	0	m/d	v_a
Bottom Algae:			
Growth model	First-order		
Max Growth rate	1.0	$mgA/m^2/d$ or /d	C_{gb}
Temp correction	1.07		θ_{gb}
First-order model carrying capacity	1000	mgA/m^2	$a_{b,max}$
Respiration rate	0.18	/d	k_{rb}
Temp correction	1.07		θ_{rb}
Excretion rate	0.09	/d	k_{eb}
Temp correction	1.07		θ_{db}
Death rate	0.05	/d	k_{db}
Temp correction	1.07		θ_{db}
External nitrogen half sat constant	100	ugN/L	k_{sPb}
External phosphorus half sat constant	40	ugP/L	k_{sNb}
Inorganic carbon half sat constant	1.30E-05	moles/L	k_{sCb}
Light model	Half saturation		
Light constant	40	langleys/d	K_{Lb}
Ammonia preference	25	ugN/L	k_{hnxb}
Subsistence quota for nitrogen	0.72	mgN/mgA	q_{0N}
Subsistence quota for phosphorus	0.1	mgP/mgA	q_{0P}
Maximum uptake rate for nitrogen	72	mgN/mgA/d	ρ_{mN}
Maximum uptake rate for phosphorus	5	mgP/mgA/d	ρ_{mP}
Internal nitrogen half sat constant	0.9	mgN/mgA	K_{qN}
Internal phosphorus half sat constant	0.13	mgP/mgA	K_{qP}
Detritus (POM):			
Dissolution rate	0.2	/d	k_{dt}
Temp correction	1.07		$_{dt}$
Fraction of dissolution to fast CBOD	1.00		F_f
Settling velocity	0.08	m/d	v_{dt}
Pathogens:			
Decay rate	0.8	/d	k_{dx}

Parameter	Value	Units	Symbol
Temp correction	1.07		θ_{dx}
Settling velocity	1	m/d	v_x
Light efficiency factor	1.00		v_x
pH:			
Partial pressure of carbon dioxide	347	ppm	p_{CO2}

B.3.3 Model Validation

Typically, the performance of a calibrated model is evaluated through "validation." Model validation is defined as "subsequent testing of a pre-calibrated model to additional field data, usually under different external conditions, to further examine the model's ability to predict future conditions" (Chapra, 1997). Its purpose is to ensure that the calibrated model properly assesses all the variables and conditions that can affect model results and demonstrate the ability to predict field observations for periods separate from the calibration effort (Donigian, 2003).

Validation of the Bear Creek model was conducted using the data collected on August 25, 2009 and August 26, 2009. System rates and coefficients were initially set equal to the values selected in the calibration runs. Minor adjustments were made to nutrient rates (oxidation, hydrolysis, sorption and settling rates) and bottom algae (growth and respiration rates). These adjustments were made using best professional judgment based on previous experience with similar modeling projects. All adjustments in validation runs were incorporated in the July 15, 2009 model runs so that all three models contained the same system rates and coefficients.

Headwater and tributary flows were set equal to the average of morning and afternoon flow measurements on each respective day. Similarly, model inputs for headwater and tributary nutrients, DO, CBOD and pH were also based on average field measurements or calculated based on field measurements (in the case of organic nitrogen, organic phosphorus and inorganic phosphorus) on each respective day. Initial model inputs for air temperature, dew point temperature, wind speed, cloud cover and shade were based on weather station data (see Section 2.3 for discussion on station location. The stations used for this analysis are within one-half mile of the Bear Creek watershed). In calibration runs, model inputs for air temperature and dew point temperature were decreased from measured values in the August 26 model to obtain a better model fit for water temperature. In general, average hourly air temperature measurements reported on August 26, 2009 were 2º C higher than on August 25, 2009. Adjusted August 26, 2009 were approximately 1º C higher than inputs used in the August 25, 2009 model. Decreases to the shade factor were made in Reach 1 in both August models to assist in matching DO concentrations at the first sampling location.

The sediment digenesis routine was used to estimate SOD. Percent reach with SOD coverage was estimated from sediment characterization data collected during sampling. SOD coverage was set at the percent of creek bottom with sand, silt or clay (Table B-9). The validation results are presented in Figures B-8 to B-16 and suggest that the model performs nearly as well or better than the calibration for most parameters.

Table B-9. Rates used for the Percent Bottom SOD Coverage in Bear Creek

	Reach Number								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Bottom SOD Coverage	50%	50%	50%	50%	35%	10%	20%	100%	20%

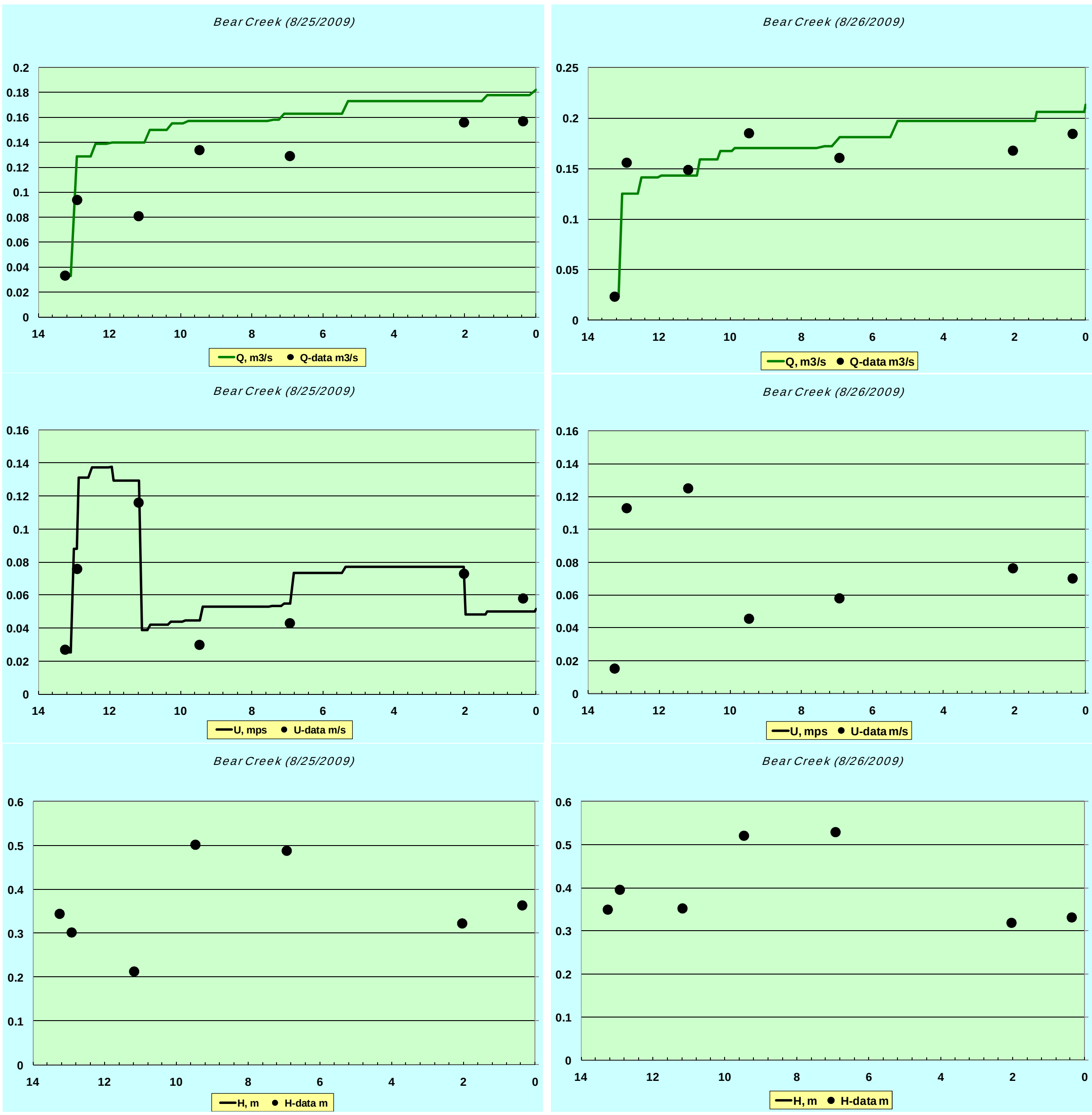

Figure B-8. Validations of Observed and Simulated Flow (Q), Velocity (U) and Depth (H) in Bear Creek

