Elk River Watershed Association

Phase II Report on Data Collection and Modeling Results for the:

Elk River Bacteria and Turbidity TMDL

Big Elk Lake and Mayhew Lake Nutrient TMDL

Wenck File #2378-01

June 2010

Revised September 2010

Prepared by:

WENCK ASSOCIATES, INC.
1800 Pioneer Creek Center
P.O. Box 249
Maple Plain, Minnesota 55359-0249
(763) 479-4200

wq-iw8-14i

Table of Contents

Tables

Figures

Executive Summary

Section 303(d) of the Federal Clean Water Act (CWA) requires the Minnesota Pollution Control Agency (MPCA) to identify water bodies that do not meet water quality standards and to develop total maximum daily pollutant loads for those water bodies. A total maximum daily load (TMDL) is the amount of a pollutant that a water body can assimilate without exceeding the established water quality standard for that pollutant. Through a TMDL, pollutant loads are allocated to point and non-point sources within the watershed that discharge to the water body.

The Elk River Watershed Association (ERWSA) has reduced nutrient and sediment loads in the watershed through watershed best management practices (BMPs) to improve water quality. However, some 303(d) impairments exist. Table E. 1 summarizes impairments addressed in this report. Figure E.1 shows the locations of the impaired waters in the state of Minnesota, and their location within their watershed.

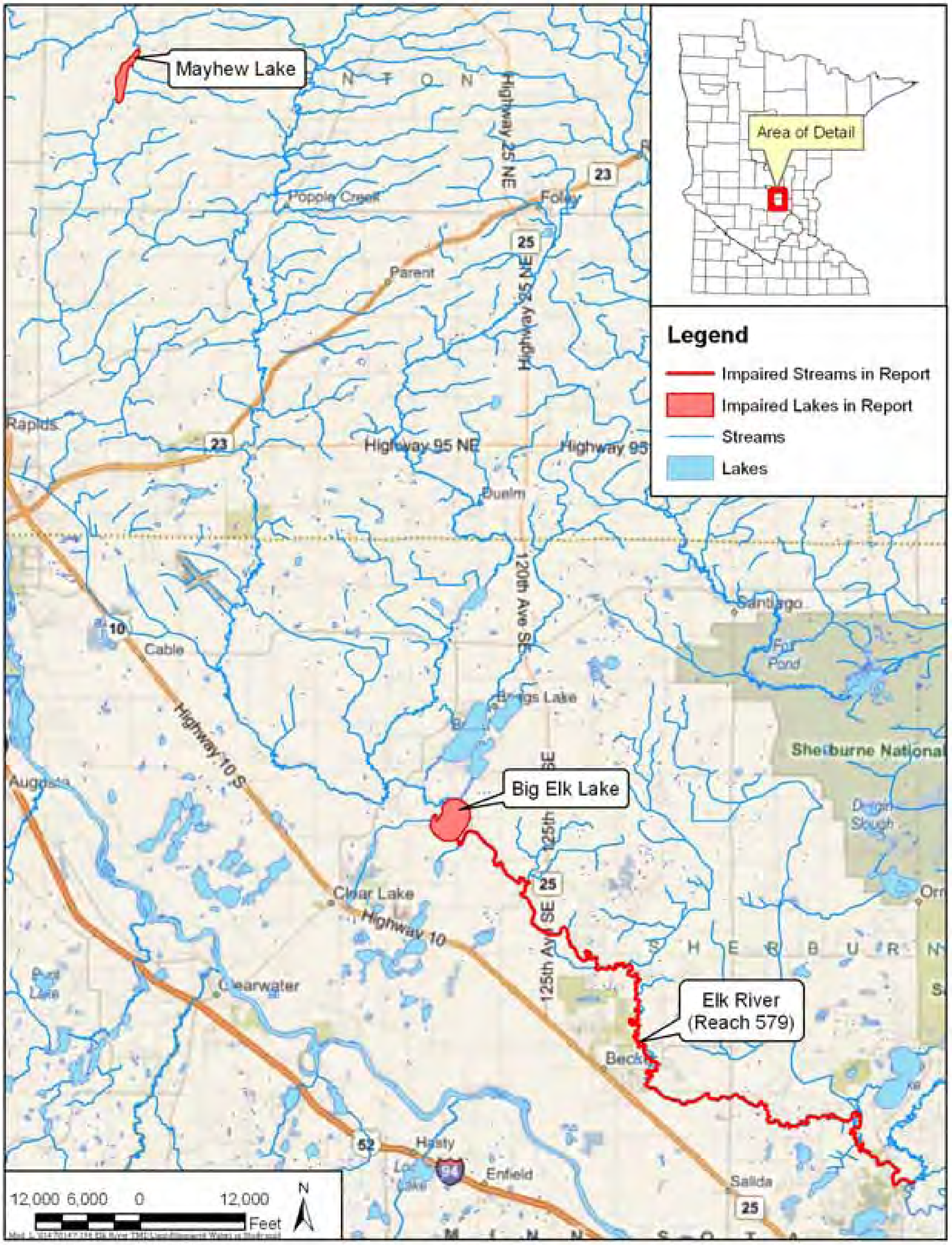
Table E.1 Impairments Addressed in this Report

Water Body	Impairment
Mayhew Lake (05-0007-00)	Excess nutrient concentration impairing aquatic recreation
Big Elk Lake (71-0141-00)	Excess nutrient concentration impairing aquatic recreation
Elk River: Big Elk Lake to St. Francis River (07010203-579)	Excess turbidity and bacterial concentrations impairing aquatic life and aquatic recreation

This TMDL study was undertaken to quantify the pollutant reductions needed for these impaired waters to meet State water quality standards. This TMDL study is being conducted in three phases. Phase I consisted of evaluating existing data and developing a work plan for Phase II and Phase III. The current Phase, Phase II, included data collection, analysis, and water quality modeling. This Phase II Report summarizes the results of Phase II.

The impairments in this watershed were addressed together because the tributary watersheds for the impairments overlap. This means that the implementation plans to address each of the impairments and meet the TMDLs set forth in this report will also overlap.

Figure E.1 Location of Impaired Waters



The total drainage area of the sub-watersheds draining to the impaired portion of the Elk River is 214,639 acres. Mayhew and Big Elk Lakes are located within this drainage area with individual sub-watershed areas of 18,521 and 152,484 acres respectively.

Mayhew and Big Elk Lake Nutrient Impairments

Required load reductions to meet state standards in Mayhew and Big Elk Lakes are 78% and 57% respectively. The state total phosphorus standard for Mayhew Lake (a deep lake) is 40 µg/L, while the state standard for Big Elk Lake (a shallow lake) is 60 µg/l. Internal load management and reduction of phosphorus from watershed runoff will both be required to meet phosphorus load reduction goals in Mayhew Lake. Reduction of phosphorus from watershed runoff will be required to meet goals in Big Elk Lake. To meet required watershed load reductions, a mix of capital projects and land-use based BMPs will be necessary.

Elk River Turbidity

The Elk River turbidity impairment is driven by the nutrient impairment in Big Elk Lake. Summer algal blooms in Big Elk Lake resulting from the nutrient impairment cause turbidity readings that do not meet the state standard resulting in a turbidity impairment in Elk River downstream of Big Elk Lake. Water quality modeling and data analysis shows that the turbidity impairment will be mitigated by achieving the in-lake nutrient standard for Big Elk Lake; therefore the nutrient load allocation for Big Elk Lake is the surrogate for turbidity due to the direct link between the impairments. The load reductions required to meet the nutrient endpoint will result in turbidity levels which meet the State established standard.

Elk River Bacteria

A load reduction of 72.5% is required in terms of *E.Coli* within the listed reach to meet the State standards. Based on *E.Coli* bacteria available in the watershed, the primary implementation strategies will focus on riparian pasture management and agricultural BMPs.

1.0 Introduction

1.1 PURPOSE

The State of Minnesota has determined that the Elk River Reach #579 does not meet the State established standards for bacteria and turbidity and that Mayhew Lake and Big Elk Lake exceed the State established standards for nutrients. This TMDL study addresses these four 303d impairments and is conducted in three Phases. Phase I entailed evaluating existing data, identifying data gaps and planning for future phases. Phase II entailed collection of data, data analysis, and modeling. The TMDLs for these impaired waters will be established in Phase III of this study in accordance with section 303(d) of the Clean Water Act.

This Report documents Phase II of the TMDL study. It provides a summary of data collected during Phase II, results of data analysis and water quality modeling, and a quantification of the pollutant load reductions needed to meet State water quality standards for each listed water body.

1.2 PROBLEM IDENTIFICATION

Water quality evaluations conducted by the State of Minnesota have determined that Mayhew Lake, Big Elk Lake, and reach 579 of the Elk River exceed State established Standards as described below (Table 1.1).

The Clean Water Act Requires the State to develop TMDLs for impaired waters. A TMDL is the amount of pollutant that a water body can assimilate without exceeding the pollutant's water quality standard.

Table 1.1: Impaired waters in the Elk River Watershed

Water Body	HUC	DNR Lake ID # or stream reach #	Listing Year	Affected Use	Pollutant or Stressor	Target Start Date	Target Completion Date
Mayhew Lake	07010203	05-0007-00	2008	Aquatic Recreation	Excessive nutrients	2008	2011
Big Elk Lake	07010203	71-0141-00	2008	Aquatic Recreation	Excessive nutrients	2010	2014
Elk River	07010203	579	2006 & 2008 respectively	Aquatic Life and Aquatic Recreation	Turbidity and pathogens (fecal coliform)	2008	2016

The impairments listed above were based on water quality monitoring conducted by Sherburne Soil and Water Conservation District (SWCD), Benton SWCD, the Minnesota Pollution Control Agency (MPCA), the Briggs Lake Chain Association and the MPCA Citizen Lake and Stream Monitoring Programs (CLMP & CSMP) over the last ten years. Water quality data collection and analysis was conducted in accordance with a QAPP submitted for this project which is on file at the MPCA.

2.0 Description of Applicable Water Quality Standards and Numeric Targets

2.1 MAYHEW LAKE AND BIG ELK LAKE

The MPCA has established numerical thresholds based on ecoregions for determination of Minnesota lakes as either impaired or unimpaired. The protected beneficial use for all lakes is aquatic recreation. Table 2.1 outlines the MPCA water quality goals that were used to determine that Mayhew and Big Elk Lake should be placed on the 303 (d) list of impaired waters in Minnesota. New water quality standards became effective to State rules in Minnesota Water Quality Rule Ch 7050 on March 17th, 2008 and were subsequently approved by the US Environmental Protection Agency (EPA) on May 23rd, 2008 (Table 2.2). The newly approved standards for nutrients are based on ecoregion and lake classification. The changes to the standards also include two indicators of eutrophication that measure lake response to excess phosphorus. The new goals were used to determine the endpoint goals for both Mayhew Lake and Big Elk Lake.

Table 2.1: MPCA goals used to list Big Elk Lake and Mayhew Lake Impairments (North Central Hardwood Forests Ecoregion) (MPCA 2007).

Impairment Designation	TP (µg/L)	Chl-a (µg/L)	Secchi (m)
Full Use	**<40**	**<15**	**≥ 1.6**
Review	**40-45**	**N/A**	**N/A**
Impaired	**>45**	**>18**	**<1.1**

Table 2.2: New MPCA goals and standards for protecting Class 2B waters. Values are summer averages (June 1 through September 30) (MPCA 2008).

Ecoregion	TP (µg/L)	Chl-a (µg/L)	Secchi (m)	Applicable Lake Goals
CHF- Aquatic Rec. Use (class 2b) Deep Lakes	**<40**	**<14**	**>2.5**	**Mayhew Lake**
CHF- Aquatic Rec. Use (Class 2b) Shallow lakes[1]	**<60**	**<20**	**>1.0**	**Big Elk Lake**

1Shallow lakes are defined as lakes with a maximum depth of 15 feet or less, or with 80% or more of the lake area shallow enough to support emergent and submerged rooted aquatic plants (littoral zone).

Under the new standards, Mayhew Lake is considered a deep lake with a numeric target of 40 µg/L total phosphorus concentration. Big Elk Lake is considered a shallow lake with a numeric target of 60 µg/L total phosphorus concentration. Therefore, this TMDL presents load allocations and estimated load reductions assuming endpoints of 40 µg/L and 60 µg/L for Mayhew Lake and Big Elk Lake respectively.

Numeric standards for chloryophyll-a and Secchi depth for Mayhew Lake and Big Elk lake are presented in Table 2.2 as well.

2.2 ELK RIVER

2.2.1 Turbidity

The numeric criteria for turbidity, based on stream use classification, are provided in Table 2.3 (Minnesota Rules Chapter 7050.0220). The impaired reach covered in this TMDL is classified as a Class 2B water and has a turbidity standard of 25 NTU.

Table 2.3 Minnesota Turbidity Standards by Stream Classification

Class	Description	Turbidity (NTUs)
1B	Drinking water	10
2A	Cold water fishery, all recreation	10
2B	Cool and warm water fishery, all recreation	25
2C	Indigenous fish, most recreation	25

Turbidity, a measure of impaired water clarity, is caused by the suspension of sediment, organic matter or algae in the water. High turbidity limits the beneficial uses of streams such as aquatic life and recreation. In source water areas, high turbidity can increase the cost of treatment for drinking water. Turbidity exceedances in reach 579 are caused by extreme algae blooms in Big Elk Lake, located at the upstream end of the impaired reach.

The standard and goal for turbidity in Class 2B waters is 25 nephelometric turbidity units (NTU). Transparency and TSS values reliably predict turbidity and can serve as surrogates at sites where there are an inadequate number of turbidity observations. For waters to be considered impaired, there must be at least 3 observations, and 10% of the observations must violate the standard. The surrogate values of transparency and TSS that correspond to the 25 NTU turbidity standard are as follows:

- transparency tube <20 centimeters
- TSS >100 mg/L

Endpoint turbidity measurements must meet the turbidity standard for Class 2B waters, 25 NTUs.

2.2.2 Bacteria

Elk River reach 579 is classified as a Class 2B water and is protected for aquatic life (warm and cool water fisheries and associated biota) and recreation (all water recreation activities including bathing). The Minnesota standard for bacteria in Class 2B waters is as follows:

Minn. R. ch. 7050.0222 subp. 4, *E. Coli* water quality standard for class 2B and 2C waters states that *E. coli* shall not exceed 126 organisms per 100 milliliters as a geometric mean of not less than five samples in any calendar month, nor shall more than ten percent of all samples taken during any calendar month individually exceed 1,260 organisms per 100 milliliters. The standard applies between April 1 and October 31.

Endpoint *E. Coli* concentrations were determined to be the State water quality standard of a monthly geometric mean of 126 cfu/ 100 ml and no value exceeding 1,260 cfu/ 100 ml for the period of April 1 through October 31. However, the focus of this TMDL is on the "chronic" standard of 126 cfu/ 100 ml. It is believed that achieving the necessary reductions to meet the chronic standard will also reduce the exceedances of the acute standard (MPCA 2002).