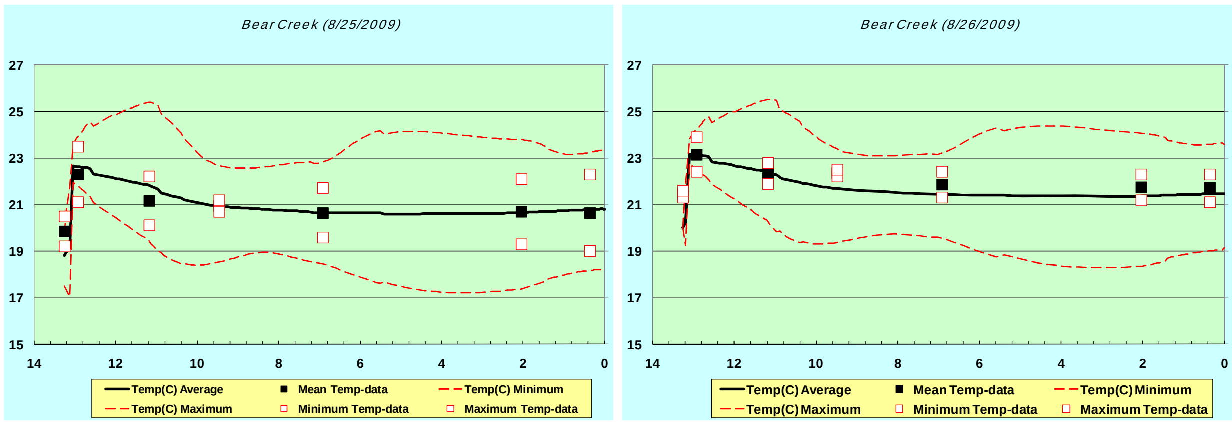

Figure B-9. Temperature Validation in Bear Creek

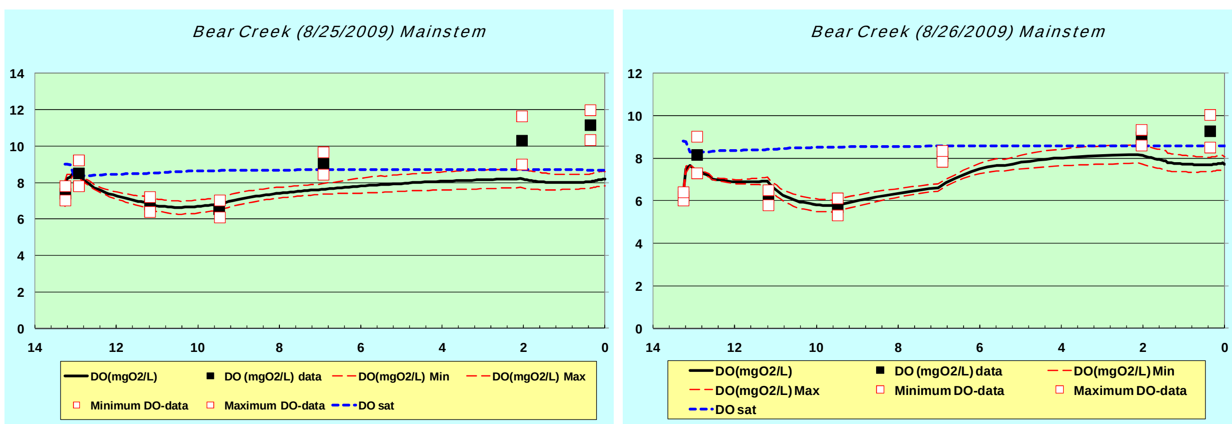

Figure B-10. DO Validation in Bear Creek

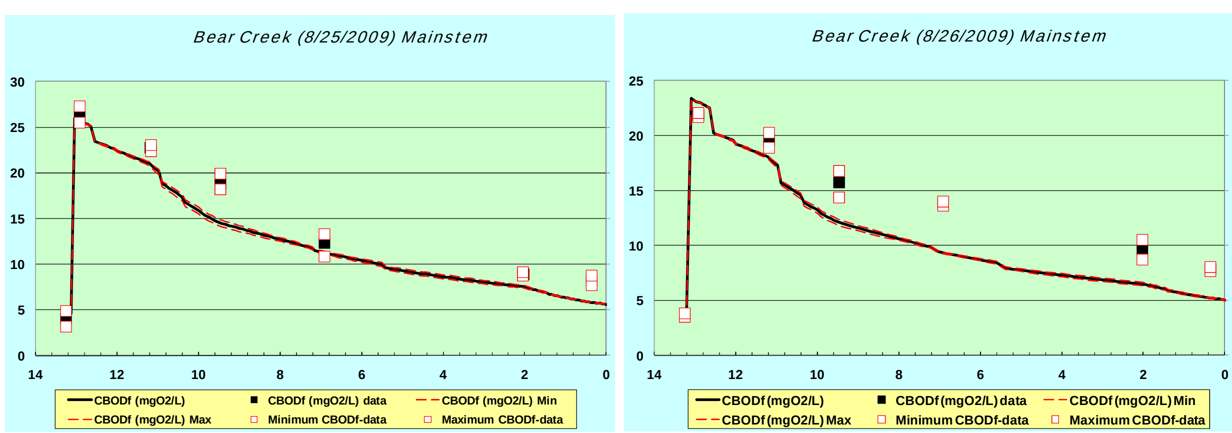

Figure B-11. CBOD Validation in Bear Creek

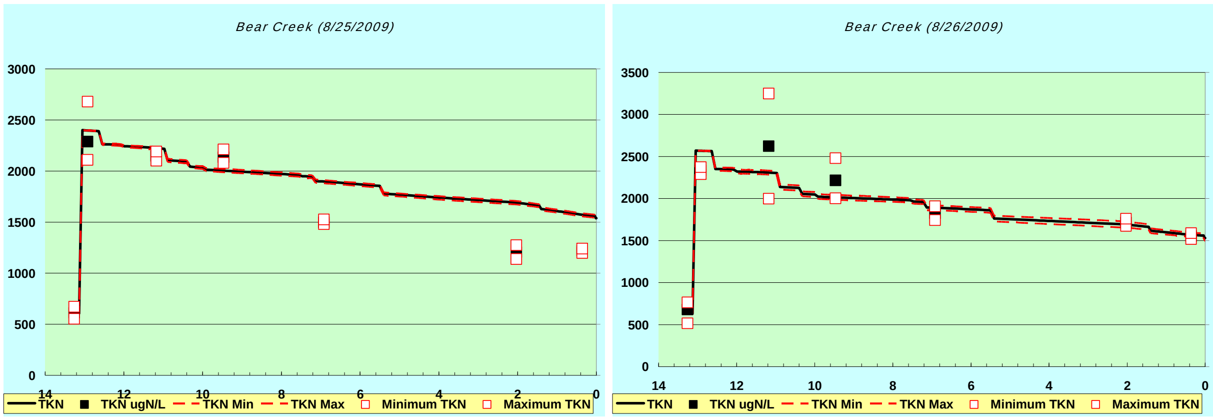

Figure B-12. TKN Validation in Bear Creek

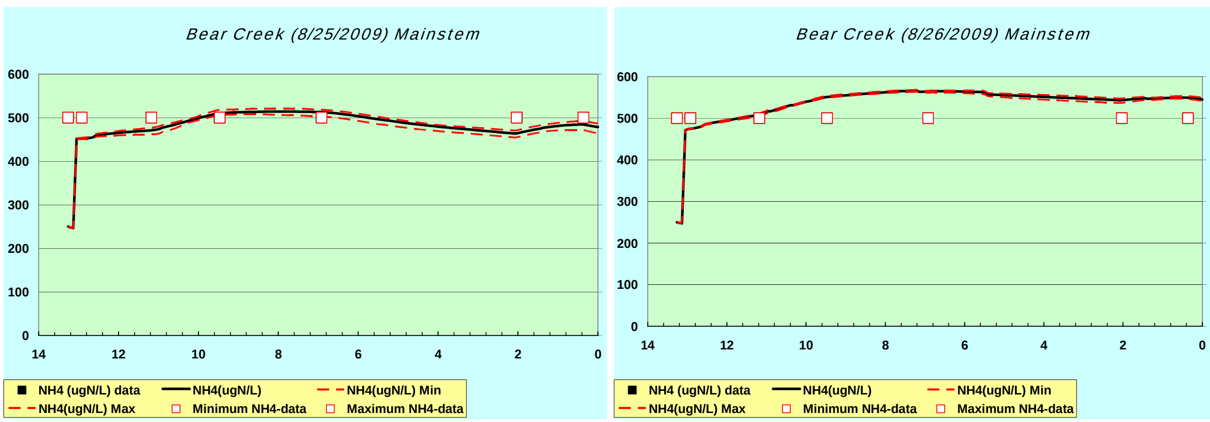

Figure B-13. Ammonium Validation in Bear Creek (all measured ammonia was below the detection limit of 500 µg/L)

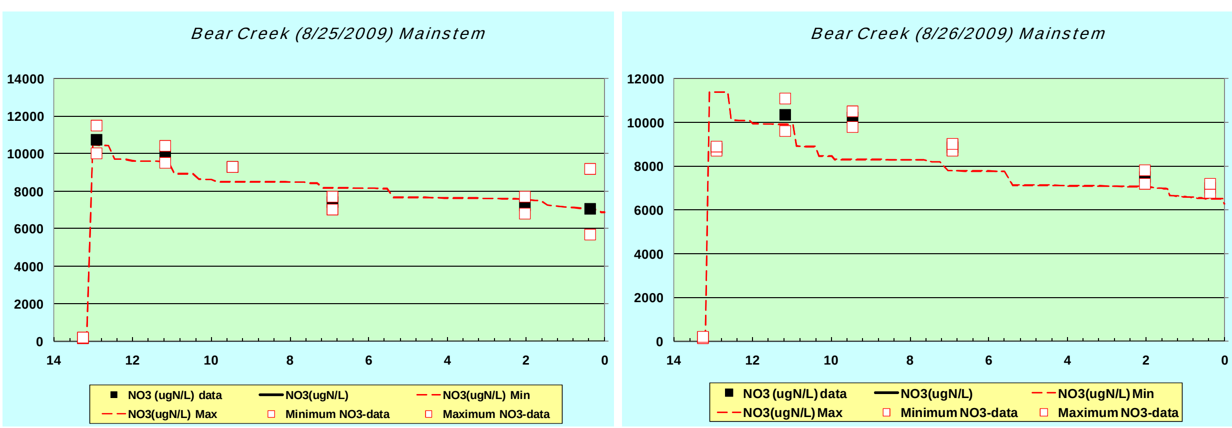

Figure B-14. Nitrate Validation in Bear Creek

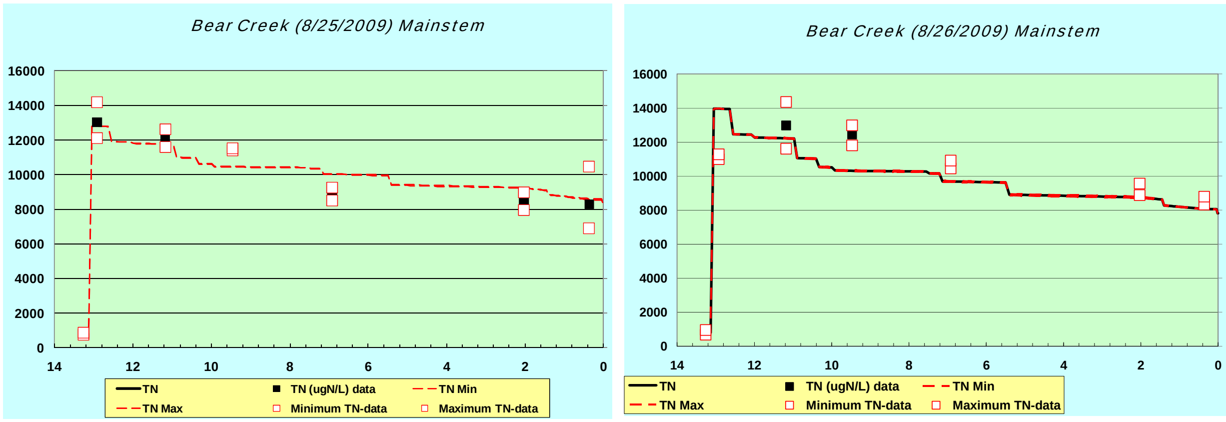

Figure B-15. Total Nitrogen Validation in Bear Creek

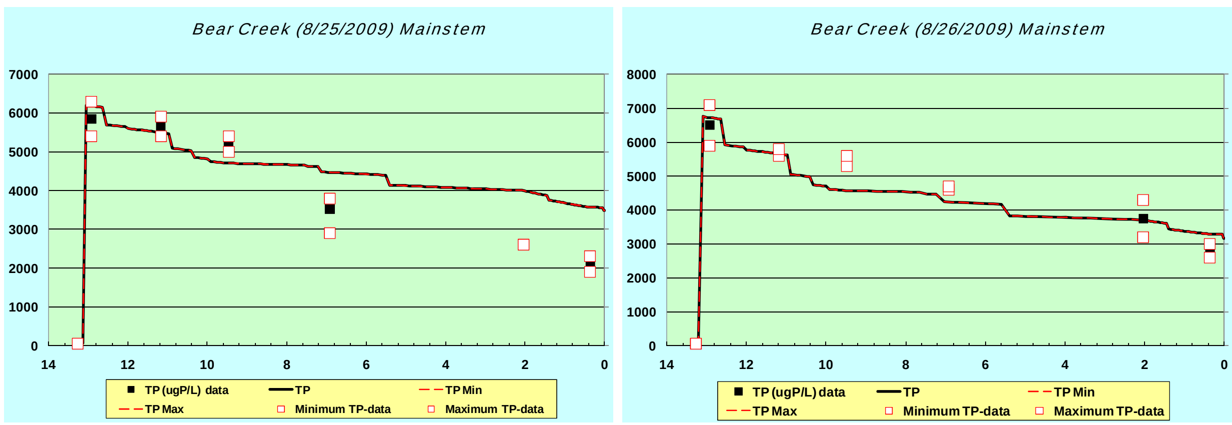

Figure B-16. Total Phosphorus Validation in Bear Creek

B.3.4 Model Goodness of Fit Discussion

The calibration and validation periods were assessed visually and statistically. The figures presented above demonstrate that the model follows the same patterns and trends and the measured data and the statistics quantify the differences between the simulated and measured data. The statistics used to evaluate the model are listed in Table B-10 and the statistical comparison between the model results and observed data are included in Table B-11.

The statistics demonstrate that the model results in prediction similar to those measured in the field. Specifically, the following statistics demonstrate a good model fit:

- The RMSE for DO is near 1 mg/L
- Coefficient of determination (r^2) is high for all parameters and suggests a high degree of correlation between the simulated model results and observed water quality data.

- The percent Bias is generally less than 15 percent for all parameters and for parameters of importance, such as minimum DO, it is less than 10 percent.

The model calibration and validation runs use the same kinetic parameters to achieve a good comparison with measured data. This is supported with a visual and statistical comparison. Based on this comparison the QUAL2K model for Bear Creek is suitable for assessing DO problems and for TMDL Development.

Table B-10. Quantitative Calibration Metrics.

Calibration Metric	Equation
Root Mean Squared Error (RMSE)	$\sqrt{\frac{\sum(Predicted - Observed)^2}{n-1}}$
Coefficient of determination (r^2)	$1 - \frac{\sum(Squared\ Errors)}{\sum(Total\ Sum\ of\ Squares)}$
Percent Bias (pBias)	$\frac{\sum(Predicted - Observed)}{\sum Observed} * 100$
Average Error	$\sum_{i=1}^{n} \frac{\lvert Simulated\ Value - Observed\ Value \rvert}{n_{obs}}$
Residual Error	$\sum_{i=1}^{n} \frac{(Simulated\ Value - Observed\ Value)}{n_{obs}}$
Relative Error	$\frac{\sum \lvert Simulated\ Value - Observed\ Value \rvert}{\sum Observed} * 100$

Table B-11. Summary Statistics for Calibration and Validation Runs.

Statistic	Model Period	Flow	DO	Min DO	Max DO	TN	TKN	NO_3	TP
Root Mean Squared Error (RMSE)	Calibration	0.02	0.50	0.51	0.89	3,703	636	568	973
	Validation	0.03	1.32	1.08	1.61	3,933	622	1,029	714
	Entire Period	0.03	1.10	0.91	1.39	3,783	612	886	785
Coefficient of determination (r^2)	Calibration	0.81	0.95	0.89	0.88	607	244	0.97	0.78
	Validation	0.83	0.68	0.60	0.69	1,166	241	0.91	0.89
	Entire Period	0.84	0.80	0.82	0.69	997	236	0.93	0.84
Percent Bias (pBias)	Calibration	7.86	-3.69	1.12	-1.94	0.98	0.97	1.47	-10.83
	Validation	11.64	-8.86	-6.11	-11.11	0.91	0.86	-2.08	5.28
	Entire Period	10.64	-7.45	-4.36	-8.40	0.93	0.89	-0.99	-0.18
Average Error	Calibration	0.02	0.34	0.38	0.74	3.29	9.90	417	658
	Validation	0.02	0.91	0.80	1.14	-0.89	4.27	679	491
	Entire Period	0.02	0.72	0.66	1.00	0.42	6.22	592	547
Residual Error	Calibration	0.01	-0.22	0.05	-0.14	426	180	97	-427
	Validation	0.02	-0.71	-0.46	-0.95	814	175	-155	203
	Entire Period	0.01	-0.55	-0.29	-0.68	685	177	-71	-7
Relative Error	Calibration	17.10	5.62	8.06	10.21	277	180	6.33	16.67
	Validation	17.78	11.39	10.73	13.27	-82	73	9.08	12.75
	Entire Period	17.60	9.82	10.09	12.36	38	109	8.24	14.08

References – Appendix B

Chapra, S.C., Pelletier, G.J. and Tao, H. 2007. QUAL2K: A Modeling Framework for Simulating River and Stream Water Quality, Version 2.07: Documentation and Users Manual.

Donigian. A.S. 2003. Watershed Model Calibration and Validation: The HSPF Experience. WEF National TMDL Science and Policy 2002, November 13-16, 2002. Phoenix, AZ. WEF Specialty Conference Proceedings on CD-ROM.

United States Environmental Protection Agency (EPA), 1985. Rates, Constants and Kinetics Formulations In Surface Water Quality Modeling. Second Edition. EPA/600/3-85/040. Prepared by Tetra Tech, Inc. and Humboldt State University.

EPA, 1997. Technical Guidance Manual for Developing Total Maximum Daily Loads, Book 2: Streams and River. Part 1: Biochemical Oxygen Demand/Dissolved Oxygen and Nutrients/Eutrophication. EPA 823-B-97-002. Office of Water. Washington D.C.

Appendix C – Development of TSS Targets Using Reference LDCs

Overview

This procedure is used when a lotic system is placed on the 303(d) list for a pollutant and the designated use being addressed is aquatic life. In cases where pollutant data for the impaired stream is not available a reference approach is used. The target for pollutant loading is the 25th percentile calculated from all data available within the EDU in which the water body is located. Additionally, it is also unlikely that a flow record for the impaired stream is available. If this is the case, a synthetic flow record is needed. In order to develop a synthetic flow record, calculate an average of the log discharge per square mile of USGS gaged rivers for which the drainage area is entirely contained within the EDU. Selection of these gages is based on location, land use/soil/topography similarities to the Bear Creek watershed and the availability of flow data of sufficient age and duration. From this synthetic record develop a flow duration from which to build a LDC for the pollutant within the EDU.

From this population of load durations follow the reference method used in setting nutrient targets in lakes and reservoirs. In this methodology the average concentration of either the 75th percentile of reference lakes or the 25th percentile of all lakes in the region is targeted in the TMDL. For most cases available pollutant data for reference streams is also not likely to be available. Therefore follow the alternative method and target the 25th percentile of load duration of the available data within the EDU as the TMDL LDC. During periods of low flow the actual pollutant concentration may be more important than load. To account for this during periods of low flow the LDC uses the 25th percentile of EDU concentration at flows where surface runoff is less than 1 percent of the stream flow. This result in an inflection point in the curve below which the TMDL is calculated using load calculated with this reference concentration.

Methodology

The first step in this procedure is to locate available pollutant data within the EDU of interest. These data along with the instantaneous flow measurement taken at the time of sample collection for the specific date are recorded to create the population from which to develop the load duration. Both the date and pollutant concentration are needed in order to match the measured data to the synthetic EDU flow record.

Secondly, collect average daily flow data for gages with a variety of drainage areas for a period of time to cover the pollutant record. From these flow records normalize the flow to a per square mile basis. Average the log transformations of the average daily discharge for each day in the period of record. For each gage record used to build this synthetic flow record calculate the Nash-Sutcliffe statistic to determine if the relationship is valid for each record. This relationship must be valid in order to use this methodology. This new synthetic record of flow per square mile is used to develop the load duration for the EDU. The flow record should be of sufficient length to be able to calculate percentiles of flow (typically 20 years or more).

Figure B-1 shows the application of the approach in the Bear Creek EDU (Central Plains/Cuivre/Salt EDU). Watershed-size normalized data for the individual gages in the EDU were calculated and compared to a pooled data set of all the gages (Figure C-1, Table C-1). Table C-1 demonstrates the pooled data set can confidently be used as a surrogate for the EDU analyses.

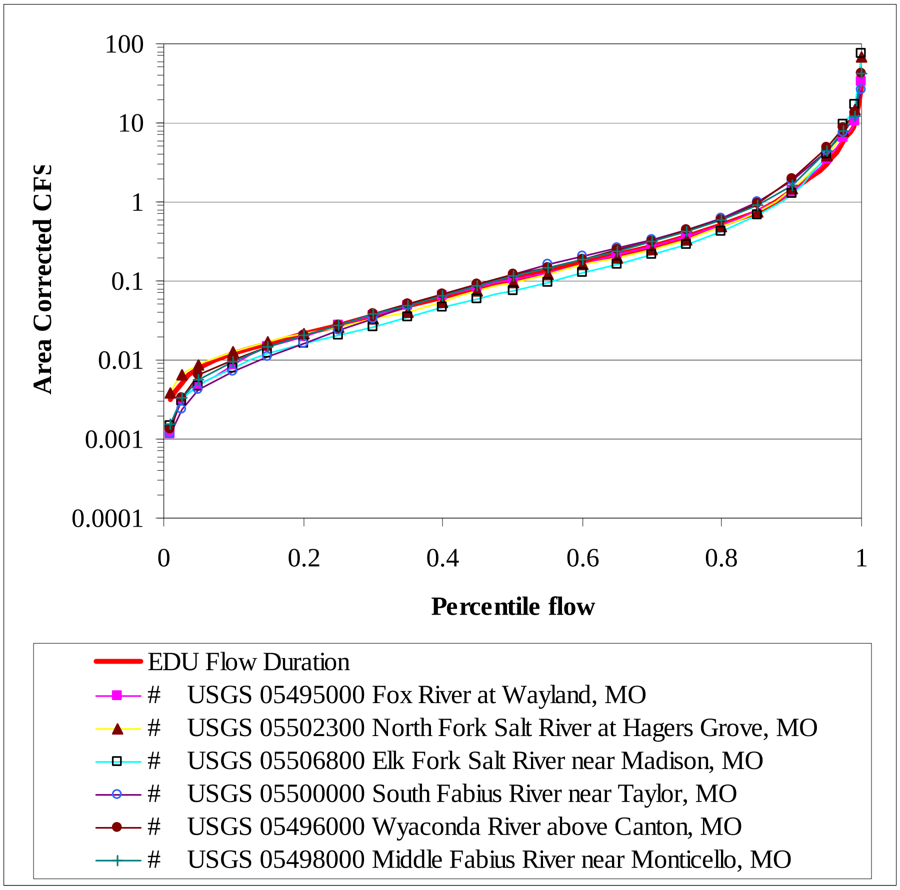

Figure C-1. Synthetic Flow Development in the Central Plains/Cuivre/Salt EDU

Table C-1. Stream Flow Stations Used to Estimate Flows in Bear Creek

River/Station Name	Data Source	Station Number	Drainage Area (mi^2)	Lognormal Nash-Sutcliffe
Fox River at Wayland, MO	USGS	05495000	502	99%
North Fork Salt River at Hagers Grove, MO	USGS	05502300	365	65%
Elk Fork Salt River near Madison, MO	USGS	05506800	200	59%
South Fabius River near Taylor, MO	USGS	05500000	620	97%
Wyaconda River above Canton, MO	USGS	05496000	393	89%
Middle Fabius River near Monticello, MO	USGS	05498000	393	90%

The next step is to calculate pollutant-discharge relationships for the EDU, these are log transformed data for the yield (tons/mi^2/day) and the instantaneous flow (cfs/mi^2). Figure C-2 shows the EDU relationship. Further statistical analyses on this relationship are included in Table C-2.

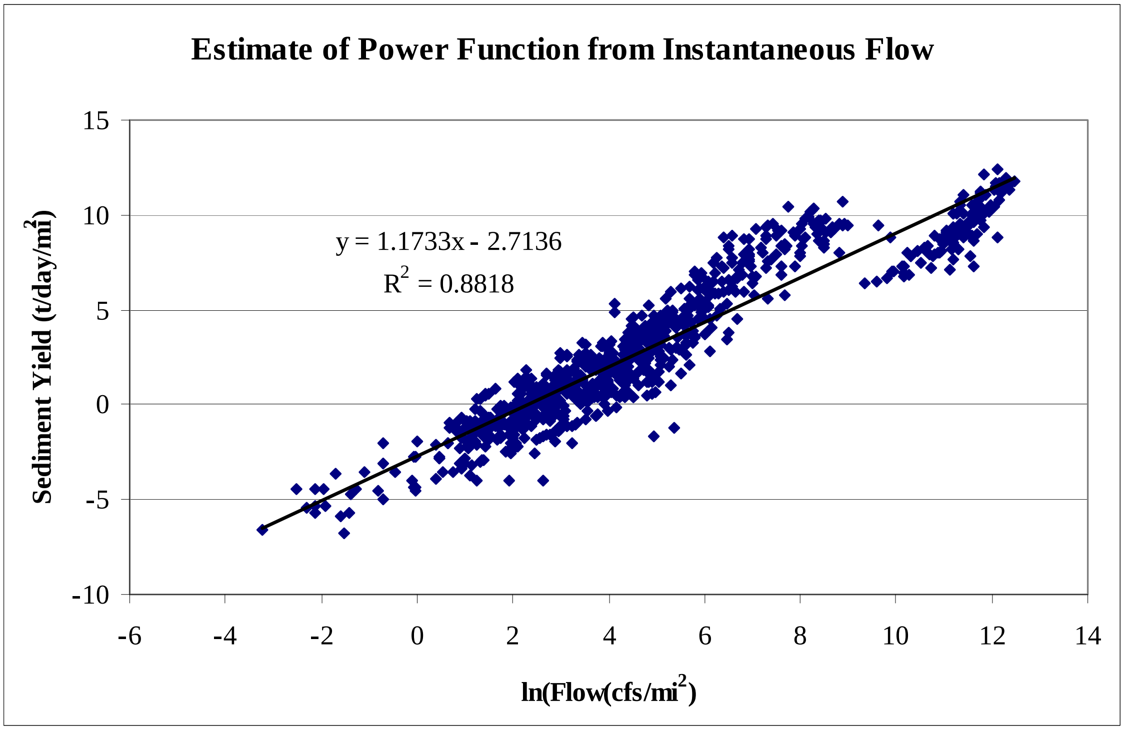

Figure C-2. Estimate of Power Function from Instantaneous Flow in the Central Plains/Cuivre/Salt EDU

Table C-2. Central Plains/Cuivre/Salt EDU Flow and Sediment Statistics

m	**1.17333666**	**b**	**-2.713579317**
Standard Error (m)	**0.014616874**	**Standard Error (b)**	**0.085650887**
r^2	**0.881768781**	**Standard Error (y)**	**1.395877336**
F	**6443.714572**	**DF**	**864**
SSreg	**12555.40732**	**SSres**	**1683.481136**

The standard error of y was used to estimate the 25th percentile level for the TMDL line. This was done by adjusting the intercept (b) by subtracting the product of the one-sided Z_{75} statistic times the standard error of (y). The resulting TMDL Equation is the following:

Sediment yield (t/day/mi^2) = exp (1.17333666 * ln (flow) -2.713579317)

A resulting pooled TMDL of all data in the watershed is shown in the following graph:

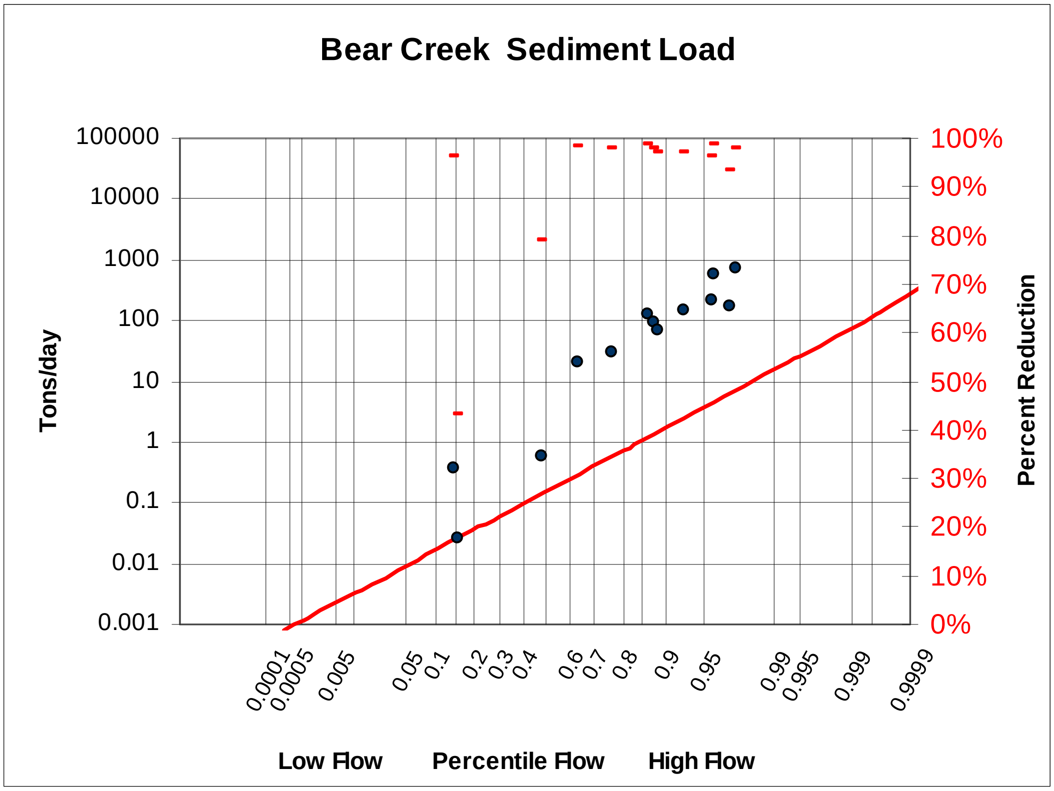

Figure C-3. TMDL LDC for TSS

To apply this process to a specific watershed would entail using the individual watershed data compared to the above TMDL curve that has been multiplied by the watershed area. Data from the impaired segment is then plotted as a load (tons/day) for the y-axis and as the percentile of flow for the EDU on the day the sample was taken for the x-axis.

For Bear Creek the 25th percentile TSS concentration target is 44 mg/L. The TMDL, LA and WLA were calculated based on this concentration and the current limits for permitted facilities in the watershed.

For more information contact:
Environmental Protection Agency, Region 7
Water, Wetlands and Pesticides Division
Total Maximum Daily Load Program
901 North 5th Street
Kansas City, Kansas 66101
Website: http://www.epa.gov/region07/water/tmdl.htm

Appendix D – Development of Nutrient Targets Using Ecoregion Nutrient Criteria with LDCs

Overview

This procedure is used when a lotic system is placed on the 303(d) impaired water body list for nutrient pollutants and the designated use being addressed is aquatic life. In cases where EPA-approved state numeric criteria for the impaired stream is not available a reference approach is used. The target for pollutant loading is the EPA recommended ecoregion nutrient criterion for the specific ecoregion in which the water body is located (EPA, 2000). If a flow record for the impaired stream is not available a synthetic flow record is needed. To develop a synthetic flow record a user should calculate an average of the log discharge per square mile of USGS gaged rivers for which the drainage area is contained within the EDU. Selection of these gages is based on location, land use/soil/topography similarities to the Bear Creek watershed and the availability of flow data of sufficient age and duration. From this synthetic record develop a flow duration and build a LDC for the pollutant within the EDU.

See EPA (2000) for more detailed information as to how recommended ecoregion nutrient criteria were developed. This appendix describes how the nutrient criteria (TN and TP) are expressed in this TMDL.