This standard, current as of 2008, represents a change from the historic use of fecal coliform as a regulated pathogen indicator. Because the change is recent, historic in-stream water quality data available for this TMDL study was fecal coliform, not *E. Coli.* Water quality data collected in 2009 as part of Phase II of the TMDL was analyzed for *E. Coli*. Both the fecal coliform data and *E. Coli* data was used to analyze watershed sources of bacteria and in-stream bacteria concentrations and to determine effective load reduction strategies. The *E. Coli* standard was determined to be as protective as the fecal coliform standard, and load reductions that are applicable to fecal coliform will result in similar load reductions to E. Coli bacteria (MPCA 2007).

For reference, the historical fecal coliform standards were as follows: that Fecal Coliform shall not exceed 200 organisms per 100 milliliters as a geometric mean of not less than five samples in any calendar month, nor shall more than ten percent of all samples taken during any calendar month individually exceed 2,000 organisms per 100 milliliters. The standard applies between April 1 and October 31.

3.0 Background

3.1 WATERSHED DESCRIPTION

The entire Elk River Watershed is located northwest of the Twin Cities metropolitan area in the North Central Hardwood Forests ecoregion and is a major tributary to the Upper Mississippi River. The full drainage area of the Elk River consists of approximately 392,320 acres (613 square miles) of Sherburne County, Benton County, Mille Lacs County, and Morrison County. However; the majority of the Elk River Watershed lies within Benton and Sherburne Counties. The Elk River headwaters are located in northern Benton County, and the river extends south eastward towards the City of Elk River were it outlets into the Mississippi River. The Elk River has a gradient of approximately three feet per mile.

In 1994 the Elk River Watershed Association Joint Powers Board was formed as a result of Local Water Planning efforts in Sherburne and Benton Counties. Concerned citizens identified the water quality of the Elk River and lakes in the Elk River Watershed as priorities for improvement. Thus, the two Counties determined that a watershed approach would be the most effective way to improve water quality. A Joint Powers Board was formed by Sherburne and Benton SWCDs and Counties for the purpose of coordinating efforts within the Elk River Watershed.

Land use in the northern portion of the watershed is primarily agricultural and feedlot density is high. The high percentage of agricultural land use in riparian areas leads to an extremely high potential to introduce large amounts of phosphorus, sediment, and bacteria to surface waters. Furthermore, the numerous small to medium sized feedlots and riparian pastures offer additional opportunities for manure to enter surface water directly. The southern portion of the watershed is mainly comprised of irrigated agriculture and urban/residential developments. With the exception of Mayhew Lake, all of the lakes greater than 10 acres are located within Sherburne County. The lake shore property in the watershed tends to be densely populated. Much of this development occurred prior to the adoption of shore land ordinances. Subsequently, many lots are as small as 50 feet in width and most natural vegetation has been removed from the shorelines and replaced with turf grass. Septic systems provide waste water treatment for these areas.

Land use within the Elk River watershed will be influenced over the coming years by its close proximity to two major employment centers; the St. Cloud Metropolitan Area and the “Twin Cities” of Minneapolis and St. Paul. Sherburne County is served by two major transportation corridors, US TH 10 and US TH 101/169, along with the recent opening of the Northstar Commuter Rail which provide for convenient connections to careers and leisure activities in the major metropolitan area. Most of the demand for building permit requests in both the cities and the townships is taking place within the southern portions of the watershed, within Sherburne County. Development pressure has eased in recent years due to the economic conditions.

The Elk River offers recreational opportunities for canoeists, anglers, hunters and non-game wildlife viewers close to the Minneapolis- St. Paul Metropolitan area. The Department of Natural Resources (DNR) has identified twenty five potential canoe accesses along the river and there are several lakes with public boat accesses.

In addition to the three water bodies evaluated in this TMDL, there are several other impaired water bodies located within the Elk River Watershed (Table 3.1). Impaired waters not covered with this TMDL project will be addressed in the state of Minnesota's new approach in surface water assessment, monitoring and implementation planning. This new approach addresses surface water resource restoration and protection strategies on a major (8 digit Hydrologic Unit Code- HUC) watershed level in a 10 year cycle. This process is scheduled to begin for the Mississippi River St. Cloud Watershed (which includes the surface waters with the Elk River Watershed) in the fall of 2010. This approach will address all the impaired surface water resources within this watershed and prescribe protection measures for unimpaired surface water resources.

Table 3.1: Impaired waters located within the Elk River watershed. These impairments are not addressed in this TMDL.

Water Body	DNR Lake ID or Stream Reach #	Year Listed	Impairment	Target Start Date	Target Finish Date
Julia Lake	71-145	2008	Excess Nutrients (Phosphorus)	2010	2014
Rush Lake	71-147	2008	Excess Nutrients (Phosphorus)	2010	2014
Briggs Lake	71-146	2008	Excess Nutrients (Phosphorus)	2010	2014
Rice Creek	07010203-512	2006	Dissolved oxygen and turbidity	2014	2021
Elk River	07010203-579	2006	aquatic macroinvertebrate bioassessments	2008	2016
Rice Creek	07010203-512	2006	Dissolved oxygen, turbidity	2014	1021
Battle Brook	07010203-535	2006	aquatic macroinvertebrate bioassessments	2016	2021
Lake Orono	71-013	2008	Excess Nutrients (Phosphorus)	2010	2013
Mayhew Creek	07010203-509	2002	fish and aquatic macroinvertebrate bioassessments	2009	2017

3.1.1 Land Use

The Elk River watershed is comprised of a variety of land uses. The National Agriculture Statistics Services (NASS) 2008 cropland data was used to determine land use within the sub-watersheds tributary to the Elk River reach 579, including Big Elk and Mayhew lakes. This data is an appropriate data set for agricultural watersheds as the use categories are specific in describing agriculture uses, such as separately classifying corn, soybeans, and alfalfa.

Land use is presented in Table 3.2. Overall, pasture/hay is the most frequent land use covering 73,567 acres or 34.3% of the 214,639 acre total area. Deciduous forest is the next highest land use with 20.1% of the total acreage. Other agricultural land uses such as corn and soybeans (row crops) comprise 15.3% and 9% of the total acreage respectively.

Table 3.2: Land Use within the TMDL watersheds

Landuse	Acres	Percent
Pasture/Hay	73,567.25	34.27%
Deciduous Forest	43,085.61	20.07%
Corn	32,761.08	15.26%
Soybeans	19,244.32	8.97%
Herbaceous Wetlands	13,524.16	6.30%
Developed/Open Space	12,607.98	5.87%
Open Water	3,623.01	1.69%
Evergreen Forest	2,490.50	1.16%
Grass Pasture	2,263.93	1.05%
Developed/Low Intensity	1,883.14	0.88%
Grassland Herbaceous	1,815.45	0.85%
Alfalfa	1,756.21	0.82%
Potatoes	1,728.90	0.81%
Spring Wheat	1,001.34	0.47%
Developed/Medium Intensity	676.98	0.32%
Rye	528.04	0.25%
Dry Beans	486.38	0.23%
Sweet Corn	380.95	0.18%
Developed/High Intensity	287.01	0.13%
Oats	208.61	0.10%
Shrubland	142.71	0.07%
Winter Wheat	140.36	0.07%
Woody Wetlands	114.06	0.05%
Peas	112.75	0.05%
Barren	59.94	0.03%
Fallow Idle Cropland	46.27	0.02%
Barley	27.12	0.01%
Woodland	25.57	0.01%
Sugarbeets	20.15	0.01%
Sorghum	7.75	0.004%
Sunflowers	4.59	0.002%
Canola	3.87	0.002%
Wetlands	3.10	0.001%
Mixed Forest	3.10	0.001%
Other Crops	2.32	0.001%
Clover Wildflowers	1.55	0.001%
Seed/Sod/Grass	0.77	0.0004%
Flaxseed	0.77	0.0004%
Total	214,639.19	100.00%

3.1.2 Population

The total population in the watershed is estimated to be 152,400 based on US Census data from 2000. Sherburne County has shown a 54 percent increase in population since 1990 and Benton County has shown a 13 percent increase. The Minnesota State Demographic Center estimated the

2005 population of Benton County at 38,979 and Sherburne County at 82,815 people. The 2015 projected populations of Benton and Sherburne Counties are 47,980 and 119,040 people respectively.

3.2 WATER BODY DESCRIPTIONS

Mayhew Lake is a 130 acre basin located in the upper northwest corner of the Elk River watershed. Mayhew Lake is oriented as a long and narrow basin that is relatively shallow with an average depth of 13 feet and maximum depth of 20 feet. Mayhew Lake has a littoral zone covering 64 acres, or 49 percent of the basin. Mayhew Creek flows into Mayhew Lake at the northeast end of the basin and serves as the outflow point of Mayhew Lake at the southwest end of the basin. A concrete, fixed crest weir dam was installed at the outlet of the lake in 1951. The structure, which was initially built by the state of Minnesota and Benton County, is now owned by the MN DNR as is noted by the 1995 Lake Assessment Program report to be at the elevation of 1,088.5 feet. There are two other unnamed tributaries that flow into the east end of Mayhew Lake. Mayhew Lake has a contributing watershed area of 18,521 acres, resulting in a watershed to lake area ratio of 142:1. This indicates Mayhew Lake has a short residence time.

Big Elk Lake is a shallow, 360-acre basin with an average depth of five feet and a maximum depth of nine feet. Big Elk Lake meets the definition of a shallow lake because of its maximum depth, and because its littoral zone covers 100 percent of the basin. Big Elk Lake is a flow through system on the main stem of the Elk River which enters the lake in the northwest corner on river mile 39.7 and exits at the southeast corner of the lake at river mile 38.5. Lily Creek also flows into Big Elk Lake at the north end of the lake, connecting Big Elk Lake to the Briggs Chain of Lakes including Julia, Rush and Briggs Lakes. Big Elk Lake has a large contributing watershed of 152,484 acres resulting in a watershed to lake area ratio of 425:1. Due to the shallow nature of the lake, the lake volume is relatively small at only 1,540 ac-ft. The large inflow volume from the Elk River and additional tributaries results in a very short residence time for the lake, ranging from less than one to more than 60 days depending on flow in the Elk River.

Mayhew Lake and Big Elk Lake are characterized by recreational use, fish populations and health, aquatic plants, and shoreline habitat and conditions. A summary of these characteristics for each of the lakes can be found in Table 3.3.

Mayhew Lake has one county owned gravel public access on the southwest corner of the lake. Improvements have been made recently to the county park on the west side of the lake which offers a fishing pier and picnic area. The park is well maintained and encourages shore fishing. Big Elk Lake has one DNR owned concrete public access on the east side of the lake off of County Road 88.

Table 3.3: Lake Characterization

Lake Name	**Mayhew Lake**	**Big Elk Lake**
Public Boat Access	1 (gravel)	1 (concrete)
Most Recent Fish Survey	2008	2009
Primarily Managed Fish Species	Walleye, Black Crappie Northern Pike (Secondary)	Northern Pike, Walleye
Fish Stocking	Walleye, 2009	Walleye, 2009 (privately stocked)

The Elk River is an 83.4 mile long river with its origin as an intermittent stream in north central Benton County. The Elk River flows south-southeast to its confluence with the Mississippi River in the City of Elk River, Minnesota. The reach of the Elk River listed for turbidity and bacteria impairment is a 23.2 mile reach, extending from the outflow of Big Elk Lake at river mile 38.6 to its confluence with the St. Francis River at river mile 15.4 (Figure 5.8). The contributing watershed area to the listed reach of the Elk River includes the area upstream of Big Elk Lake for a total of 214,639 acres.

The United States Geological Survey (USGS) has maintained a permanent flow gauging station on the Elk River 5 miles downstream of the listed reach at river mile 9.5. Daily flows have been recorded at the USGS station since 1977. There is one major and two minor inflows between the listed reach and the USGS station (the St. Francis River, Tibbets Creek and a small inflow to Lake Orono). Average daily flows were measured at the upstream and downstream end of the impaired reach during 2009 and they correlated well with USGS flows. Evaluation of these flow data indicated that unit area flows were a good predictor of upstream flows based on the USGS data set. Therefore, the combination of the USGS data set, and the 2009 data collected in the listed reach during the TMDL study provided a long-term context. The use of these data in development of the TMDLs is discussed in Section 5.1.3 of this report.

3.2.1 Water Quality

Historical water quality data as well as data collected as part of Phase II of the TMDL study was analyzed to develop each TMDL. Specific data collection was done in accordance with the Workplan developed in Phase I of this study. Field monitoring was conducted between March and October of 2009, the flow season. Water quality samples were collected in Mayhew Lake monthly and at each tributary to Mayhew Lake every two weeks during the flow season. Water quality was measured in Big Elk Lake and its tributaries two weeks. Flow was measured every time water quality samples were collected at stream sites. Discrete flow measurements and water quality samples were collected on the impaired Elk River reach and its tributaries every two weeks during flow season. Sample locations were selected based on subwatershed boundaries to maximize coverage. River stage was recorded continuously in the listed reach at ER 37.3 and ER 16.6 as well as at ER 44.6 and TR ER 41.6 upstream of Big Elk Lake. Discrete flow measurements were also collected at these locations. The MPCA used these data to develop continuous flow records for these locations. Data was collected during wet and dry weather and over a range of flow conditions. Monitoring locations are shown on Figures 3.1 through 3.3.