Methodology

The first step in this procedure is to gather available nutrient data within the ecoregion of interest. These data along with the instantaneous flow measurement taken at the time of sample collection for the specific date are required to develop the LDC. Both dates and nutrient concentrations are needed in order to match the measured data used with the synthetic EDU flow record.

Secondly, collect average daily flow data from gages with a variety of drainage areas for a period of time to cover the nutrient record. From these flow records normalize the flow to a per square mile basis. Average the log transformations of the average daily discharge for each day in the period of record. For each gage record used to build the synthetic flow record calculate the Nash-Sutcliffe value to determine if the relationship is valid for each record. This relationship must be valid in order to use this methodology. This new synthetic record of flow per square mile is then used to develop the LDC for the EDU. The flow record should be of sufficient length to be able to calculate percentiles of flow (typically 20 years or more).

The following example shows the application of the approach for the Central Plains/Cuivre/Salt EDU. Watershed-size normalized data for the individual gages in the EDU were calculated and compared to a pooled data set of all the gages (Figure D-1, Table D-1). Table D-1 demonstrates the pooled data set can confidently be used as a surrogate for the EDU analyses.

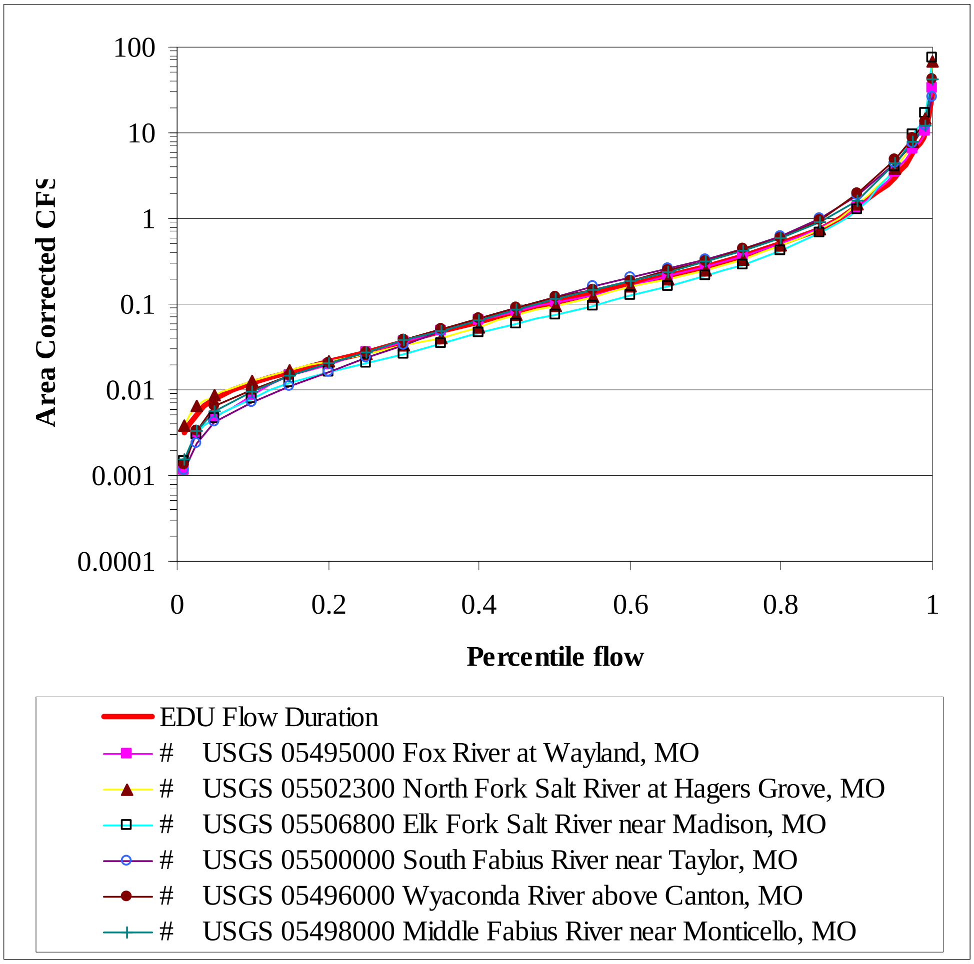

Figure D-1. Synthetic Flow Development in the Central Plains/Cuivre/Salt EDU

Table D-1. Stream Flow Stations Used to Estimate Flows in Bear Creek

River/Station Name	Data Source	Station Number	Drainage Area (mi^2)	Lognormal Nash-Sutcliffe
Fox River at Wayland, MO	USGS	05495000	502	99%
North Fork Salt River at Hagers Grove, MO	USGS	05502300	365	65%
Elk Fork Salt River near Madison, MO	USGS	05506800	200	59%
South Fabius River near Taylor, MO	USGS	05500000	620	97%
Wyaconda River above Canton, MO	USGS	05496000	393	89%
Middle Fabius River near Monticello, MO	USGS	05498000	393	90%

The next step was to collect previously measured water quality data from within the ecoregion. Measured TN concentrations are adjusted so their median is equal to the EPA recommended ecoregion TN criterion. This is accomplished by subtracting the difference between the EPA recommended ecoregion TN criterion and the median from the measured data. This results in the data retaining most of its natural variability yet having a median which meets the EPA recommended ecoregion TN criterion. Where this adjustment would result in a negative concentration the minimum measured concentration is substituted. Figure D-2 shows an example of this process where the solid line is the measured distribution of the natural log TN concentration with the natural log flow and the dashed line represents a data distribution (the adjusted data) which would comply with the EPA recommended ecoregion TN criterion.

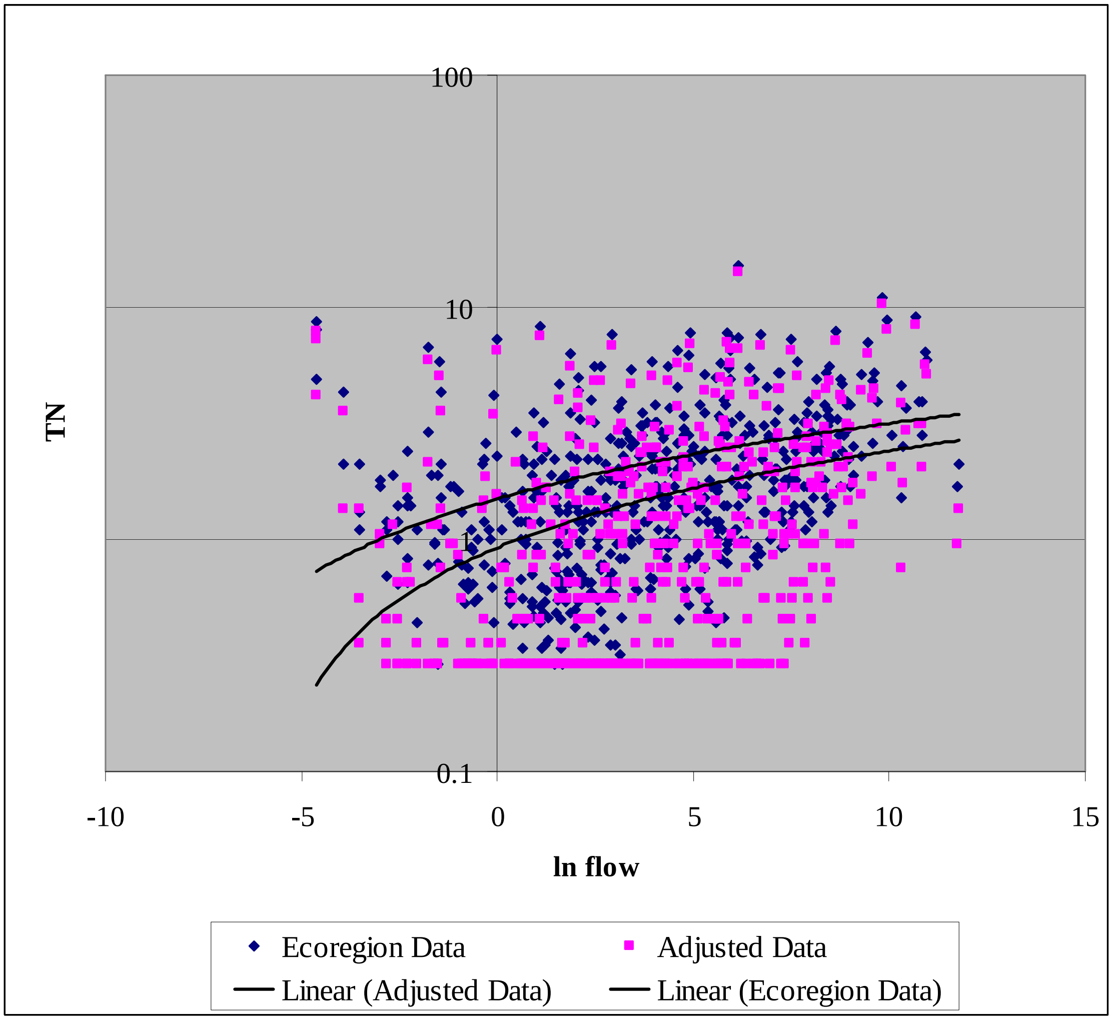

Figure D-2. Graphic Representation of Data Adjustment in Central Plains/Cuivre/Salt EDU

The next step was to calculate the TN-discharge relationship for the ecoregion using the adjusted data, this is natural log transformed data for the yield (pounds/mi^2/day) and the instantaneous flow (cfs/mi^2). Figure D-3 shows this relationship for this TMDL.

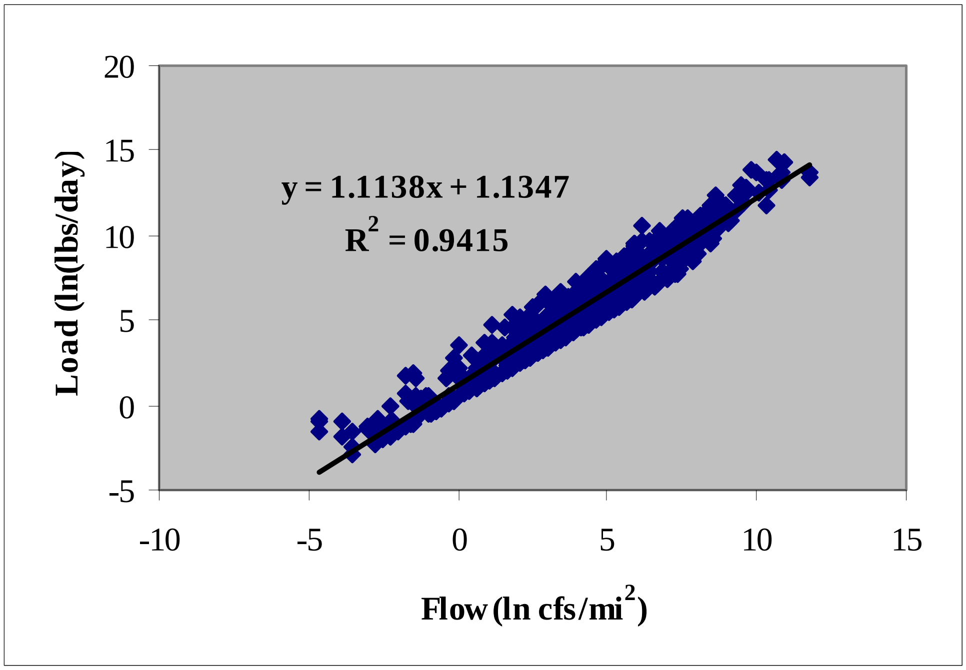

Figure D-3. Load / Flow Relationship Used to Set LDC TMDL

This relationship was used to develop a LDC for which the relationship between flow and nutrient distribution is taken into account. In this LDC the targeted concentration is allowed to change at different percentiles of flow exceedance. However, meeting the LDC will result in a water body in which the median concentration is equal to the EPA recommended ecoregion criterion.

To apply this process to a specific watershed entails using the individual watershed data compared to the TMDL curve that has been multiplied by the watershed area (mi^2). Data from the impaired segment is then plotted as a load (pounds/day) for the y-axis and as the percentile of flow for the EDU on the day the sample was taken for the x-axis. These data points do not have to be collected at the segment outlet. The spreadsheet applies an outlet flow (percentile exceedance) to the concentration based on the synthetic flow estimate for the specific date the sample was taken (Figure D-4).