Figure 3.1: Mayhew Lake monitoring locations

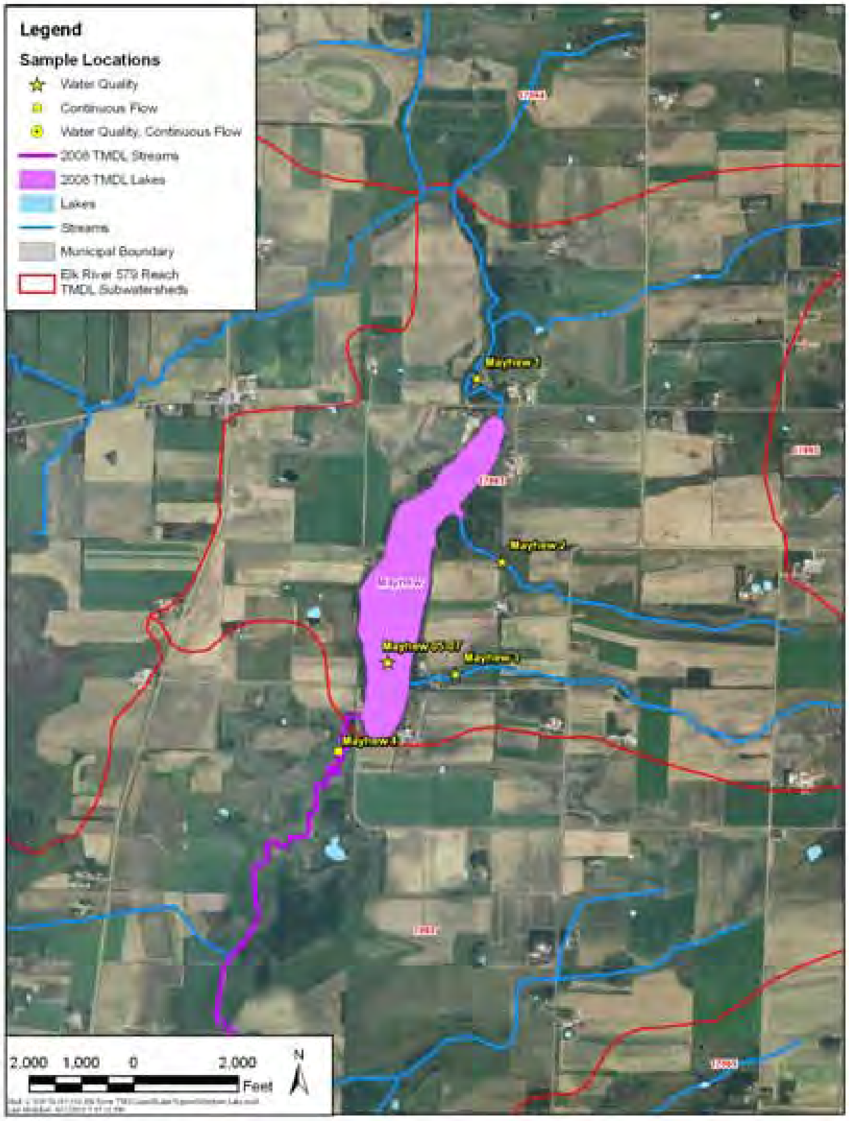


Figure 3.2: Big Elk Lake monitoring locations

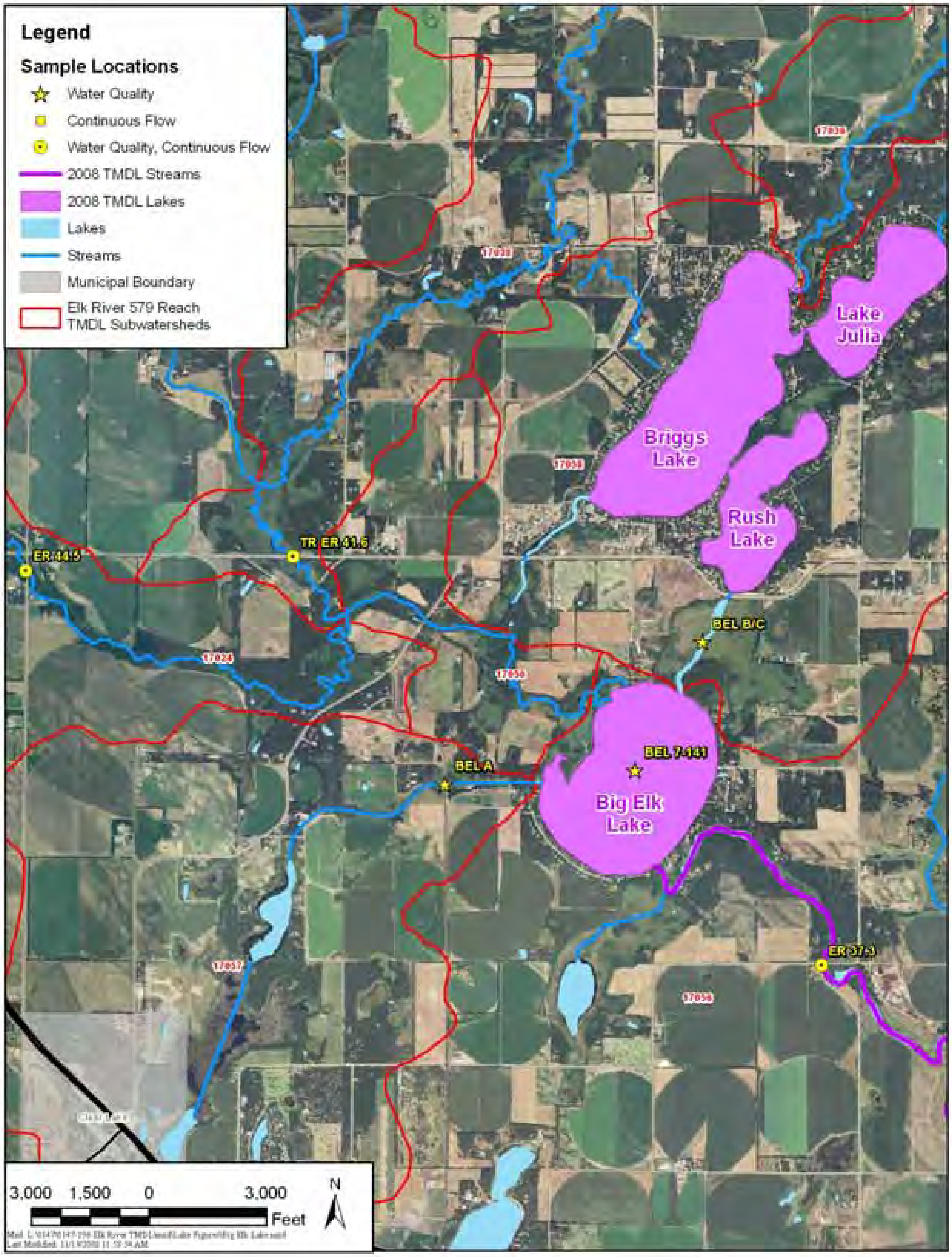
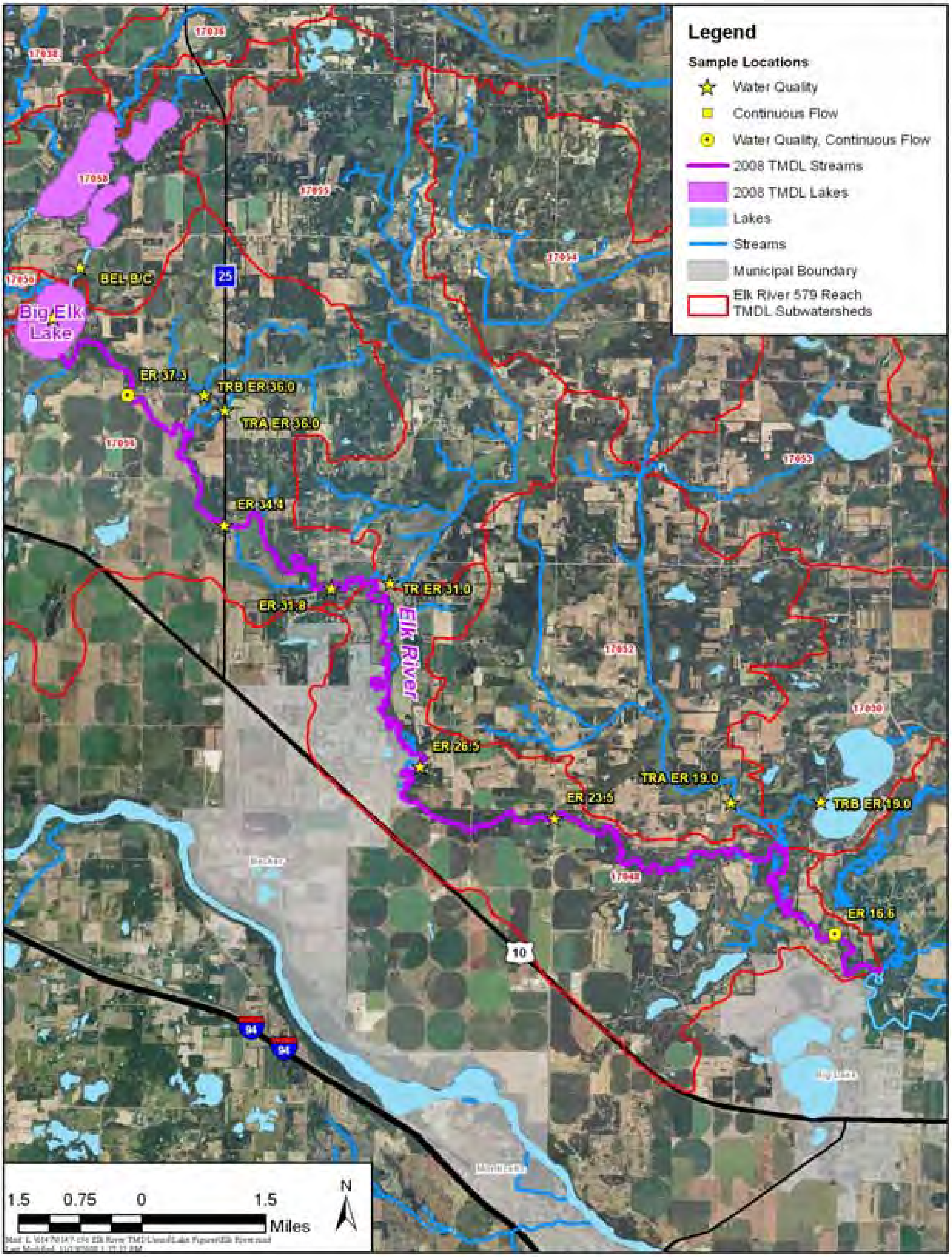


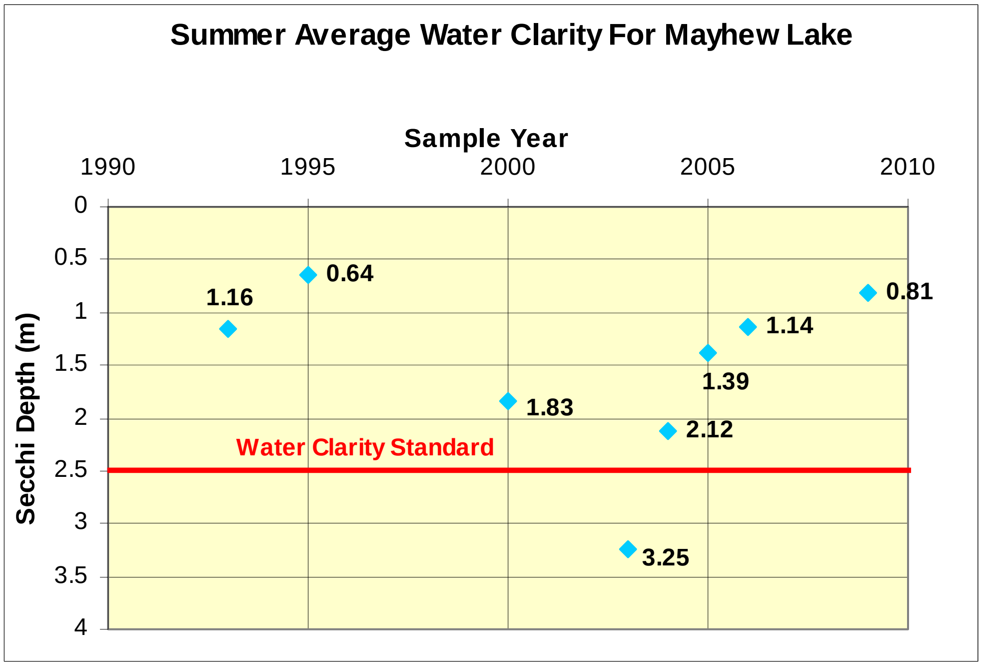
Figure 3.3: Elk River Reach 579 monitoring locations



3.2.1.1 Mayhew Lake

Historical water quality data for Mayhew Lake was retrieved from the MPCA EDA website. Water clarity data (i.e., Secchi depth measurements) are available from 1993 through 2006. Total phosphorus and chlorophyll-a data are available from 1995 through 2006. Water clarity, phosphorus, and chlorophyll-a data were also collected in 2009 as part of Phase II of the TMDL. Mean Secchi depth measurements for Mayhew Lake have varied from a low of 0.64 meters in 1995 to a high of 3.25 meters in 2003 (Figure 2.4). The 2009 summer average was 0.81 meters. The most recent years of water clarity measurements, 2003 through 2009, show a decline in lake water clarity; however, some of the data seemed to have been entered with incorrect units (three of the measurements exceeded the maximum lake depth, and many more exceeded the lake depth at the measurement location). For the purpose of Figure 3.4, values that appeared to have been misentered were corrected. In any case, the Secchi depth data is not given equal weight with TP or Chlorophyll-a in terms of evaluation of lake water quality or trends. 2003 is the only year in which the average summer Secchi depth met the new State standard of readings greater than 2.5 meters for deep lakes in the North Central Hardwood Forest ecoregion.

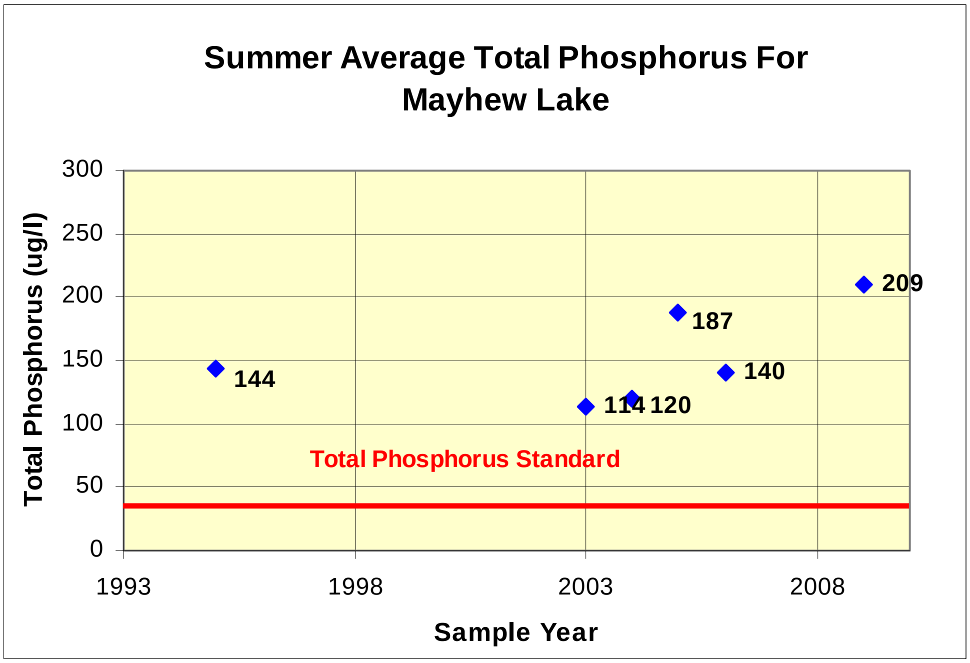
Figure 3.4: Summer average Secchi depth readings in Mayhew Lake



T:\2378_ERWSA\Mayhew\Copy of Mayhew WQ_All_Data.xls\Graphs

Average summer growing season total phosphorus has ranged from 110 µg/L to 223 µg/L (Figure 3.5). The reported decline in lake water clarity values observed from 2003 through 2009 appears to correlate with observed total phosphorus concentrations in Mayhew Lake. Total phosphorus concentrations in Mayhew Lake have exceeded the State standard of 40 µg/L for lakes of the North Central Hardwood Forests ecoregion in all monitoring years with 2009 presenting the highest average on record.