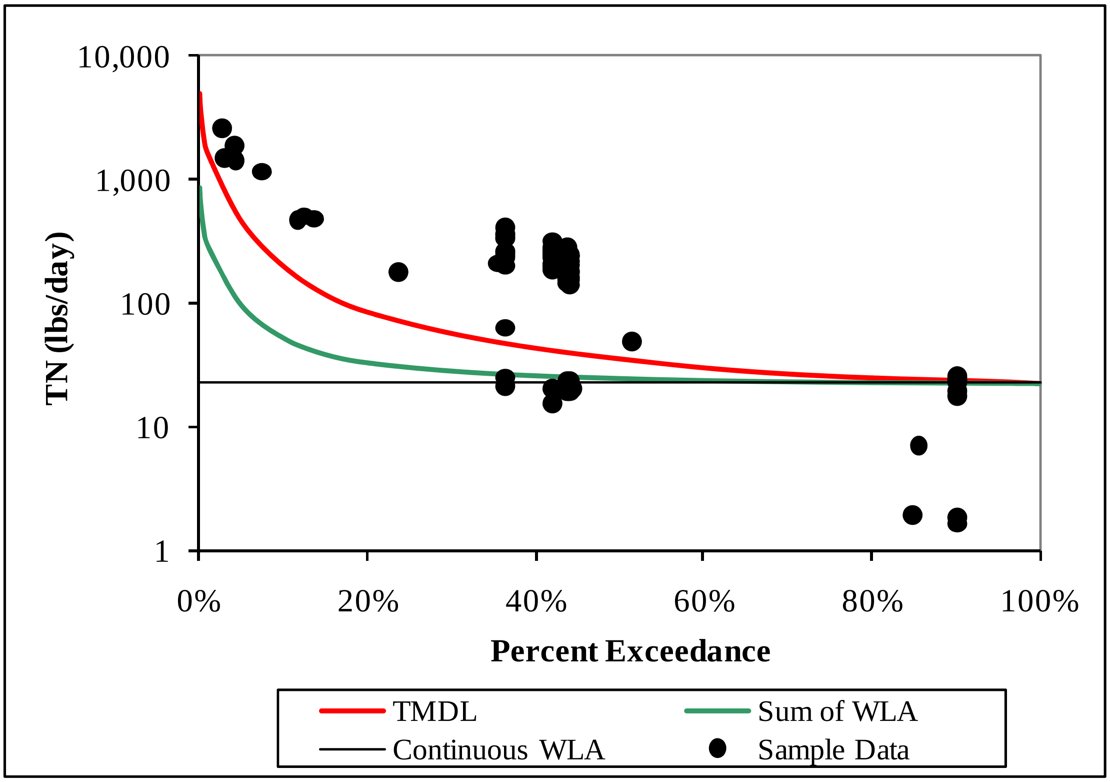

Figure D-4. Example of TMDL LDC Using This Method

The resulting LDC with plotted site specific measured data can now be used to target implementation by identifying flows in which TN concentrations are higher than would be expected in a stream meeting the EPA recommended ecoregion TN criterion.

For more information contact:
Environmental Protection Agency, Region 7
Water, Wetlands and Pesticides Division
Total Maximum Daily Load Program
901 North 5th Street
Kansas City, Kansas 66101
Website: http://www.epa.gov/region07/water/tmdl.htm

Appendix E – Stream Flow and Water Quality Stations Used to Develop TMDLs in the Bear Creek Watershed

Table E-1. Stream Flow Stations Used to Estimate Flows in Bear Creek

River/Station Name	Data Source	Station Number	Drainage Area (mi^2)
Fox River at Wayland, MO	USGS	05495000	502
North Fork Salt River at Hagers Grove, MO	USGS	05502300	365
Elk Fork Salt River near Madison, MO	USGS	05506800	200
South Fabius River near Taylor, MO	USGS	05500000	620
Wyaconda River above Canton, MO	USGS	05496000	393
Middle Fabius River near Monticello, MO	USGS	05498000	393

Table E-2. Stations Used to Develop Water Quality Data Targets in Bear Creek

USGS Gage Number	Station Name	Drainage Area (mi^2)
6898100	Thompson River at Mount Moriah, MO	891
6898800	Weldon River near Princeton, MO	452
6899580	NO Creek near Dunlap, MO	34
6899585	NO Creek at Farmersville, MO	67.4
6899950	Medicine Creek near Harris, MO	192
6900100	Little Medicine Creek near Harris, MO	66.5
6901500	Locust Creek near Linneus, MO	550
6902000	Grand River near Sumner, MO	6880
6905725	Mussel Fork near Mystic, MO	24

Table E-3. Water Quality Data Used in TMDL Development

USGS Gage Number	Sample Date	Flow (cfs)	Total Suspended Solids (mg/L)	TN (mg/L)	TP (mg/L)
6898100 - Thompson River at Mount Moriah, MO					
6898100	11/9/1999	22	527		0.86
6898100	1/13/2000	8.6		0.7	E 0.04
6898100	3/23/2000	33			0.26
6898100	5/18/2000	19	27		0.14
6898100	7/13/2000	49			0.2
6898100	9/6/2000	10			0.53
6898100	11/28/2000	15	< 10	0.77	E 0.03
6898100	1/3/2001	7.5		0.75	< 0.06
6898100	3/15/2001	4860		5.6	1.92
6898100	5/2/2001	276	156	1.7	0.26
6898100	7/13/2001	126			0.16
6898100	9/20/2001	53		E 0.67	0.11
6898100	11/8/2001	41	14		E 0.06

USGS Gage Number	Sample Date	Flow (cfs)	Total Suspended Solids (mg/L)	TN (mg/L)	TP (mg/L)
6898100	1/17/2002	14	< 10	0.74	E 0.03
6898100	3/14/2002	91	43	1.9	0.1
6898100	5/9/2002	223	347	1.8	0.39
6898100	8/1/2002	26	30		0.12
6898100	9/3/2002	17	176		0.3
6898100	11/7/2002	18	< 10		0.05
6898100	1/15/2003	15	< 10		E 0.04
6898100	3/28/2003	50	11	0.68	0.07
6898100	5/22/2003	196	107	5.1	0.22
6898100	7/15/2003	76	66	1.4	0.28
6898100	8/29/2003	6.1	< 10		0.08
6898100	9/4/2003	10	146		0.34
6898100	11/4/2003	325	644	4	1.08
6898100	1/23/2004	23	< 10	0.82	E 0.04
6898100	3/25/2004	268	186	5	0.3
6898100	5/20/2004	E 837	593	7.6	1.03
6898100	7/9/2004	118	17	2.8	0.28
6898100	9/10/2004	259	82	1.2	0.26
6898100	11/8/2004	70	132		0.24
6898100	1/21/2005	31	< 10	0.95	E 0.03
6898100	3/3/2005	144	42	2.4	0.09
6898100	5/25/2005	342	292	3.8	0.39
6898100	7/8/2005	96	67		0.19
6898100	9/16/2005	23	< 10	E 0.32	0.05
6898100	11/10/2005	12	< 10		0.04
6898100	1/20/2006	23	< 10		0.04
6898100	3/31/2006	23	< 10		0.04
6898100	5/25/2006	81	100		0.22
6898100	7/27/2006	15	23		0.1
6898100	9/8/2006	44	28		0.13
6898100	11/9/2006	23	< 10		0.05
6898100	1/4/2007	381	333	7.4	0.77
6898100	2/14/2007	24	< 10	3.9	E 0.03
6898100	3/21/2007	291	218	3.4	0.32
6898100	4/6/2007	394	192	3.2	0.3
6898100	5/23/2007	298	63	3.3	0.17
6898100	6/20/2007	133	82	2.1	0.18
6898100	7/25/2007	54	17		0.09
6898100	9/19/2007	132	26	E 0.83	0.1
6898100	11/16/2007	137	48	2.1	0.14
6898100	1/24/2008	200	20	2.4	0.07
6898100	3/12/2008	682	328	2.9	0.55
6898100	5/29/2008	481	196	3.4	0.29
6898100	7/10/2008	1280	1440	5.2	1.52
6898100	9/17/2008	569	300	1.7	0.43
6898100	10/22/2008	1380	2930	5.2	2.44

USGS Gage Number	Sample Date	Flow (cfs)	Total Suspended Solids (mg/L)	TN (mg/L)	TP (mg/L)
6898100	1/14/2009	235	74	1.7	0.09
6898100	3/5/2009	264	254	2.2	0.35
6898100	5/7/2009	614	336	3.1	0.45
6898100	7/16/2009	1220	718	3.2	0.64
6898100	9/3/2009	288	109	1.2	0.25
6898800 - Weldon River near Princeton, MO					
6898800	11/9/1999	5.3		0.29	0.043
6898800	1/11/2000	10		0.38	< 0.05
6898800	3/21/2000	13			E 0.03
6898800	5/16/2000	2.4	< 10		< 0.05
6898800	7/11/2000	9.4			0.09
6898800	9/6/2000	1.8			0.07
6898800	11/30/2000	5.2	< 10	0.6	< 0.060
6898800	1/5/2001	8.1		0.54	< 0.06
6898800	3/15/2001	2840		3.9	1.28
6898800	5/2/2001	152	119	2.5	0.24
6898800	7/11/2001	63			0.13
6898800	9/18/2001	18		E 0.35	< 0.06
6898800	11/6/2001	36	18	0.6	0.1
6898800	1/15/2002	20	< 10	0.57	< 0.06
6898800	3/12/2002	101	114	2.6	0.21
6898800	5/7/2002	527	210	2.3	0.5
6898800	7/30/2002	17	14		0.07
6898800	8/15/2002	8.7	20		0.07
6898800	9/5/2002	3.3	13		E 0.04
6898800	10/24/2002	5	< 10	E 0.34	E 0.03
6898800	11/5/2002	6.5	< 10		< 0.04
6898800	12/10/2002	4.3	< 10	E 0.29	E 0.02
6898800	1/14/2003	1.9	< 10		E 0.02
6898800	3/7/2003	8.6	< 10	0.64	E 0.03
6898800	3/26/2003	7.3	< 10		0.04
6898800	5/20/2003	168	264	1.7	0.33
6898800	7/17/2003	6.1	19		0.08
6898800	9/5/2003	0.73	52		< 0.04
6898800	11/6/2003	99	120	4.5	0.5
6898800	1/21/2004	30	19	2.5	0.13
6898800	3/23/2004	90	39	1.7	0.12
6898800	5/18/2004	473	267	15	1.73
6898800	7/7/2004	44	14		0.08
6898800	9/8/2004	166	85	0.86	0.2
6898800	11/10/2004	20	< 10	E 0.35	E 0.03
6898800	1/19/2005	11	< 10	0.59	< 0.04
6898800	3/1/2005	80	51	1.1	0.07
6898800	5/23/2005	128	266	2.2	0.34
6898800	7/6/2005	23	< 10		E 0.04
6898800	9/14/2005	6	10		0.05

USGS Gage Number	Sample Date	Flow (cfs)	Total Suspended Solids (mg/L)	TN (mg/L)	TP (mg/L)
6898800	11/8/2005	6.5	21		0.04
6898800	1/18/2006	9.4	< 10		< 0.04
6898800	3/31/2006	117	750	3	0.8
6898800	5/23/2006	6.1	12		0.04
6898800	7/25/2006	1.5	60		0.11
6898800	9/6/2006	9.2	42		0.08
6898800	11/7/2006	5.5	< 10		0.06
6898800	1/4/2007	82	44	3.7	0.23
6898800	2/16/2007	7.2	< 10	0.42	E 0.03
6898800	3/23/2007	625	1250	5.5	1.52
6898800	4/6/2007	174	86	1.4	0.15
6898800	5/23/2007	97	28	1	0.09
6898800	6/20/2007	35	31		0.12
6898800	7/25/2007	19	15		0.07
6898800	9/19/2007	42	24		0.07
6898800	11/14/2007	24	13	E 0.46	0.06
6898800	1/24/2008	60	140	1.6	0.26
6898800	3/12/2008	615	472	1.9	0.48
6898800	5/29/2008	166	79	1.2	0.17
6898800	7/10/2008	307	426	2.8	0.6
6898800	9/17/2008	325	364	1.4	0.41
6898800	10/22/2008	6480	1850	4.9	1.93
6898800	1/14/2009	78	< 15	0.92	E 0.04
6898800	3/6/2009	121	112	0.76	0.14
6898800	5/7/2009	260	126	1.2	0.21
6898800	7/16/2009	98	54		0.16
6898800	9/3/2009	274	145	1.1	0.26
6899580 - No. Creek near Dunlap					
6899580	1/22/1998	3.7	1		
6899580	6/2/1998	3.2	51		
6899580	3/30/1999	4.4		0.48	E 0.05
6899580	4/22/1999	14		0.77	0.13
6899580	6/21/1999	0.25	70		0.14
6899580	10/25/1999	0.01		8.6	0.19
6899580	11/29/1999	0.01	73		0.24
6899580	12/20/1999	0.1			0.09
6899580	1/24/2000	0.1	28	1.4	0.12
6899580	2/23/2000	0.06			0.14
6899580	4/20/2000	0.81			0.16
6899580	5/9/2000	0.17	54	6.7	0.3
6899580	6/14/2000	6.4		6.3	0.46
6899580	6/22/2000	0.4		1.3	0.18
6899580	7/25/2000	0.11	45	1.4	0.15
6899580	10/24/2000	0.37		1.6	0.67
6899580	11/15/2000	0.68	21	2.1	0.14
6899580	12/19/2000	0.08		E 1.4	E 0.06

USGS Gage Number	Sample Date	Flow (cfs)	Total Suspended Solids (mg/L)	TN (mg/L)	TP (mg/L)
6899580	1/24/2001	1.6	18	2.9	0.1
6899580	2/15/2001	40		2.8	0.34
6899580	3/27/2001	10		1.6	0.12
6899580	4/24/2001	19		1.3	0.18
6899580	5/22/2001	9.9	41	1.3	0.15
6899580	6/19/2001	2.7		1.6	0.23
6899580	6/25/2001	5.2		1.1	0.18
6899580	7/26/2001	59	290	1.7	0.35
6899580	8/9/2001	0.47		E 0.75	0.12
6899580	9/13/2001	0.1		E 2.4	0.15
6899580	10/23/2001	38	386	2.3	0.72
6899580	11/29/2001	0.28	78		0.19
6899580	12/13/2001	1	20		0.1
6899580	2/28/2002	1.7	22	1.2	0.07
6899580	3/21/2002	2.1	< 10		E 0.03
6899580	4/18/2002	4.3	36	0.75	0.12
6899580	5/23/2002	2.4	< 10	E 0.51	0.07
6899580	6/13/2002	0.53	20	0.64	0.1
6899580	6/28/2002	0.07	40		0.11
6899580	7/23/2002	0.01	< 10	E 8.0	0.17
6899580	8/22/2002	1	44	7.3	0.91
6899580	12/19/2002	0.01	37		0.16
6899580	3/13/2003	0.41	< 10		0.17
6899580	3/20/2003	0.34	12		0.15
6899580	4/25/2003	2.1	82	1.2	0.22
6899580	4/30/2003	0.62	12		0.14
6899580	5/6/2003	6.4	164	3.5	0.38
6899580	6/12/2003	3	68	8.2	0.24
6899580	7/9/2003	0.01	43	4.9	0.27
6899580	9/19/2003	0.26	144	1.1	0.28
6899580	10/23/2003	0.03	70		0.28
6899580	11/18/2003	0.1	23		0.22
6899580	12/11/2003	22	120	3.7	0.43
6899580	1/8/2004	1	17	2.3	0.11
6899580	2/27/2004	5.8	14	1.9	0.11
6899580	3/18/2004	52	117	2	0.25
6899580	4/20/2004	2.7	33		0.1
6899580	5/11/2004	1.3	< 10		0.08
6899580	6/22/2004	9.1	49	1.1	0.17
6899580	7/16/2004	0.41	23	E 0.78	0.14
6899580	8/23/2004	0.72	67	E 0.77	0.14
6899580	9/14/2004	0.76	520	E 2.6	0.79
6899580	10/26/2004	1	< 10		0.28
6899580	11/16/2004	3.7	< 10	0.46	0.06
6899580	12/14/2004	6.2	18	0.65	0.08
6899580	1/25/2005	0.08	18	1.2	0.14