Figure 3.5: Summer average total phosphorus concentrations in Mayhew Lake



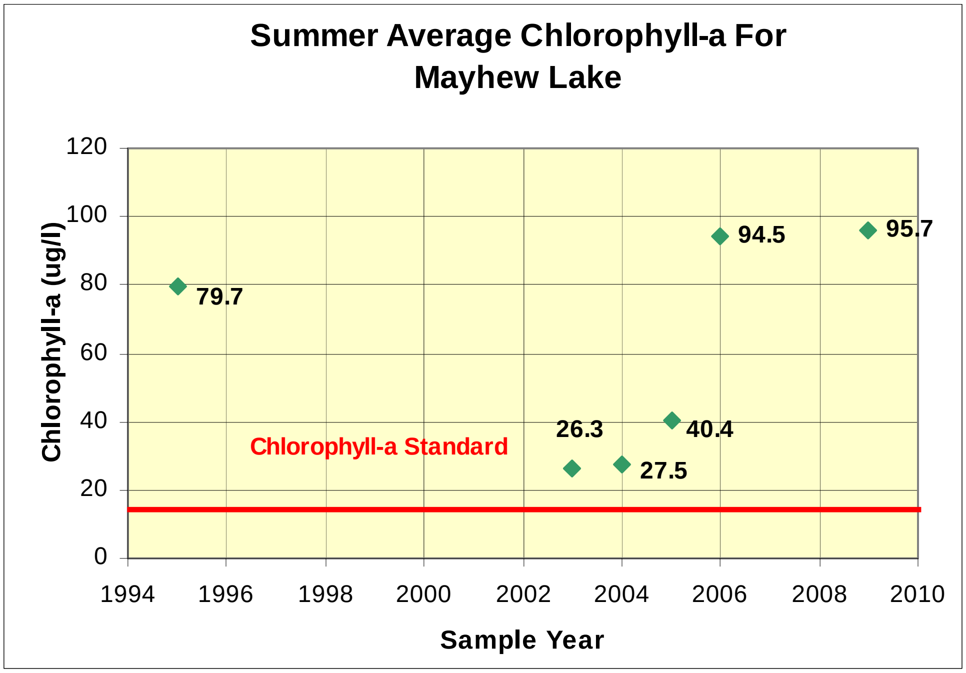
T:\2378_ERWSA\Mayhew\All WQ Data.xls\Summer TP_CHla

The highest observed average chlorophyll-a concentration was 95.7 µg/L in 2009 (Figure 3.6). Concentrations have exceeded the State standard of 14 µg/L for lakes of the North Central Hardwood Forests ecoregion in all monitoring years and recent years, 2006 and 2009, present the highest concentrations on record for Mayhew Lake.

Each of the Trophic Status Indicators (TSI's, Secchi, phosphorus and chlorophyll-a) show a trend of declining water quality between 2003 and 2009. The 2003 to 2009 trend correlates with increased precipitation between 2003 and 2009. Increased precipitation in a lake with long residence times can correspond to higher watershed loads of phosphorus, which would explain the observed decline water quality. The trend is not necessarily reflective of changing watershed conditions, but continued evaluation is recommended. Annual precipitation in Benton County for measured years shown in the graphs is as follows:

2003: 26.56 inches
2004: 27.28 inches
2005: 30.59 inches
2006: 30.39 inches
2009: 33.80 inches

Figure 3.6: Summer average chlorophyll-a concentrations in Mayhew Lake

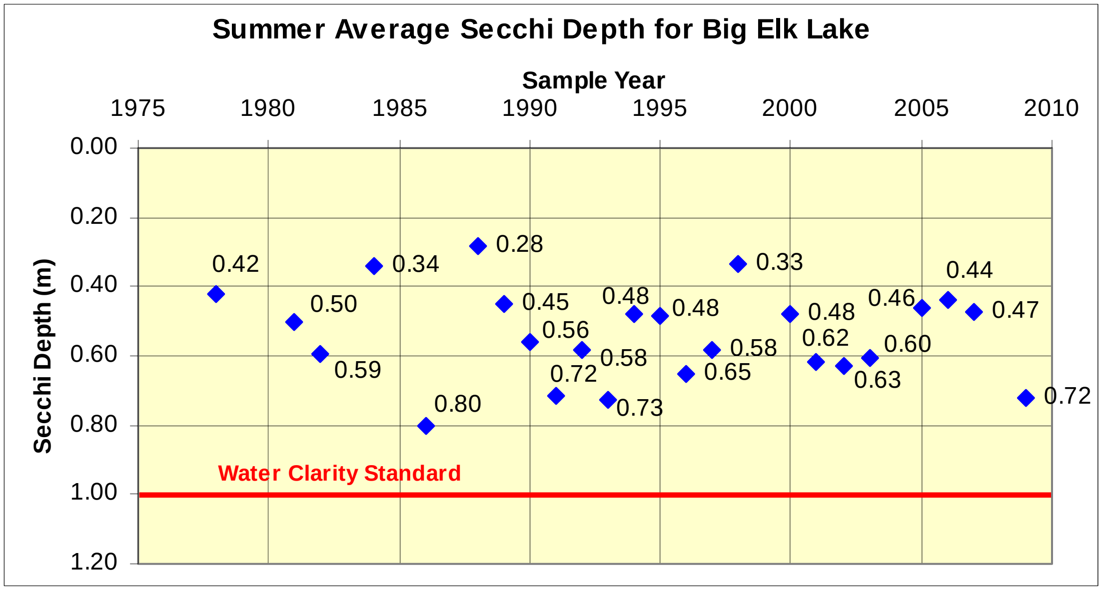


T:\2378_ERWSA\Mayhew\ All WQ Data.xls\Summer TP_CHla

3.2.1.2 Big Elk Lake

Water quality data for Big Elk Lake was retrieved from the MPCA Electronic Data Access (EDA) website. Water clarity data (i.e. Secchi depth measurements) are available from 1978 through 2007. Total phosphorus and chlorophyll-a data are available from 1981 through 2007. Water clarity, total phosphorus, and chlorophyll-a data as well as other water quality data was collected in 2009 as part of Phase II of the TMDL. Secchi depth measurements for Big Elk Lake have varied from a low of 0.28 meters in 1988 to a high of 0.80 meters in 1986 (Figure 3.7). From 2000 to 2007, summer average Secchi depth was relatively stable ranging from 0.44 to 0.63 meters. The 2009 summer average Secchi depth was 0.72 meters. All measured years for water clarity fall below the State standard of 1.0 meters for shallow lakes in the North Central Hardwood Forest ecoregion. The data reveals no significant improving or declining trend.

Figure 3.7: Summer average Secchi depth readings for Big Elk Lake

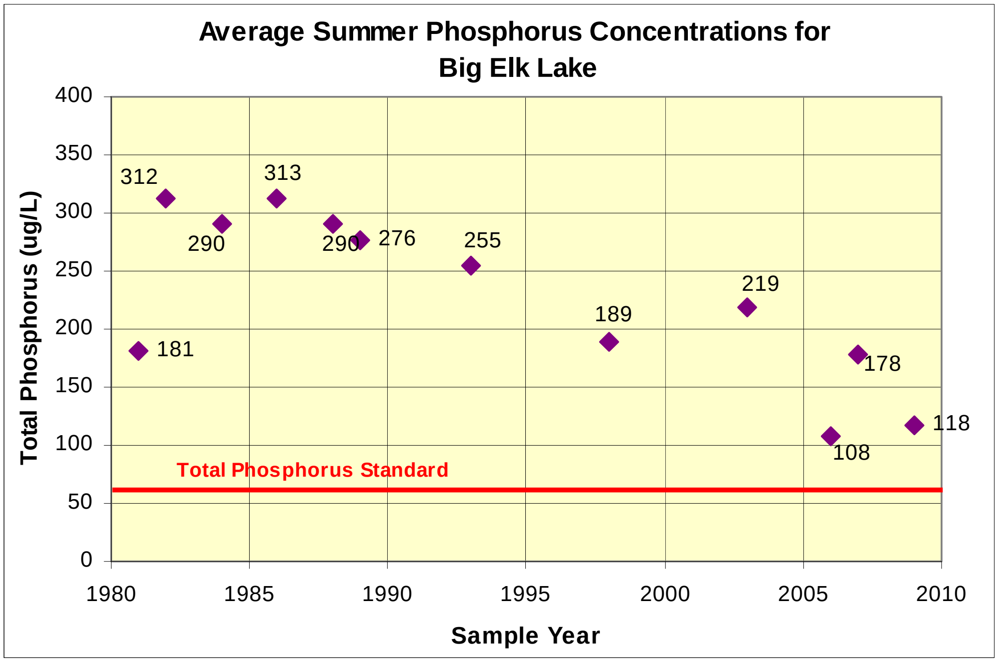


T:\2378_ERWSA\Big Elk Lake\Copy of EDA_71_0141_Elk Lake.xls\Graphs

Average summer growing season total phosphorus concentrations have ranged from 108 µg/L in 2006 to 313 µg/L in 1986 (Figure 3.8). Total phosphorus concentrations in Big Elk Lake ranged from 181 to 313 µg/L from 1980 to 2000. Monitoring data from the four sample years since 2000 showed average total phosphorus concentrations ranging from 108 – 219 µg/L with the 2006, 2007, and 2009 sample years presenting the lowest averages on record. However, despite the lower total phosphorus concentrations observed in recent years, concentrations have exceeded the State standard of 60 µg/L for shallow lakes of the North Central Hardwood Forests ecoregion in all monitoring years.

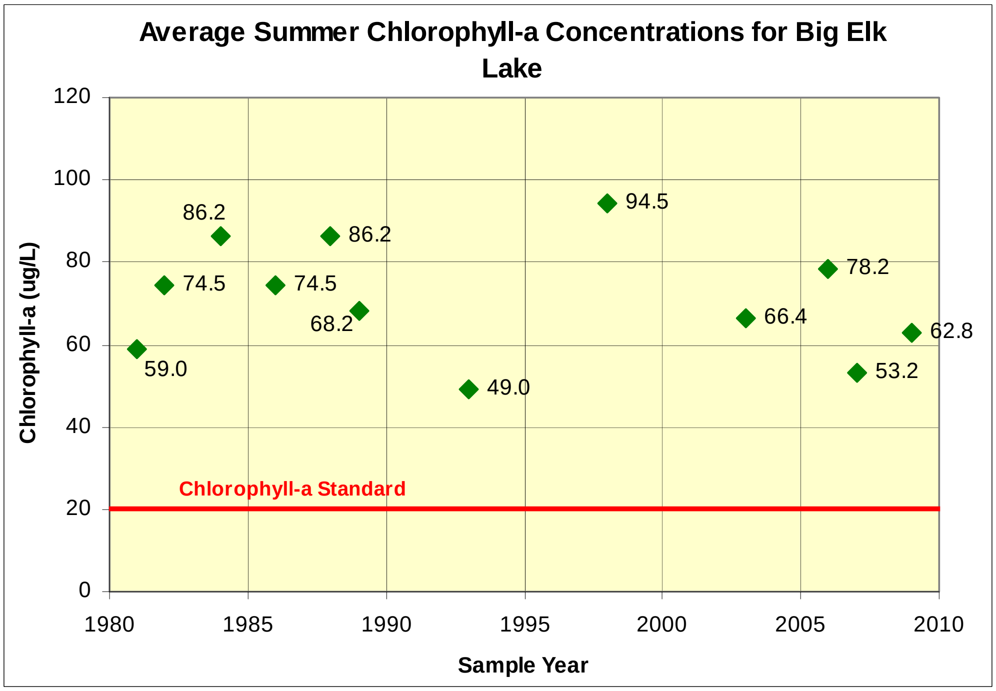
Average summer growing season chlorophyll-a concentrations have ranged from a low of 49 µg/L in 1993 to 94.5 µg/L in 1998 (Figure 3.9). The 2009 average concentration was 62.8 µg/L. There has been a moderate amount of observed variation in summer growing season average chlorophyll-a concentrations in Big Elk Lake. Chlorophyll-a concentrations have increased or decreased by more than 50 percent between monitoring years, with no clear trends across monitoring years. Average summer growing season chlorophyll-a concentrations in Big Elk Lake have exceeded the State standard of 20 µg/L for shallow lakes of the North Central Hardwood Forests ecoregion during all monitoring years.

Figure 3.8: Summer average total phosphorus concentrations for Big Elk Lake



T:\2378_ERWSA\Big Elk Lake\All WQ Data.xls\All Years TP

Figure 3.9: Summer average chlorophyll-a concentrations for Big Elk Lake



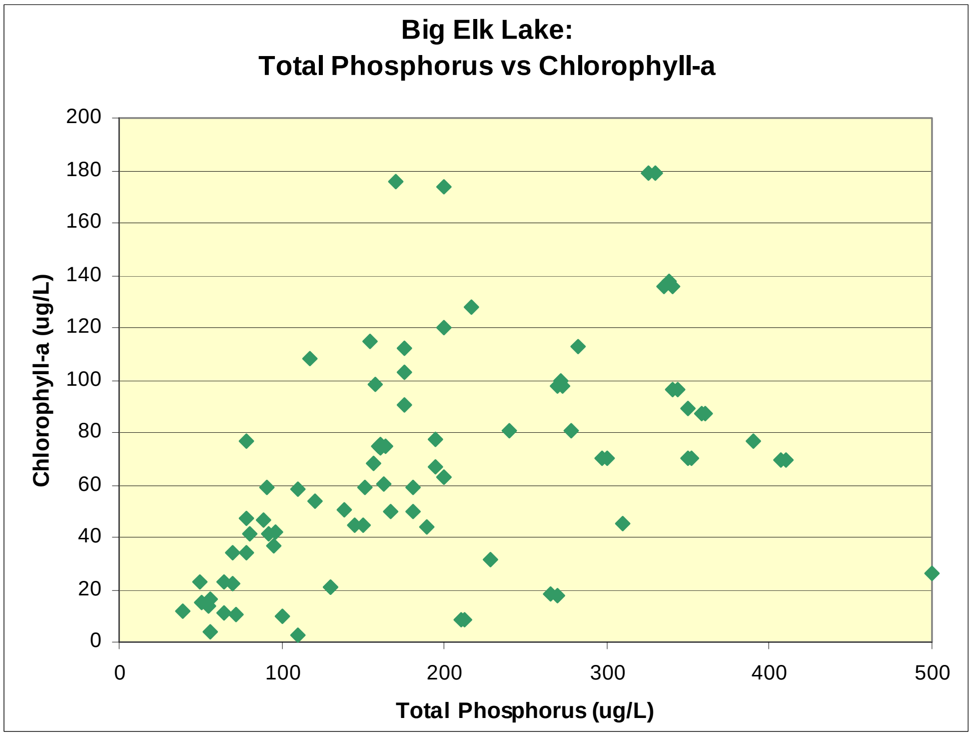
T:\2378_ERWSA\Big Elk Lake\Copy of EDA_71_0141_Elk Lake.xls\Graphs

Discrete chlorophyll-a concentrations were compared to discrete total phosphorus concentrations in Big Elk Lake (Figure 3.10). In general, high chlorophyll-a concentrations are associated with high total phosphorus concentrations. Variability in the relationship between TP and Chlorophyll-a in Big Elk Lake is likely due to a combination of factors:

1. First, the residence time of Big Elk Lake is short relative to generation times for algae. Figure 5.2 in the Phase I Report shows the relationship between Elk River inflows to Big Elk Lake and residence time in Big Elk Lake as it relates to the flow duration curve for that location. About 40% of the time, the lake has a residence time less than 7 days. About 80 % of the time, the residence time for Big Elk Lake is less than 14 days. The high flow-through rate of this lake indicates that the lake hydrodynamics are influencing growing conditions for chlorophyll-a.
2. It is common to have high variability in chlorophyll-a at the high TP concentrations observed in Big Elk Lake, as TP is far in excess of algal needs. Such variability can be observed in the relationships shown in figure 3.10.