USGS Gage Number	Sample Date	Flow (cfs)	Total Suspended Solids (mg/L)	TN (mg/L)	TP (mg/L)
6899580	2/10/2005	21	138	1.4	0.16
6899580	3/17/2005	2.9	< 10		E 0.04
6899580	4/5/2005	3.6	< 10		0.04
6899580	5/12/2005	2	52		0.14
6899580	6/30/2005	0.86	24	0.73	0.12
6899580	7/13/2005	0.03	< 10		0.06
6899580	8/19/2005	0.02	33		0.09
6899580	9/21/2005	0.05	53		0.12
6899580	10/5/2005	0.08	380		0.49
6899580	11/3/2005	0.01	1510		1.94
6899580	12/14/2005	0.1	44	E 1.5	0.19
6899580	1/25/2006	0.03	43		0.11
6899580	2/14/2006	0.01	22		0.1
6899580	3/9/2006	0.2	< 10		0.07
6899580	4/12/2006	2.1	72	0.95	0.16
6899580	5/9/2006	2.8	44	0.93	0.13
6899580	6/15/2006	0.23	24	5.8	0.13
6899580	7/19/2006	0	152		0.59
6899580	8/10/2006	3.1	147	1.6	0.34
6899580	9/21/2006	0.02	170	E 4.3	0.31
6899580	10/25/2006	0.02	93	E 2.1	0.35
6899580	12/13/2006	0.52	17	0.92	0.12
6899580	1/26/2007	0.84	< 10	1	E 0.04
6899580	2/20/2007	56	162	3.8	0.68
6899580	3/15/2007	8.1	37	1.2	0.09
6899580	4/27/2007	76	225	2.9	0.38
6899580	5/10/2007	18	110	2.7	0.23
6899580	6/28/2007	19	485	7.6	0.64
6899580	7/19/2007	E 0.03	165	E 1.3	0.21
6899580	8/23/2007	0.24	75	1.5	0.21
6899580	9/27/2007	0.19	105		0.25
6899580	10/16/2007	0.06	136	E 1.2	0.36
6899580	11/8/2007	0.01	16		0.28
6899580	12/20/2007	3.1	20	2.2	0.14
6899580	1/10/2008	22	58	2	0.23
6899580	2/26/2008	E 65	86	2.9	0.35
6899580	3/25/2008	8.3	34	0.95	0.1
6899580	4/16/2008	11	102	1.2	0.18
6899580	5/22/2008	2.1	138	E 1.0	0.22
6899580	6/17/2008	13	74	1.3	0.22
6899580	7/15/2008	0.8	46	1.1	0.14
6899580	8/12/2008	0.55	24	E 0.54	0.1
6899580	9/23/2008	3	< 10	0.44	0.09
6899580	10/28/2008	6.6	< 15	0.65	0.13
6899580	11/18/2008	11	< 15	0.65	0.1
6899580	12/2/2008	5.8	< 15	0.54	0.07

USGS Gage Number	Sample Date	Flow (cfs)	Total Suspended Solids (mg/L)	TN (mg/L)	TP (mg/L)
6899580	1/27/2009	1.9	< 15	E 0.34	E 0.04
6899580	2/24/2009	3	16		0.05
6899580	3/12/2009	16	250	2.1	0.34
6899580	4/24/2009	6.5	16	E 0.48	0.08
6899580	5/15/2009	29	730	2.7	0.65
6899580	6/23/2009	20	< 150	1.8	0.27
6899580	8/18/2009	56	266	2	0.38
6899585 - No Creek at Farmersville, MO					
6899585	11/16/2006	0.13	< 10	0.44	0.26
6899950 - Medicine Creek near Harris, MO					
6899950	10/26/1999	2.3			E 0.045
6899950	11/30/1999	3	6		< 0.05
6899950	12/21/1999	0.1		0.65	< 0.05
6899950	1/25/2000	0.5	3		< 0.05
6899950	2/22/2000	15			E 0.04
6899950	3/27/2000	8.7			E 0.03
6899950	4/18/2000	4			E 0.03
6899950	5/10/2000	10	< 10		0.05
6899950	6/21/2000	6		0.87	0.08
6899950	7/26/2000	6.6	37		0.11
6899950	9/20/2000	3.4		0.54	0.07
6899950	10/26/2000	6.1			0.07
6899950	11/14/2000	5.8	< 10	0.93	0.09
6899950	12/18/2000	3.1		E 0.34	< 0.06
6899950	1/25/2001	12	< 10	3.2	0.11
6899950	2/13/2001	131		2.8	0.3
6899950	3/29/2001	100		2	0.21
6899950	4/26/2001	76		1	0.21
6899950	5/24/2001	52	68	1.3	0.18
6899950	6/19/2001	79		1.5	0.33
6899950	6/26/2001	60		1.1	0.18
6899950	7/25/2001	353	1610	3.2	1.34
6899950	8/8/2001	13		E 0.55	0.09
6899950	9/12/2001	7.4		0.5	0.07
6899950	10/25/2001	33	118	2.6	0.37
6899950	11/28/2001	3.4	12	E 0.35	E 0.03
6899950	12/12/2001	6.2			< 0.06
6899950	1/3/2002	4.6	< 10	0.55	< 0.06
6899950	1/8/2002	5	< 10	E 0.45	< 0.06
6899950	2/27/2002	9.9	12	1.3	0.07
6899950	3/19/2002	18	< 10		0.06
6899950	4/17/2002	68	130	1.4	0.24
6899950	5/21/2002	38	38	1	0.1
6899950	6/28/2002	5.6	13		E 0.06
6899950	7/24/2002	3.6	< 10		0.08
6899950	8/21/2002	17	41		0.14

USGS Gage Number	Sample Date	Flow (cfs)	Total Suspended Solids (mg/L)	TN (mg/L)	TP (mg/L)
6899950	9/10/2002	1.4	< 10		E 0.05
6899950	10/17/2002	1.4	< 10		E 0.03
6899950	11/19/2002	2	< 10		E 0.03
6899950	12/18/2002	2.8	< 10		0.04
6899950	1/30/2003	0.9	< 10		E 0.03
6899950	2/20/2003	3.4	< 10		E 0.03
6899950	3/12/2003	3.9	< 10		0.1
6899950	4/23/2003	14	12		0.25
6899950	5/8/2003	27	104	2.9	0.29
6899950	6/11/2003	51	282	5.8	0.47
6899950	7/10/2003	65	161	1.5	0.3
6899950	8/25/2003	0.61	< 10		0.06
6899950	9/17/2003	4.5	49	1.4	0.36
6899950	10/22/2003	1.3	< 10		0.05
6899950	11/20/2003	3	< 10		0.06
6899950	12/10/2003	368	E 692	5.5	2.81
6899950	1/7/2004	6.2	< 10	1.7	0.06
6899950	2/26/2004	55	66	2.4	0.34
6899950	3/16/2004	71	53	1.7	0.22
6899950	4/22/2004	21	12		0.06
6899950	5/13/2004	11	< 10		0.05
6899950	6/23/2004	42	49	1.2	0.18
6899950	7/14/2004	32	76	1.3	0.24
6899950	8/25/2004	378	1700	4.9	1.77
6899950	9/16/2004	25	15		0.1
6899950	10/27/2004	50	131	1.5	0.31
6899950	11/18/2004	16	< 10		0.04
6899950	12/16/2004	26	< 10	0.82	0.05
6899950	1/27/2005	169	280	2.3	0.53
6899950	2/9/2005	105	165	2.2	0.25
6899950	3/16/2005	28	< 10		0.06
6899950	4/8/2005	77	79		0.21
6899950	5/11/2005	24	15		0.08
6899950	6/29/2005	77	620	5.6	1.27
6899950	7/12/2005	5.7	< 10		0.05
6899950	8/17/2005	6.2	< 10	0.71	0.06
6899950	9/20/2005	3.6	14	E 0.37	0.05
6899950	10/5/2005	2.8	11		0.04
6899950	11/2/2005	2	< 10		E 0.03
6899950	12/15/2005	4.4	< 10		E 0.02
6899950	1/26/2006	2.6	< 10		E 0.03
6899950	2/17/2006	1.3	< 10		0.04
6899950	3/8/2006	9.8	< 10		0.06
6899950	4/13/2006	12	15		0.08
6899950	5/10/2006	18	20	0.59	0.07
6899950	6/14/2006	2.4	< 10		0.04

USGS Gage Number	Sample Date	Flow (cfs)	Total Suspended Solids (mg/L)	TN (mg/L)	TP (mg/L)
6899950	7/18/2006	4.8	16		0.13
6899950	8/9/2006	16	150	1.5	0.38
6899950	9/20/2006	1.4	< 10		< 0.04
6899950	10/24/2006	3	< 10		0.08
6899950	11/15/2006	2.6	< 10		0.09
6899950	12/14/2006	4.4	24	1.5	0.07
6899950	1/25/2007	8	< 10	1.3	0.06
6899950	2/21/2007	460	379	7.4	1.37
6899950	3/14/2007	60	72	2	0.2
6899950	4/27/2007	971	660	4.5	1.19
6899950	5/9/2007	349	424	2.8	0.63
6899950	6/27/2007	10	19	0.65	0.08
6899950	7/18/2007	4.6	10		0.08
6899950	8/21/2007	57	763	3.2	0.93
6899950	9/25/2007	9.8	< 20		0.08
6899950	10/16/2007	46	84	1.2	0.25
6899950	11/6/2007	14	< 10	0.49	0.09
6899950	12/19/2007	57	35	1.7	0.13
6899950	1/9/2008	483	406	2.6	0.56
6899950	2/27/2008	202	140	3.5	0.45
6899950	3/26/2008	64	49	0.97	0.12
6899950	4/16/2008	119	170	1.5	0.27
6899950	5/21/2008	36	19		0.1
6899950	6/18/2008	112	148	1.4	0.28
6899950	7/16/2008	19	35		0.14
6899950	8/13/2008	25	46		0.1
6899950	9/24/2008	98	536	2.6	0.61
6899950	10/29/2008	60	39	0.92	0.17
6899950	11/19/2008	75	42	0.83	0.12
6899950	12/3/2008	49	16	0.61	0.06
6899950	1/28/2009	19	< 15	0.72	0.04
6899950	2/25/2009	34	22	0.61	0.06
6899950	3/11/2009	715	1180	4.9	1.37
6899950	4/22/2009	61	85	0.92	0.17
6899950	5/13/2009	377	1900	6.5	2.37
6899950	6/24/2009	75	220	2.4	0.42
6899950	7/22/2009	20	24		0.1
6899950	8/20/2009	180	455	2.2	0.54
6900100 - Little Medicine Creek near Harris					
6900100	1/22/1998	8.7	1		
6900100	6/2/1998	11	26		
6900100	1/5/1999	4.8	5	0.67	< 0.05
6900100	3/31/1999	12		0.37	E 0.03
6900100	4/21/1999	35		1.1	0.16
6900100	6/22/1999	4.7	30	0.97	0.11
6900100	8/25/1999	0.62		0.56	E 0.04

USGS Gage Number	Sample Date	Flow (cfs)	Total Suspended Solids (mg/L)	TN (mg/L)	TP (mg/L)
6900100	10/26/1999	0.67			E 0.03
6900100	11/30/1999	0.73	1		< 0.05
6900100	12/21/1999	0.1		0.82	0.06
6900100	1/25/2000	0.5	4		< 0.05
6900100	2/22/2000	1.8			E 0.04
6900100	3/27/2000	1.1			< 0.05
6900100	4/18/2000	2			E 0.04
6900100	5/10/2000	1.4	< 10		E 0.03
6900100	6/21/2000	1.2		1.5	0.07
6900100	7/26/2000	1.6	< 10		0.07
6900100	9/20/2000	1.6			0.05
6900100	10/26/2000	1.8			0.08
6900100	11/14/2000	1.8	< 10	1	E 0.06
6900100	12/19/2000	0.91		0.44	E 0.04
6900100	1/25/2001	3.2	< 10	3.2	E 0.04
6900100	2/13/2001	46		3.2	0.42
6900100	3/29/2001	35		1.9	0.14
6900100	4/26/2001	18		0.87	0.15
6900100	5/24/2001	16	31	1.4	0.12
6900100	6/19/2001	17		1.9	0.26
6900100	6/26/2001	13		0.92	0.09
6900100	7/25/2001	11	444	4	0.48
6900100	8/8/2001	1.4		0.59	E 0.05
6900100	9/12/2001	1.2		0.79	0.07
6900100	10/25/2001	7.5	54	2.2	0.2
6900100	11/28/2001	1.5	< 10		< 0.06
6900100	12/12/2001	1.7	< 10		< 0.06
6900100	1/8/2002	0.38	< 10	0.8	< 0.06
6900100	2/27/2002	1.8	< 10	1.2	E 0.03
6900100	3/19/2002	2	< 10		< 0.06
6900100	4/17/2002	13	66	1	0.13
6900100	5/21/2002	9.1	14	0.67	0.07
6900100	6/28/2002	2	< 10	E 0.44	E 0.04
6900100	7/24/2002	0.59	< 10		E 0.04
6900100	8/21/2002	3.1	< 10	0.62	0.1
6900100	9/10/2002	0.15	< 10		E 0.04
6900100	10/17/2002	0.31	< 10		E 0.03
6900100	11/19/2002	0.41	< 10		0.06
6900100	12/18/2002	0.64	< 10		E 0.02
6900100	1/29/2003	0.11	< 10		0.05
6900100	2/20/2003	0.64	< 10		E 0.03
6900100	3/12/2003	1.4	< 10		< 0.04
6900100	4/23/2003	0.47	< 10	0.61	0.04
6900100	5/8/2003	3.5	127	2.4	0.19
6900100	6/11/2003	30	344	5.4	0.51
6900100	7/10/2003	138	E 2060	7.7	1.76