Despite the variability of the TP- chlorophyll-a relationship at high levels of TP and low residence times, it is generally understood that the best way to control chlorophyll-a concentrations (algal blooms and the accompanying algal turbidity observed in Elk River) in lakes it to reduce TP loads to lakes (Heiskary and Walker, 1988, Heiskary and Wilson, 2005 and 2008).

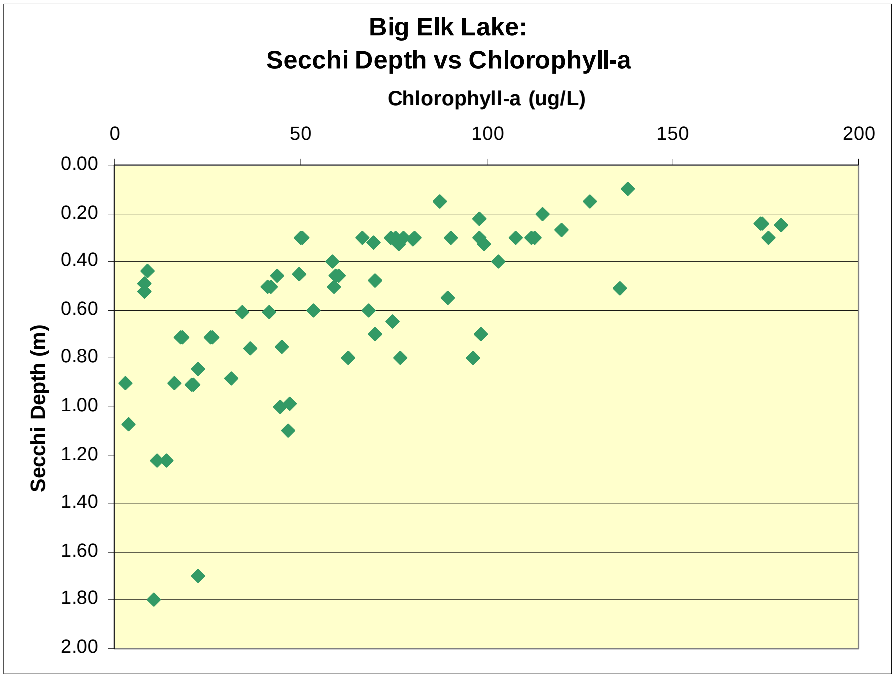
Figure 3.10: Discrete chlorophyll-a concentrations versus discrete total phosphorus concentrations for Big Elk Lake



T:\2378_ERWSA\Big Elk Lake\Copy of EDA_71_0141_Elk Lake.xls\Chla vs Flow

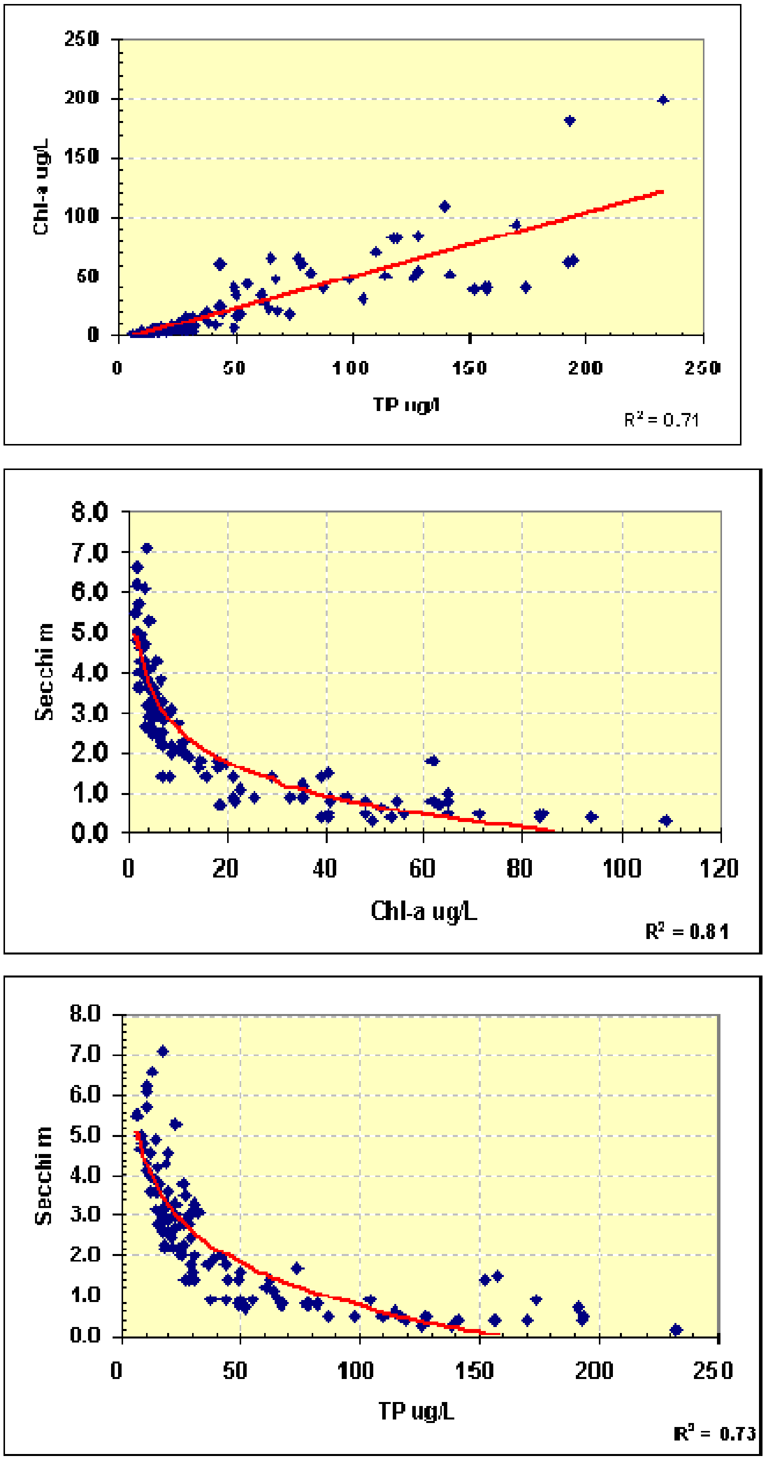
Discrete chlorophyll-a concentrations were also compared to discrete Secchi depth readings in Big Elk Lake (Figure 3.11). This comparison reveals that algal turbidity is likely the main driving factor affecting water clarity in Big Elk Lake, though turbidity from other sources like wind resuspension is also common in shallow lake systems like this one.

Figure 3.11: Discrete chlorophyll-a concentrations versus discrete Secchi depth readings for Big Elk Lake



T:\2378_ERWSA\Big Elk Lake\Copy of EDA_71_0141_Elk Lake.xls\Chla vs Flow

Figure 3.12: Relationships between phosphorus, chlorophyll-a and Secchi depth (Source: MPCA web site http://www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/lakes/lake-water-quality/asessment-definitions-and-notes.html?menuid=&missing=0&redirect=1)

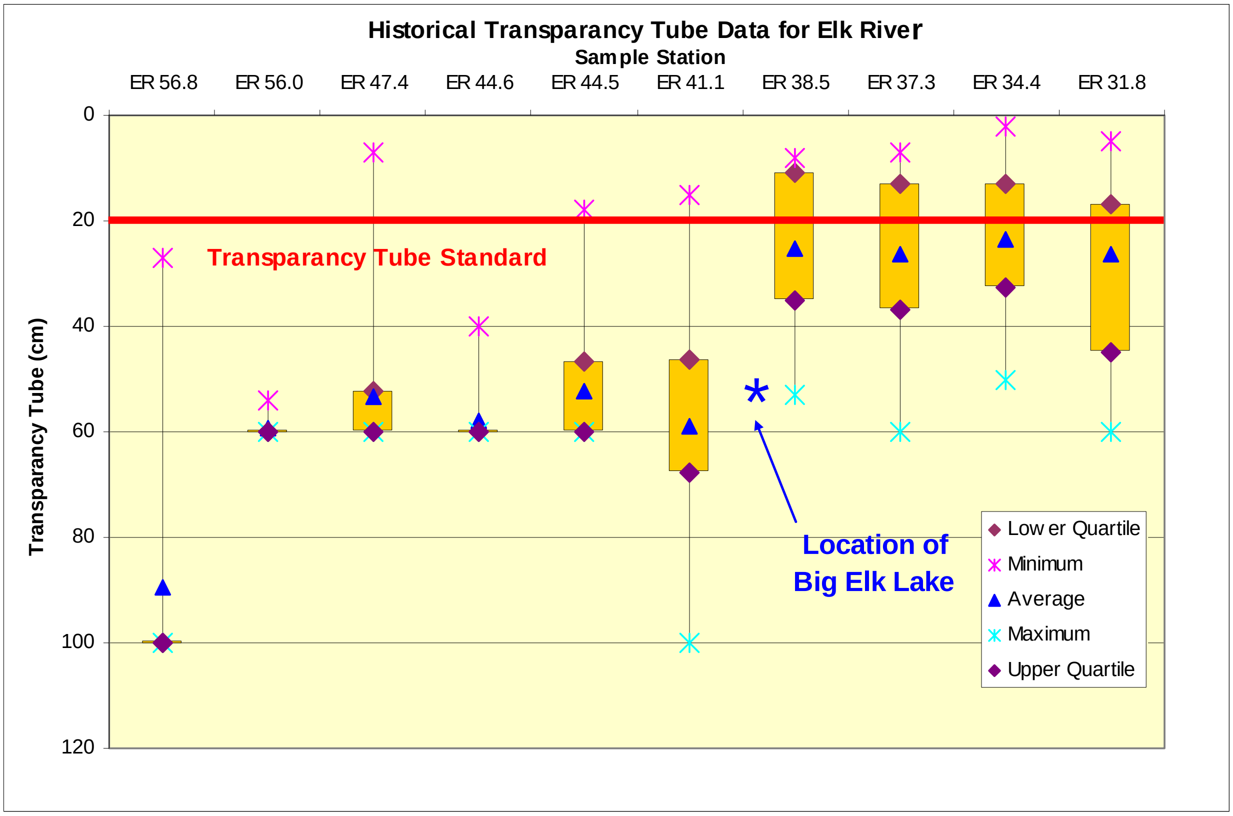


3.2.1.3 Elk River Reach 579

3.2.1.3.1 Turbidity

Historical transparency data is available for ten stations along the Elk River, six stations upstream of Big Elk Lake and four stations downstream of Big Elk Lake within the listed reach. Longitudinal transparency data for the Elk River is presented by river mile from upstream to downstream (Figure 3.13). Stations ER 56.8 through Station ER 41.1 are upstream of Elk Lake and outside of the reach listed for turbidity impairment. The median transparency value for these samples is 60 or greater. Station ER 47.4, ER 44.5 and ER 41.1 do have three or more values below 20 cm. However, the number of samples below 20 cm is not greater than 10% of the total sample measurements and therefore the reach is not considered impaired for turbidity. Sampling stations within the listed reach are Stations ER 38.5, ER 37.3, ER 34.3 and ER 31.8.

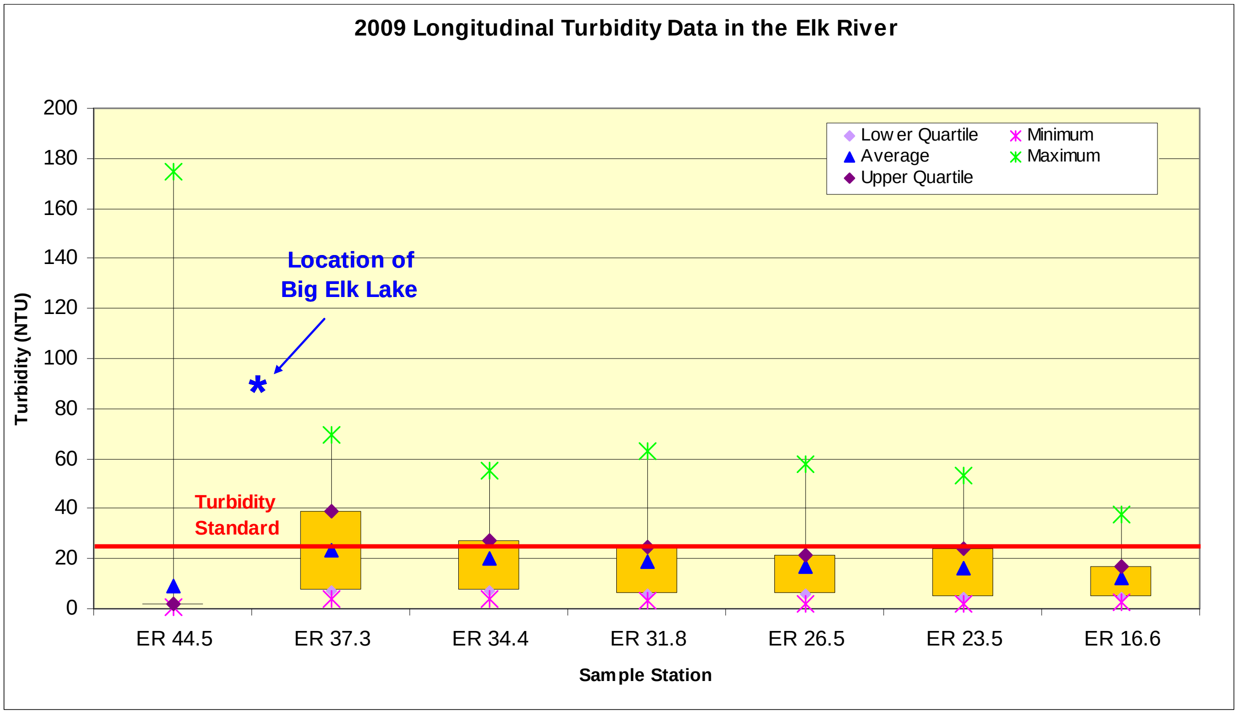
Figure 3.13: Historical longitudinal transparency tube readings in the Elk River.



T:\2378_ERWSA\Elk River\[Copy of Mainstem Elk River WQ Data.xls]Turbidity Charts

Water quality data was collected in 2009 as part of Phase II of the TMDL and turbidity data was analyzed. Turbidity data was collected at one station upstream of Big Elk Lake and at 6 stations within the listed reach of the Elk River. Box plots displaying the geometric mean turbidity values, as well as the range of observed values for each sample station are presented in Figure 3.14. State standards are displayed on the chart.

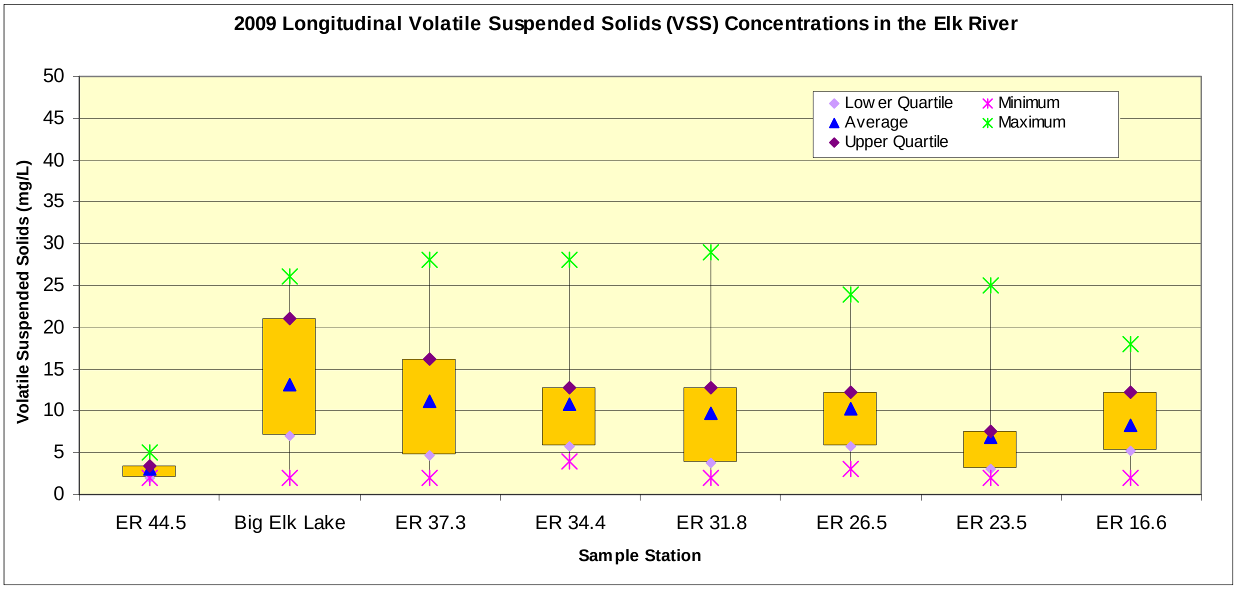
Figure 3.14: 2009 longitudinal turbidity readings in the Elk River



T:\2378_ERWSA\Elk River\[2009 WQ data.xls]Turbidity Chart

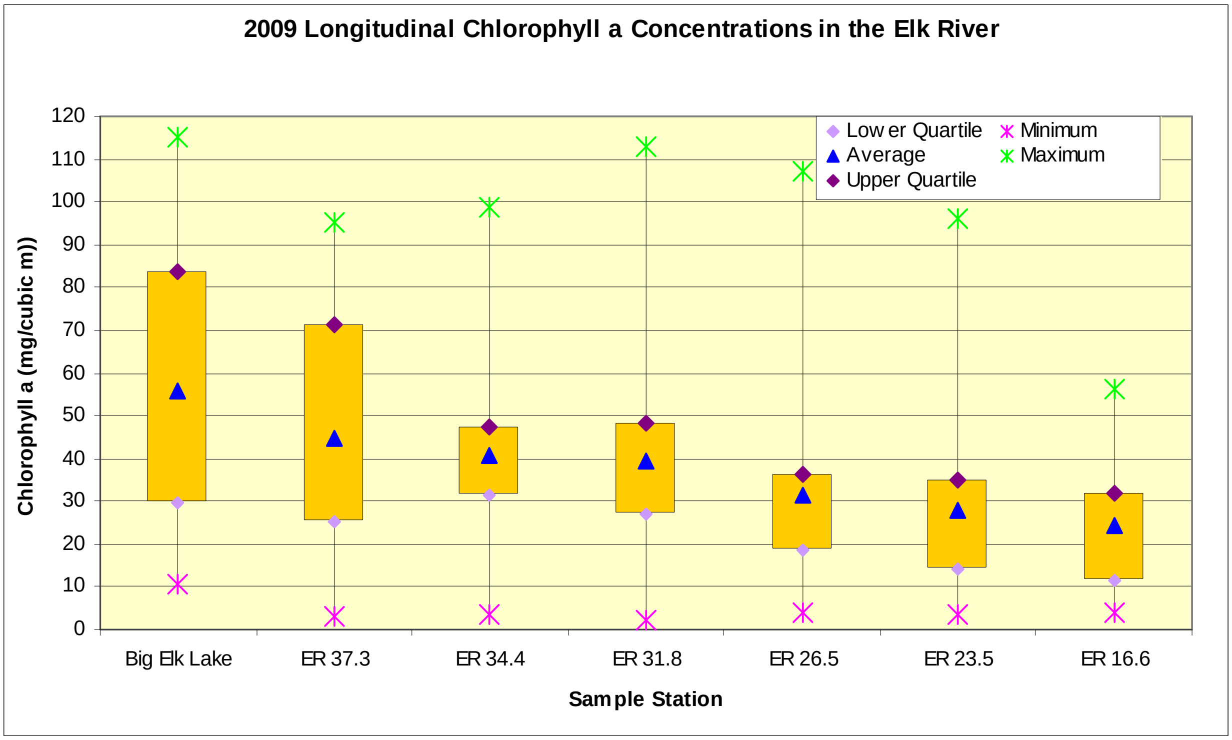
Displaying the turbidity data longitudinally helps to illustrate the influence Big Elk Lake has on the water clarity within the Elk River. Big Elk Lake is a hyper-eutrophic system with total phosphorus and chlorophyll-a concentrations well above the state water quality standards. Water clarity, measured by Secchi depth, is typically 0.5 meters or less within Big Elk Lake. Flows from the Elk River entering Big Elk Lake are typically clear and low in turbidity (see Figure 3.13). Watershed sediment and in-stream sources of turbidity upstream of the lake are not likely contributing to the turbidity downstream of the lake. Instead, watershed nutrient sources to the lake from the upper watershed coupled with the lake dynamics are the driving factor in the turbidity impairment in the Elk River downstream of Big Elk Lake. The high nutrient and chlorophyll-a concentrations in the lake lead to high algal turbidity within the lake which is discharged to Elk River. Data and observations also indicate that algae thrive in the listed reach of the Elk River. Figures 3.15 and 3.16 present longitudinal box plots of VSS and chlorophyll-a concentrations in the Elk River, indicating these are the primary contributor to the turbidity impairment.

Figure 3.15: Longitudinal VSS concentrations in the Elk River



T:\2378_ERWSA\Elk River\[2009 WQ data.xls]VSS Chart

Figure 3.16: Longitudinal chlorophyll-a concentrations in the Elk River



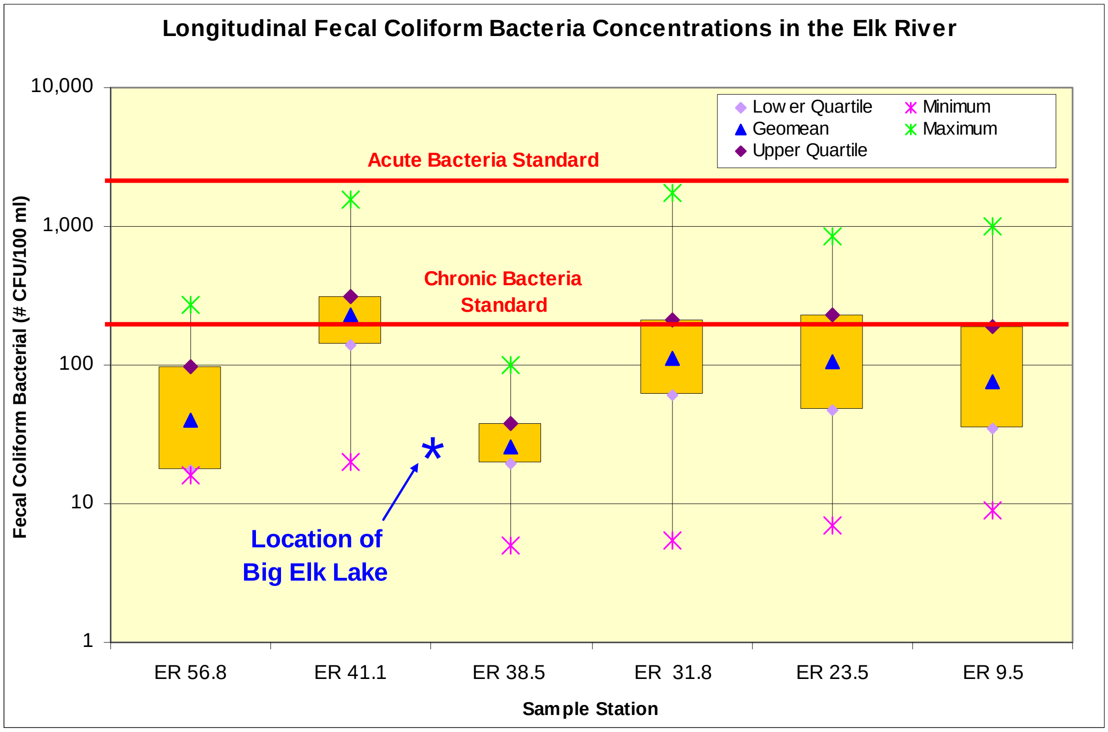
T:\2378_ERWSA\Elk River\[2009 WQ data.xls]Chlorophyl Chart

T:\2378_ERWSA\Elk River\Turbidity\[turbidity_mmb.xls]Chlorophyl Chart

3.2.1.3.2 Bacteria

Historical water quality data for the Elk River was analyzed for fecal coliform bacteria concentrations for sampling years 1974-1976 and 2002-2007. Bacteria concentrations as fecal coliform were measured at six stations along the main stem of the Elk River, two stations upstream of Big Elk Lake, three stations downstream of Big Elk Lake within the listed reach and one station downstream of the St. Francis River outside of the listed reach. Box plots displaying the geometric mean fecal coliform bacteria concentrations, as well as the range of observed values from each station are presented in Figure 3.17. The chronic (200 CFU/100ml) and acute (2,000 CFU/100ml) standards for fecal coliform are displayed on this graph.

Figure 3.17 Box plots of historical longitudinal fecal coliform bacteria concentrations in the Elk River.



T:\0147\196 Elk River TMDL\Elk River Water Quality Data\Mainstem Elk WQ Data.xls\Fecal Coliform Charts

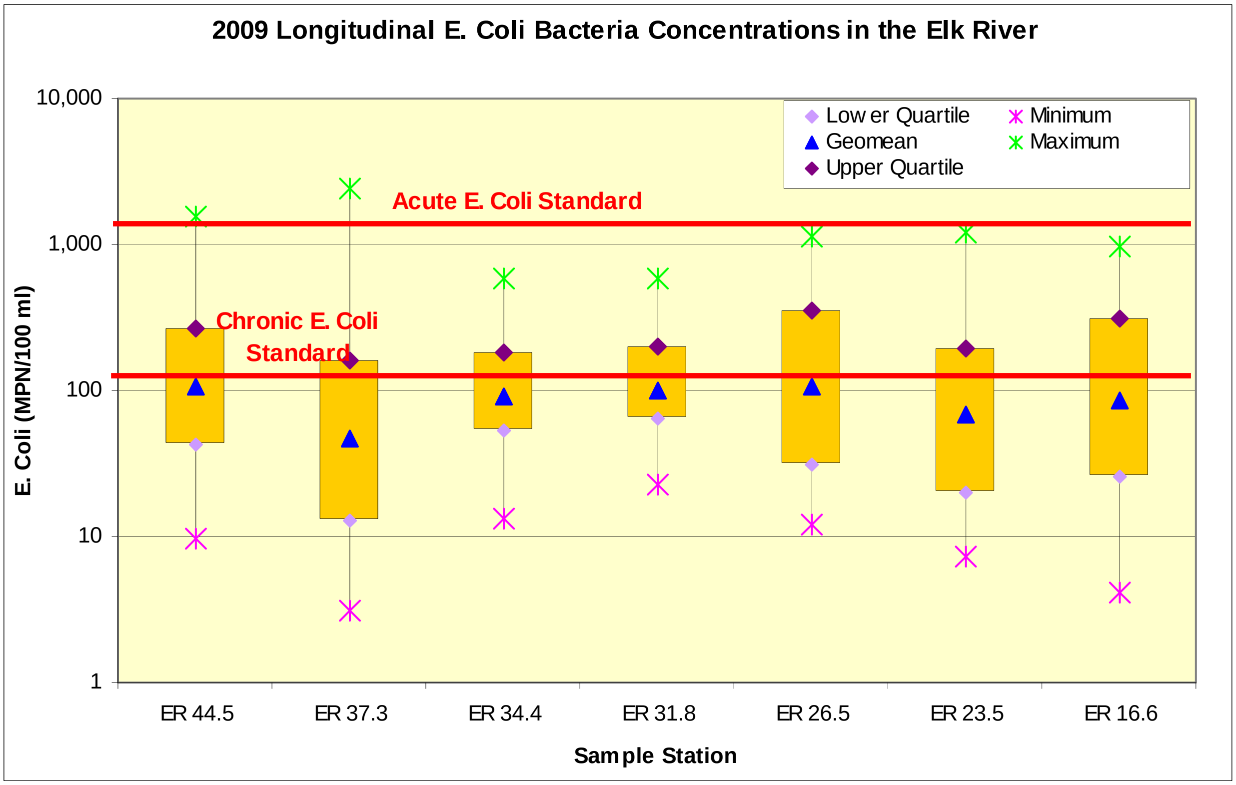
A summary of the discrete fecal coliform samples by month for the three sample stations within the listed reach of the Elk River are presented in Table 3.4. Although there were no exceedances of the acute standard, there were 15 samples exceeding the chronic standard. Eleven of the fifteen exceedances of the State chronic standard occur in August and September. Approximately 20 percent of all collected samples exceed the State chronic standard.