USGS Gage Number	Sample Date	Flow (cfs)	Total Suspended Solids (mg/L)	TN (mg/L)	TP (mg/L)
6900100	8/25/2003	0.08	13	E 0.64	0.1
6900100	9/18/2003	0.48	20	0.65	0.07
6900100	10/22/2003	0.3	< 10		0.07
6900100	11/20/2003	0.52	< 10		0.05
6900100	12/10/2003	98	470	6.5	0.93
6900100	1/7/2004	0.73	16	2.2	E 0.03
6900100	2/26/2004	10	36	2.2	0.11
6900100	3/16/2004	25	56	1.7	0.14
6900100	4/22/2004	4.6	< 10		0.04
6900100	5/13/2004	8.9	102	1.2	0.18
6900100	6/23/2004	12	33	1.3	0.13
6900100	7/14/2004	6	37	1.3	0.15
6900100	8/25/2004	2150	1400	5.8	1.91
6900100	9/16/2004	5.8	64	0.65	0.17
6900100	10/27/2004	16	146	1.3	0.29
6900100	11/18/2004	5.2	< 10		E 0.04
6900100	12/17/2004	4.6	< 10	0.85	E 0.03
6900100	1/27/2005	24	51	2.6	0.37
6900100	2/10/2005	7	48	1.8	0.11
6900100	3/16/2005	7.6	< 10		0.04
6900100	4/8/2005	15	18		0.07
6900100	5/12/2005	8.6	38	E 0.66	0.1
6900100	6/30/2005	6	20	E 0.73	0.1
6900100	7/12/2005	1.4	< 10	E 0.53	0.06
6900100	8/17/2005	0.42	< 10	0.64	0.06
6900100	9/20/2005	0.64	< 10		0.05
6900100	10/5/2005	0.22	< 10	E 0.29	E 0.04
6900100	11/2/2005	0.15	< 10		0.05
6900100	12/15/2005	1.6	< 10		E 0.03
6900100	1/26/2006	0.73	< 10		E 0.03
6900100	2/17/2006	0.37	< 10		E 0.04
6900100	3/8/2006	2.2	< 10		0.04
6900100	4/13/2006	1.5	15		0.07
6900100	5/10/2006	2.3	19		0.05
6900100	6/14/2006	0.43	< 10	0.53	0.05
6900100	7/19/2006	0.22	< 10	0.79	0.08
6900100	8/9/2006	3	122	1.2	0.25
6900100	9/20/2006	0.16	< 10		E 0.03
6900100	10/24/2006	0.35	< 10		0.06
6900100	11/16/2006	0.45	< 10		0.09
6900100	12/14/2006	1.1	13	1.5	0.06
6900100	1/25/2007	2.2	< 10	1.2	< 0.04
6900100	2/21/2007	E 130	59	6.2	1.16
6900100	3/15/2007	14	64	1.8	0.13
6900100	4/25/2007	1830	1070	7.3	2.42
6900100	5/10/2007	52	184	2.3	0.33

USGS Gage Number	Sample Date	Flow (cfs)	Total Suspended Solids (mg/L)	TN (mg/L)	TP (mg/L)
6900100	6/27/2007	1.4	10	0.56	0.06
6900100	7/18/2007	0.53	13		0.06
6900100	8/21/2007	14	663	5.6	0.92
6900100	9/25/2007	1.5	< 20	E 0.43	0.09
6900100	10/17/2007	13	424	2.2	0.81
6900100	11/8/2007	1	< 10		0.1
6900100	12/19/2007	13	31	2.2	0.15
6900100	1/10/2008	68	88	2.7	0.34
6900100	2/27/2008	58	82	3.2	0.37
6900100	3/26/2008	21	43	0.95	0.11
6900100	4/16/2008	33	88	1.4	0.21
6900100	5/21/2008	7.3	< 10		0.08
6900100	6/18/2008	20	74	1.3	0.21
6900100	7/16/2008	3	10	0.51	0.07
6900100	8/13/2008	3.3	13	0.48	0.08
6900100	9/24/2008	300	2200	5.7	1.81
6900100	10/29/2008	18	23	0.65	0.11
6900100	11/19/2008	30	33	1	0.11
6900100	12/3/2008	17	< 15	0.68	0.05
6900100	1/28/2009	4.5	< 15	0.73	E 0.03
6900100	2/25/2009	12	18	0.57	0.05
6900100	3/11/2009	118	490	3.4	0.56
6900100	4/22/2009	15	15	0.41	0.06
6900100	5/13/2009	352	1760	7.8	2.21
6900100	6/24/2009	26	160	2	0.29
6900100	7/22/2009	2.5	< 15	0.47	0.05
6900100	8/20/2009	176	1290	3.8	1.15
6901500 - Locust Creek near Linneus, MO					
6901500	8/26/2003	0.8	<10		0.05
6902000 - Grand River near Sumner, MO					
6902000	11/8/1989	373		1	0.13
6902000	1/18/1990	851		2.2	0.34
6902000	5/9/1990	5480		2.3	0.42
6902000	7/11/1990	1430		1.3	0.35
6902000	11/7/1990	1310		3.6	0.3
6902000	1/9/1991	452		2	0.24
6902000	5/17/1991	14200		2.6	0.39
6902000	7/16/1991	2510		3.2	0.41
6902000	11/6/1991	470		1.7	0.31
6902000	1/15/1992	2720		1.7	0.34
6902000	7/8/1992	340			0.11
6902000	11/12/1992	7780		2.2	0.22
6902000	12/2/1992	4980		1.4	0.28
6902000	1/6/1993	8980		1.9	0.47
6902000	2/17/1993	2510		1.4	0.25
6902000	3/17/1993	3220		1.5	0.28

USGS Gage Number	Sample Date	Flow (cfs)	Total Suspended Solids (mg/L)	TN (mg/L)	TP (mg/L)
6902000	4/8/1993	29800		1.5	0.22
6902000	5/12/1993	33700		3.7	0.2
6902000	6/16/1993	18400		11	1
6902000	7/27/1993	128000		2.1	0.55
6902000	8/25/1993	2820		1.3	
6902000	9/16/1993	23600		2.8	0.34
6902000	10/27/1993	1700		1.1	0.04
6902000	11/16/1993	3300		1.7	0.25
6902000	12/8/1993	1140			0.03
6902000	1/5/1994	755		0.92	0.05
6902000	2/3/1994	1200		2.7	0.18
6902000	3/16/1994	1750		1.8	0.18
6902000	3/30/1994	750		0.78	0.09
6902000	4/27/1994	900			0.12
6902000	5/10/1994	3700		2.6	0.28
6902000	6/14/1994	4500		5.2	1.2
6902000	8/23/1994	250			
6902000	9/14/1994	270			0.11
6902000	10/26/1994	136			0.13
6902000	11/30/1994	1200		2	0.15
6902000	12/14/1994	1140		1.8	0.2
6902000	1/5/1995	350		1.4	0.03
6902000	2/8/1995	2060		2.7	0.27
6902000	3/30/1995	2720		3.5	0.13
6902000	4/18/1995	5660		7.9	0.41
6902000	5/24/1995	51600		2.8	0.4
6902000	6/14/1995	4450		1.5	0.2
6902000	7/12/1995	6100		2.8	0.14
6902000	8/2/1995	2030		1.8	0.39
6902000	9/5/1995	496			0.13
6902000	10/24/1995	235			0.11
6902000	11/6/1995	595		1.2	0.1
6902000	12/13/1995	216		0.49	0.04
6902000	1/22/1996	430		1.1	0.08
6902000	2/14/1996	3050		2.5	1
6902000	3/26/1996	1480		2.4	0.31
6902000	4/16/1996	520			0.16
6902000	5/20/1996	4660		3.6	0.57
6902000	6/19/1996	14500		4.8	0.83
6902000	7/17/1996	1050			0.16
6902000	8/14/1996	906			0.12
6902000	9/11/1996	1170		1.6	0.14
6902000	10/9/1996	527			0.1
6902000	11/20/1996	4930		3.3	0.18
6902000	1/22/1997	466		1.4	0.07
6902000	2/12/1997	1620		2.2	0.16

USGS Gage Number	Sample Date	Flow (cfs)	Total Suspended Solids (mg/L)	TN (mg/L)	TP (mg/L)
6902000	3/17/1997	2510		1.7	0.28
6902000	4/23/1997	29800		4.6	0.28
6902000	5/27/1997	2130		E 2.9	0.44
6902000	6/17/1997	15100		5.2	0.25
6902000	7/29/1997	395			0.12
6902000	8/19/1997	511		0.98	0.18
6902000	9/9/1997	286		1.2	0.15
6902000	11/17/1997	415	6		
6902000	1/15/1998	1590	16		
6902000	6/9/1998	4290	452		
6902000	8/18/1998	587	60		
6902000	11/16/1998	4640	264	1.3	0.15
6902000	12/1/1998	6620		2.4	0.8
6902000	1/25/1999	4150	231	2.4	0.31
6902000	2/23/1999	3040		1.2	0.16
6902000	3/23/1999	2740		3.2	0.25
6902000	4/13/1999	3460		2.5	0.47
6902000	5/19/1999	31900		2.5	0.7
6902000	6/15/1999	6840	1800		
6902000	7/27/1999	429			0.17
6902000	8/10/1999	639	80		0.22
6902000	9/13/1999	365			0.21
6902000	10/26/1999	130			0.1
6902000	11/30/1999	240	10		< 0.05
6902000	12/21/1999	157		0.83	0.06
6902000	1/4/2000	198	16	0.75	0.07
6902000	2/1/2000	123		0.61	0.05
6902000	3/7/2000	565		1.7	0.27
6902000	4/3/2000	301		0.83	0.19
6902000	5/2/2000	308	95		0.22
6902000	6/12/2000	217			0.22
6902000	7/11/2000	924	180	1.3	0.32
6902000	8/2/2000	465			0.23
6902000	9/12/2000	129			0.22
6902000	10/2/2000	341			0.28
6902000	11/21/2000	220	12	1.2	0.08
6902000	12/5/2000	207		1.3	0.08
6902000	1/3/2001	E 203	< 10	1.5	E 0.03
6902000	2/14/2001	5880		3.3	0.53
6902000	3/6/2001	8040		3.8	0.79
6902000	4/17/2001	7800		3	0.76
6902000	5/1/2001	1740	90		0.22
6902000	6/19/2001	6690		4.7	1.33
6902000	7/10/2001	1830	174	1.2	0.26
6902000	8/13/2001	572			0.17
6902000	9/5/2001	404			0.17

USGS Gage Number	Sample Date	Flow (cfs)	Total Suspended Solids (mg/L)	TN (mg/L)	TP (mg/L)
6902000	10/17/2001	3210	555	2.4	0.65
6902000	11/6/2001	416	18		0.1
6902000	12/4/2001	323	16	0.46	0.12
6902000	1/8/2002	179	< 10	0.61	E 0.05
6902000	2/5/2002	347	12	0.95	0.08
6902000	3/6/2002	573	12	0.99	E 0.05
6902000	4/10/2002	4220	1440	3.8	1.16
6902000	5/7/2002	43700	2420	9.1	3.12
6902000	6/10/2002	841			0.2
6902000	7/16/2002	393	145	1.8	0.54
6902000	8/13/2002	175	< 10		0.17
6902000	9/4/2002	145	65		0.18
6902000	10/22/2002	97	39		0.11
6902000	11/27/2002	115	10		0.07
6902000	12/12/2002	102	< 10	0.45	0.05
6902000	2/12/2003	121	< 10	1.3	0.06
6902000	2/25/2003	E 130	< 10	0.52	0.08
6902000	3/21/2003	354	29	0.9	0.09
6902000	4/11/2003	163	46		0.12
6902000	5/2/2003	1940	524	3.3	0.76
6902000	6/20/2003	516	114	2	0.28
6902000	7/29/2003	130	19		0.19
6902000	8/21/2003	66	81		0.23
6902000	9/9/2003	85	58		0.18
6902000	10/21/2003	96	44		0.2
6902000	11/5/2003	75	26		0.09
6902000	12/15/2003	888	89	3.1	0.32
6902000	1/7/2004	E 275	< 10	1.6	0.08
6902000	2/3/2004	E 165	< 10	1.4	0.08
6902000	3/2/2004	997	112	2.8	0.26
6902000	4/6/2004	2040	136	2.4	0.25
6902000	5/19/2004	21000	1070	8.8	2.37
6902000	6/28/2004	1910	158	1.3	0.28
6902000	7/15/2004	7510	475	3.8	1.22
6902000	8/16/2004	715	49		0.19
6902000	9/2/2004	E 125000	543	1.7	0.57
6902000	10/12/2004	900	132	1.3	0.26
6902000	11/9/2004	1410	56	0.93	0.17
6902000	12/1/2004	813	22	0.86	0.11
6902000	1/24/2005	1530	90	1.8	0.22
6902000	2/14/2005	55000	2160	6.4	1.83
6902000	3/8/2005	1460	43	1.2	0.12
6902000	4/4/2005	992	55		0.11
6902000	5/3/2005	1530	117	1.7	0.21
6902000	6/22/2005	1600	203	1.8	0.34
6902000	7/12/2005	513	135		0.26