Table 3.4: Summary of fecal coliform bacteria samples for three monitoring stations within the listed reach of the Elk River

Month	Total Samples	# > 200 CFU/100 ml	# >2,000 CFU/100ml	Monthly Geomean
May	8	0	0	23
June	15	3	0	59
July	12	1	0	83
August	18	7	0	165
September	11	4	0	148

Water quality data was collected in 2009 as part of Phase II of the TMDL and bacterial data was analyzed for *E.Coli*, consistant with the new State standard. Bacteria concentrations as *E.Coli* were measured at seven stations along the main stem of the Elk River; one station upstream of Big Elk Lake and six stations downstream of Big Elk Lake within the listed reach. Box plots displaying the geometric mean *E. Coli* bacteria concentrations, as well as the range of observed values from each station are presented in Figure 3.18. The chronic (126 CFU/100ml) and acute (1,260 CFU/100ml) standards for *E.Coli* are displayed on this graph.

Figure 3.18: Box plots of 2009 longitudinal *E.Coli* bacteria concentrations in the Elk River (mainstem).



T:\2378_ERWSA\Elk River\[2009 WQ data.xls]E Coli Chart

A summary of the discrete *E.Coli* samples by month for the six sample stations within the listed reach of the Elk River are presented in Table 3.5. There were thirty-nine exceedances of the State chronic standard which is approximately 40 percent of all samples collected. One sample at river mile 37.3 in the month of August exceeded the State acute standard.

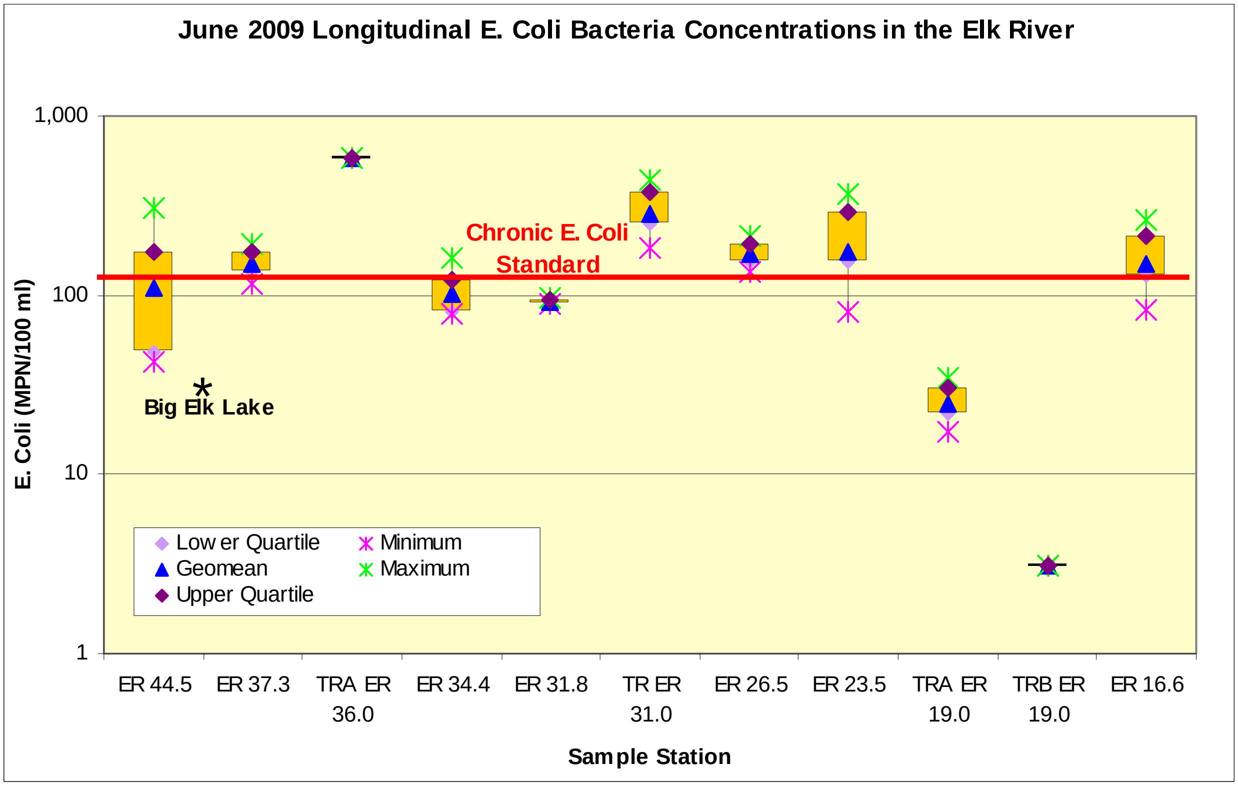
Table 3.5: Summary of *E.Coli* bacteria samples for six monitoring stations within the listed reach of the Elk River

Sample Month	Total Samples (n)	#>126 CFU/100 ml	#>1260 CFU/100ml	Monthly Geomean
April	19	2	0	19
May	12	0	0	36
June	13	6	0	**132**
July	12	6	0	**127**
August	12	10	1	**458**
September	18	15	0	**198**
October	13	0	0	29

The monthly geometric mean *E. Coli* concentrations exceed the State standard of 126 cfu/100 ml in the months of June – September. The higher concentrations of *E.Coli* in August and September correlate with the high concentrations of Fecal Coliform present in the historical data for the same months.

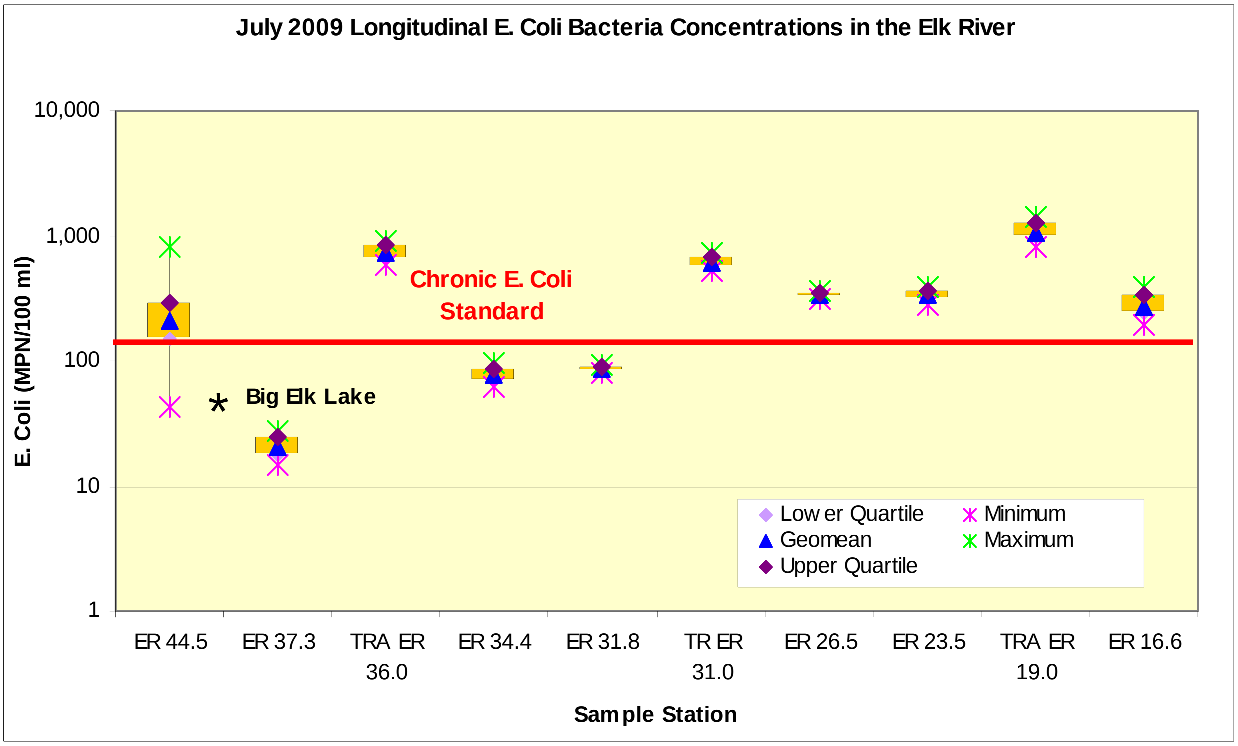
Figures 3.19 – 3.22 present longitudinal bacteria concentrations for the Elk River, including data upstream of Big Elk lake as well as tributaries, for the months where exceedances occurred (June-August). This data indicates that the bacteria impairment cannot be attributed to a specific use or subwatershed and the impairment is most likely a land use issue throughout the entire watershed, including pasturing and failing septic systems in the riparian areas.

Figure 3.19: June 2009 Longitudinal *E.Coli* Concentrations in the Elk River



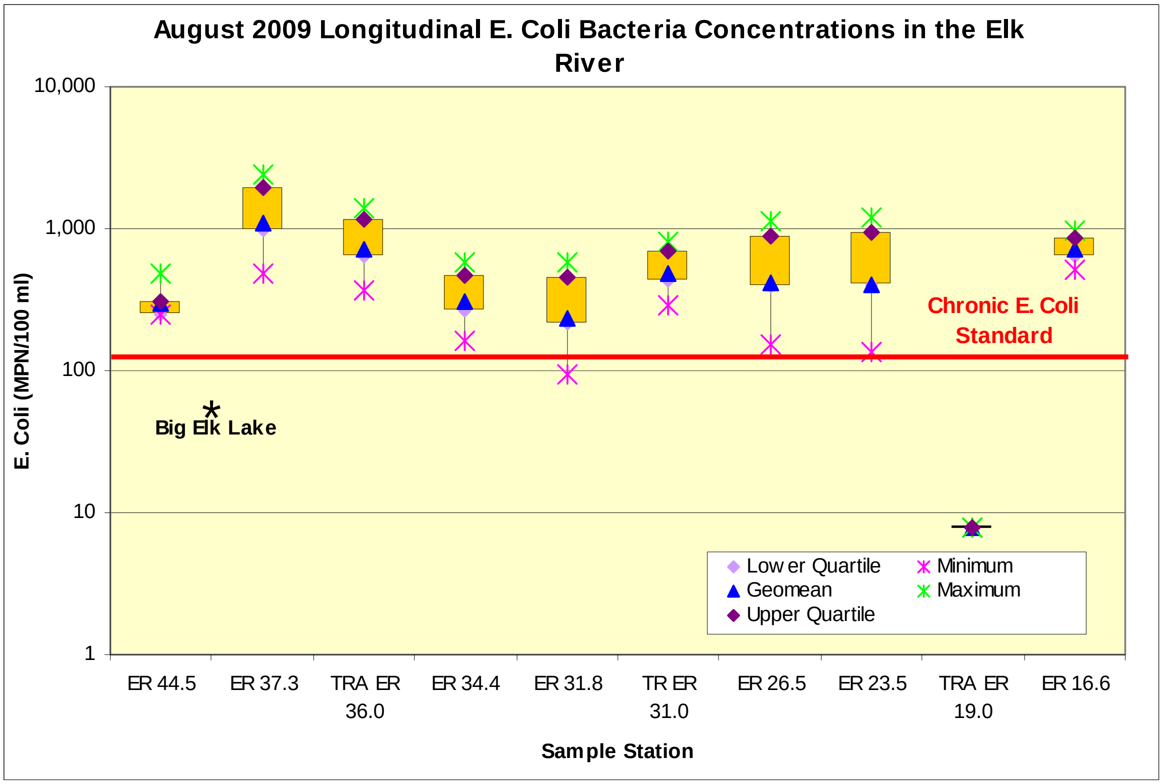
T:\2378_ERWSA\Elk River\[2009 WQ data.xls]Long. E.Coli by exceed. months

Figure 3.20: July 2009 longitudinal *E.Coli* concentrations in the Elk River



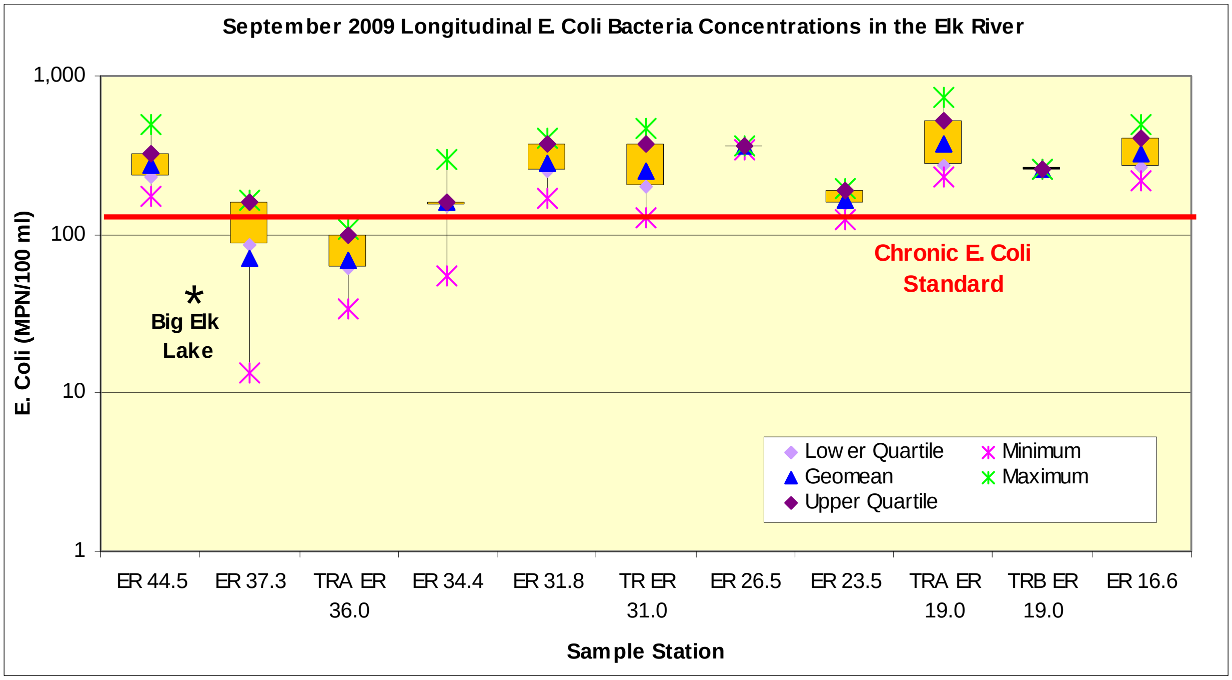
T:\2378_ERWSA\Elk River\[2009 WQ data.xls]Long. E.Coli by exceed. months