USGS Gage Number	Sample Date	Flow (cfs)	Total Suspended Solids (mg/L)	TN (mg/L)	TP (mg/L)
6902000	8/22/2005	909	252	1.9	0.41
6902000	9/7/2005	301	55		0.18
6902000	10/12/2005	315	34	1.1	0.12
6902000	11/2/2005	220	< 10	0.54	0.07
6902000	12/19/2005	272	< 10	1	0.04
6902000	1/4/2006	459	14	1.1	0.07
6902000	2/7/2006	357	< 10	0.79	0.07
6902000	3/7/2006	267	12	E 0.44	0.07
6902000	4/10/2006	1010	415	2.7	0.53
6902000	5/3/2006	12500	1180	7.1	1.48
6902000	6/21/2006	386	154		0.3
6902000	7/6/2006	259	41		0.2
6902000	8/2/2006	131	138		0.23
6902000	9/6/2006	432	170		0.34
6902000	10/10/2006	121	51		0.1
6902000	11/6/2006	289	43	1.2	0.15
6902000	12/5/2006	546	76	2.8	0.26
6902000	1/4/2007	3400	767	4.9	1.05
6902000	2/14/2007	272	< 10	1.6	0.05
6902000	3/7/2007	3450	258	3.4	0.48
6902000	4/3/2007	7510	1120	3.9	1.1
6902000	5/2/2007	4620	360	3.4	0.51
6902000	6/6/2007	4600	200	3.1	0.43
6902000	7/10/2007	447	104		0.2
6902000	8/14/2007	1230	242	2	0.37
6902000	9/11/2007	736	52		0.17
6902000	10/23/2007	3100	340	2.9	0.6
6902000	11/6/2007	569	27	1.5	0.12
6902000	12/4/2007	702	45	0.84	0.14
6902000	1/9/2008	16000	850	3.9	1.11
6902000	2/14/2008	1900	100	1.9	0.22
6902000	3/5/2008	50600	1180	3.9	1.43
6902000	4/16/2008	7050	144	2.8	0.64
6902000	6/2/2008	10700	1120	5.1	1.31
6902000	7/9/2008	4230	384	1.8	0.49
6902000	8/4/2008	8200	452	1.7	0.47
6902000	9/2/2008	803	80		0.16
6902000	10/21/2008	1940	106	1.4	0.27
6902000	11/24/2008	2600	75	1.1	0.15
6902000	12/9/2008	1500	48	0.94	0.11
6902000	2/2/2009	1080	< 15	1	0.06
6902000	3/10/2009	57300	1300	5.9	1.77
6902000	4/1/2009	10900	418	2.3	0.55
6902000	5/5/2009	8690	780	2.5	0.68
6902000	6/2/2009	3960	312	2.9	0.42
6902000	7/28/2009	986	62		0.18

USGS Gage Number	Sample Date	Flow (cfs)	Total Suspended Solids (mg/L)	TN (mg/L)	TP (mg/L)
6902000	8/17/2009	46900	1790	3.9	1.52
6902000	9/1/2009	6300	454	1.7	0.53
6905725 - Mussel fork near Mystic, MO					
6905725	1/23/1998	1.6	12		
6905725	6/3/1998	1.2	22		
6905725	1/6/1999	1.9	4	0.56	< 0.05
6905725	3/31/1999	2.4		0.54	E 0.04
6905725	4/21/1999	8.4		0.98	0.11
6905725	6/23/1999	0.54	47	0.89	0.09
6905725	10/25/1999	0.01			0.07
6905725	11/30/1999	0.01	11		0.05
6905725	12/20/1999	0.1			< 0.05
6905725	1/24/2000	0.1	24		0.05
6905725	4/20/2000	0.16			0.07
6905725	5/11/2000	0.07	< 10		0.07
6905725	6/14/2000	8.3		3.3	0.44
6905725	6/15/2000	7.3		2.7	0.25
6905725	6/20/2000	0.22		1.9	0.11
6905725	7/27/2000	0	10		E 0.04
6905725	10/25/2000	0.03			0.28
6905725	11/15/2000	0.1	< 10		0.08
6905725	12/20/2000	0.02			0.06
6905725	1/24/2001	0.24	10	4.3	0.17
6905725	2/14/2001	59		3.2	0.42
6905725	3/28/2001	4.3		2.2	0.12
6905725	4/25/2001	4.1			0.12
6905725	5/22/2001	1.1		1.1	0.08
6905725	5/23/2001	0.82	11	1.1	0.08
6905725	6/18/2001	7.6		1.4	0.21
6905725	6/28/2001	2.5			0.11
6905725	7/26/2001	4.8	228	4.7	0.4
6905725	8/9/2001	0.13		E 1.1	0.1
6905725	9/11/2001	0.03		E 1.1	0.1
6905725	10/24/2001	3.5	50	2.4	0.42
6905725	11/29/2001	0.17	< 10		E 0.06
6905725	12/13/2001	0.83	20		E 0.05
6905725	1/9/2002	0.2	10	0.97	E 0.05
6905725	2/28/2002	1.4	18	1.4	0.09
6905725	3/20/2002	0.97	< 10		E 0.04
6905725	4/18/2002	1.6	17		0.07
6905725	5/22/2002	2.2	20		0.12
6905725	6/27/2002	0.06	10	E 0.69	E 0.04
6905725	8/22/2002	0.17	22	E 0.77	0.08
6905725	2/21/2003	0.05	< 10	1.7	0.15
6905725	3/13/2003	2.5	37		0.2
6905725	3/19/2003	0.3	14	E 1.7	0.14

USGS Gage Number	Sample Date	Flow (cfs)	Total Suspended Solids (mg/L)	TN (mg/L)	TP (mg/L)
6905725	4/24/2003	0.19	26	1.9	0.1
6905725	4/30/2003	1.9	32	2.2	0.2
6905725	5/7/2003	2.5	44	2.1	0.23
6905725	6/12/2003	0.72	16	E 1.2	0.09
6905725	7/9/2003	E 0.00	11		0.1
6905725	9/17/2003	0.33	15	1.7	0.14
6905725	11/19/2003	E 0.01	38		0.27
6905725	12/11/2003	7.9	84	5	0.41
6905725	1/8/2004	0.24	19	2.1	0.17
6905725	2/20/2004	41	81	3.5	0.52
6905725	3/17/2004	25	60	1.8	0.18
6905725	4/21/2004	1.6	15		0.06
6905725	5/12/2004	0.55	< 10		0.07
6905725	6/24/2004	1.9	31	1.6	0.21
6905725	7/13/2004	11	52	1.6	0.21
6905725	8/24/2004	0.25	21	1.1	0.07
6905725	9/15/2004	0.52	< 10	E 1.1	0.09
6905725	10/28/2004	2	< 10		0.14
6905725	11/17/2004	1.8	< 10	0.67	0.06
6905725	12/17/2004	2.4	< 10	0.71	0.05
6905725	1/26/2005	18	46	1.8	0.22
6905725	2/8/2005	22	65	2.6	0.18
6905725	3/17/2005	2.9	< 10		0.13
6905725	4/7/2005	2.9	< 10		0.06
6905725	5/11/2005	11	10		0.07
6905725	6/29/2005	1.7	21		0.08
6905725	7/14/2005	0.02	< 10		0.04
6905725	8/18/2005	0.08	22	E 1.8	0.12
6905725	9/21/2005	0.05	74		0.23
6905725	10/4/2005	0.9	316	4.2	0.59
6905725	11/1/2005	0.04	22		0.16
6905725	12/13/2005	0.01	< 10		0.06
6905725	1/27/2006	0.12	< 10		0.05
6905725	2/15/2006	0.17	15	2.9	0.07
6905725	3/9/2006	0.3	< 10		0.04
6905725	4/14/2006	1.3	18		0.08
6905725	5/12/2006	1.1	10		0.07
6905725	6/15/2006	0.11	< 10		0.06
6905725	7/17/2006	0	34	1.5	0.15
6905725	8/8/2006	2.4	203	1.9	0.36
6905725	9/21/2006	0.06	11	1.1	0.06
6905725	10/23/2006	0.03	20	2.1	0.14
6905725	11/15/2006	0.03	82		0.2
6905725	12/15/2006	0.2	< 10	0.95	0.1
6905725	1/24/2007	0.62	11	1	0.1
6905725	2/22/2007	8	< 10	4.4	0.58

USGS Gage Number	Sample Date	Flow (cfs)	Total Suspended Solids (mg/L)	TN (mg/L)	TP (mg/L)
6905725	3/13/2007	6.5	25	2.3	0.17
6905725	4/24/2007	1.7	< 50		0.08
6905725	5/8/2007	74	176	2	0.36
6905725	6/28/2007	12	444	5.6	0.6
6905725	7/17/2007	0.06	26		0.08
6905725	8/22/2007	2.5	245	3.5	0.53
6905725	9/26/2007	0.04	54		0.18
6905725	10/17/2007	0.07	312	1.9	0.37
6905725	11/7/2007	0.05	11		0.16
6905725	12/18/2007	2.8	20	2.5	0.2
6905725	1/9/2008	40	68	3.1	0.28
6905725	2/26/2008	39	180	3.1	0.57
6905725	3/25/2008	6.2	21	1.4	0.1
6905725	4/17/2008	5.8	28	1.1	0.11
6905725	5/22/2008	1.2	10		0.07
6905725	6/19/2008	2.5	25	1.5	0.15
6905725	7/18/2008	0.4	16		0.1
6905725	8/14/2008	3.9	182	1.9	0.28
6905725	9/23/2008	2.1	14		0.12
6905725	10/28/2008	1.5	< 15	1.3	0.12
6905725	11/20/2008	4.8	< 15	1.3	0.1
6905725	12/4/2008	3.5	< 15	0.6	0.05
6905725	1/29/2009	0.89	< 15	0.62	0.06
6905725	2/26/2009	4.8	< 15	0.62	0.05
6905725	3/12/2009	25	170	2.3	0.28
6905725	4/23/2009	5.4	< 15	E 0.64	0.07
6905725	5/14/2009	47	214	2.4	0.34
6905725	6/26/2009	5	< 150	1.8	0.16
6905725	7/21/2009	0.32	< 15		0.05
6905725	8/19/2009	2	106	2.1	0.23

Note: Blank cells indicate that there was no data for that particular parameter on that date.

Appendix F – Supplemental Implementation Plan

This implementation plan is not a requirement of the Federal CWA. However, the contractor included it as part of the TMDL preparation. EPA recognizes that technical guidance and support are critical to determining the feasibility of and achieving the goals outlined in this TMDL. Therefore, this informational plan is included to be used by local professionals, watershed managers and citizens for decision-making support and planning purposes. It should not be considered to be a part of the established Bear Creek TMDL.

Point Sources

The TMDL will be implemented partially through permit action. Effluent limits and monitoring requirements for the Kirksville WWTP will be reevaluated to reflect the water quality targets set by the TMDL as the operating permit approaches renewal. This may result in the implementation of new or revised effluent limits and instream monitoring for $CBOD_5$, TN, TP and TSS using the WLAs developed for this TMDL. In addition, upon approval of this TMDL, the city of Kirksville's MS4 permit may be reopened and modified to include assessment monitoring and pollution control requirements sufficient to characterize and reduce impacts from their storm water discharges.

Operating permits in Missouri have, in the past, authorized discharges of bypassed wastewater at some facilities during peak flow conditions. This is true of the permit for the Kirksville WWTP. These discharges were required to meet effluent limitations, but these limitations were not as stringent as those for the main facility discharge. Changes in MDNR regulations have removed this authorization and, upon next renewal, the Kirksville WWTP permit will be issued without bypass discharges being authorized. Discharges resulting from emergency diversion shall be considered an unauthorized bypass pursuant to 40 CFR 122.41(m) and shall be reported, pursuant to 40 CFR 122.41(m).

If post-TMDL monitoring indicates that point source reductions are not achieving the desired improvements in water quality, MDNR will reevaluate the TMDL for further appropriate actions. These actions may include additional permit conditions on the Kirksville WWTP and the city's MS4 permit, revised permit conditions on other permitted facilities and further control of nonpoint sources through a nonpoint source management plan. If, at any point in this process, water quality and biological sampling determines that designated beneficial uses are being attained, either the city or MDNR may seek to have Bear Creek removed from the 303(d) List of impaired waters.

Nonpoint Sources

Nonpoint sources of sediment and nutrients are not regulated in Missouri. While cropland accounts for 2,534 acres, or approximately 15 percent of the watershed, grassland accounts for approximately 9,794 acres, or 56 percent of the land area in the watershed. In addition, there are an estimated 2,115 cattle in the watershed. Agricultural runoff from cropland

and grazing land is a potential component of nonpoint source contributions of nutrients and sediment to the impaired segment, and these should be reduced to meet the TMDL targets.

To reduce the loading and effect of nutrients and sediment on Bear Creek, efforts should be made to encourage agricultural producers in the watershed to adopt best management practices (BMPs). The concept of BMPs is one of a voluntary and site specific approach to water quality management. In the Bear Creek watershed, agricultural BMPs should focus on erosion control measures such as the expansion or enhancement of riparian zones, off-stream watering of livestock and rotational grazing practices. In addition, efforts should be made to encourage agricultural producers in the watershed to adopt sound nutrient management practices, including the proper management and storage of manure.

In an effort to most effectively implement voluntary BMPs, MDNR may work with the Natural Resources Conservation Service, local university extension offices and the local Soil and Water Conservation District to encourage area land owners to implement these practices.