Figure 3.21: August 2009 longitudinal *E.Coli* concentrations in the Elk River



T:\2378_ERWSA\Elk River\[2009 WQ data.xls]Long. E.Coli by exceed. months

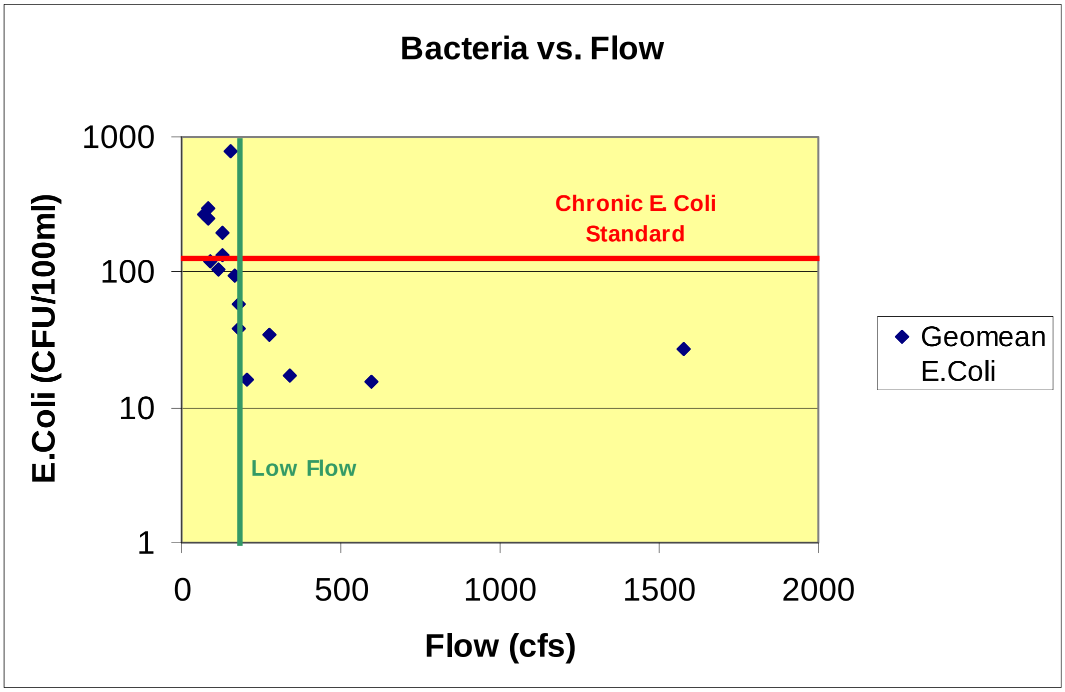
Figure 3.22: September 2009 longitudinal *E.Coli* concentrations in the Elk River



T:\2378_ERWSA\Elk River\[2009 WQ data.xls]Long. E.Coli by exceed. months

Figure 3.23 presents a correlation between bacteria concentrations and flow conditions. This data indicates that the bacteria impairment is prevalent in lower flow conditions.

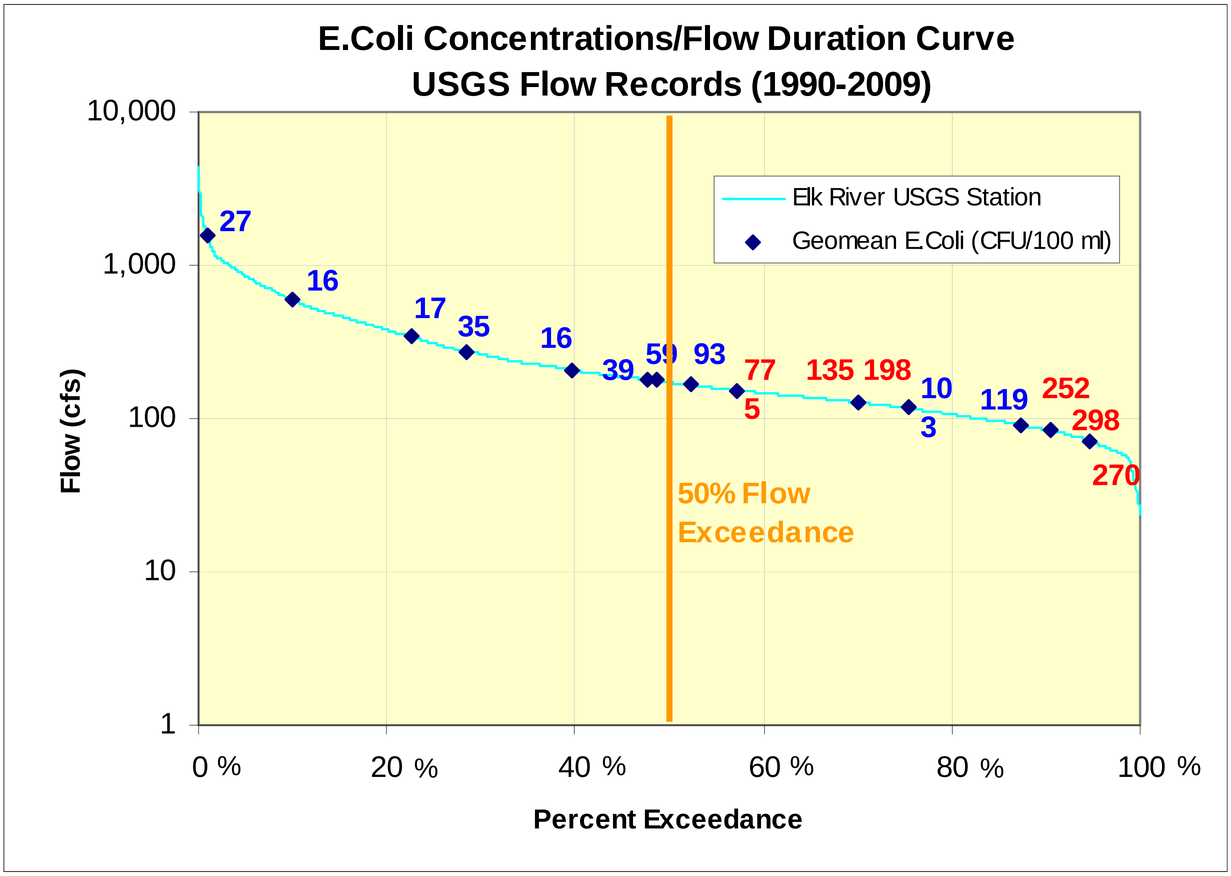
Figure 3.23: Bacteria concentrations vs. flow for Elk River impaired reach



T:\2378_ERWSA\Elk River\[2009 WQ data.xls]Bacteria vs. Flow

Figure 3.24 presents geomean bacteria concentrations along the flow duration curve for the listed reach. *E.Coli* concentrations exceeding the State standard occur in the upper mid-range, dry, or low flow conditions. No impairment is indicated for higher flow regimes.

Figure 3.24: Flow duration curve with bacteria concentrations

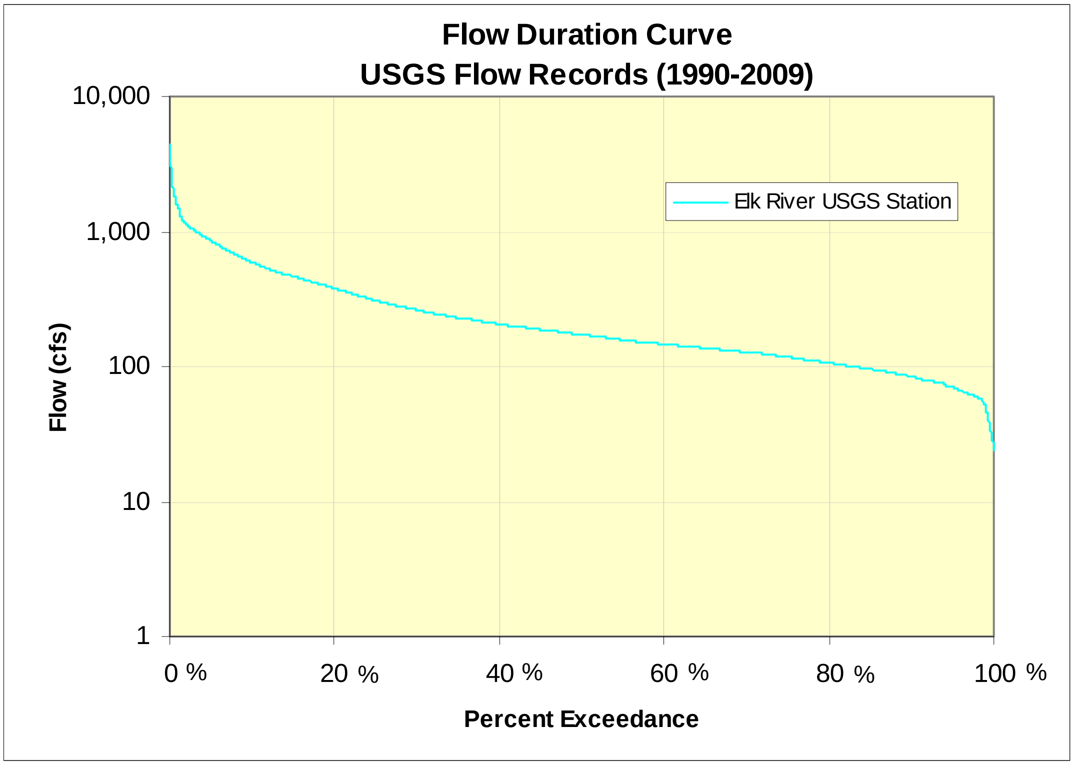


T:\2378_ERWSA\Elk River\Bacteria\[Bacteria Load Calcs - Annual Flow.xls]20 year flow duration (daily)

3.2.2 Hydrology

Average daily discharge has been monitored and reported at the USGS station 05275000 located in Big Lake at CSAH 15 (approximately 5 miles below Elk River Reach 579) periodically since 1911 and yearly since 1990. Monthly average flows since 1911 at the USGS station range from 112 cubic feet per second (cfs) in January to 659 cfs in April. The maximum average daily flow at the USGS stations was 7,170 cfs on April 16, 1965. The lowest average daily flow was recorded on August 1st, 1934 was 4.0 cfs. The average annual runoff estimated from 1911-2009 is 6.70 inches. The average annual runoff over the last two years (2008 and 2009) was 5.68 and 5.45 respectively (USGS Water Data Report 2009). Figure 3.25 presents a flow duration curve which was generated from the USGS station flow records for 1990 to 2009. Additional flow sites are identified in this report and were used in developing the TMDLs.

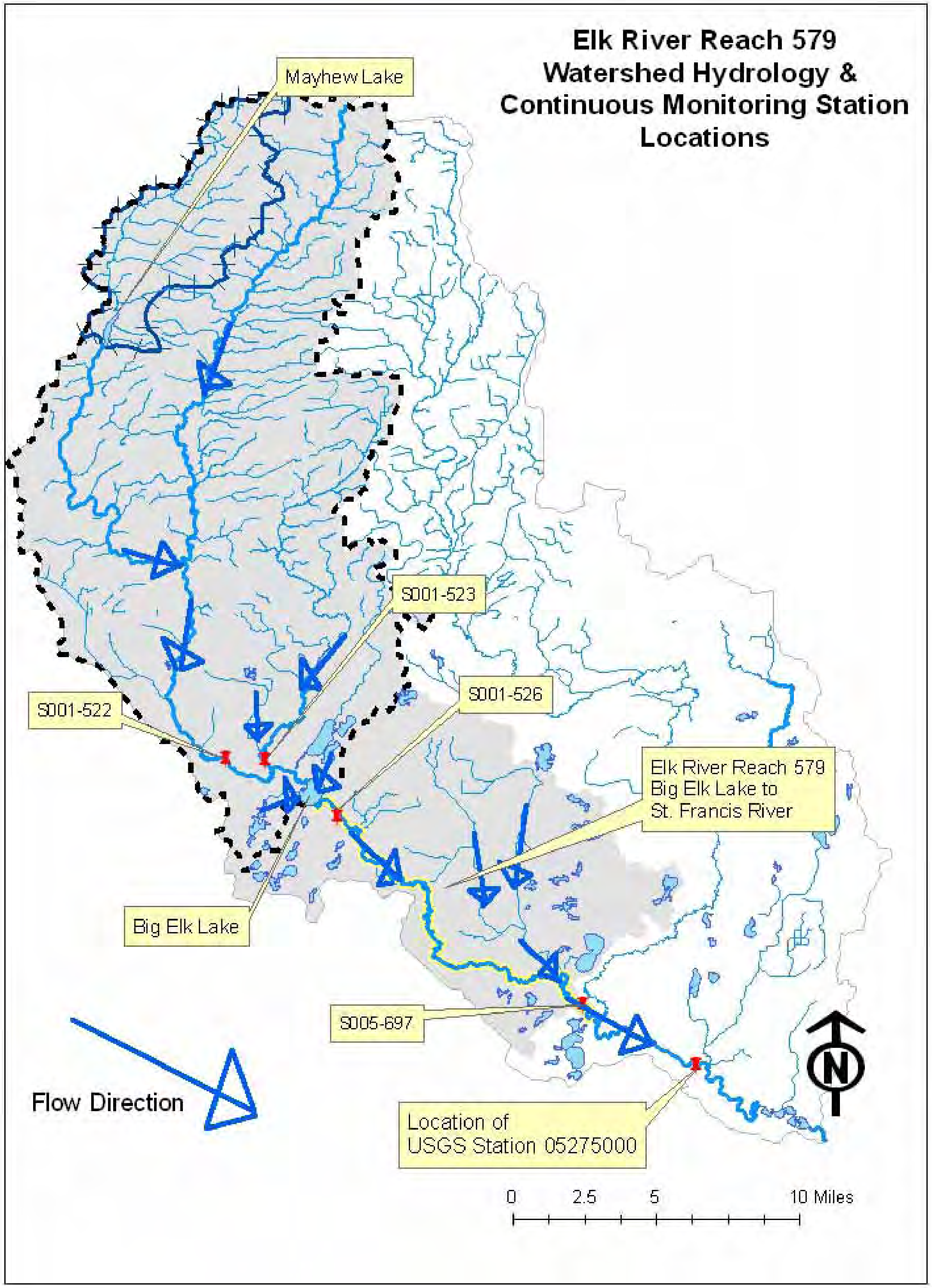
Figure 3.25: Flow duration curve



T:\2378_ERWSA\[USGS runoff_mmb.xls]20 year annual

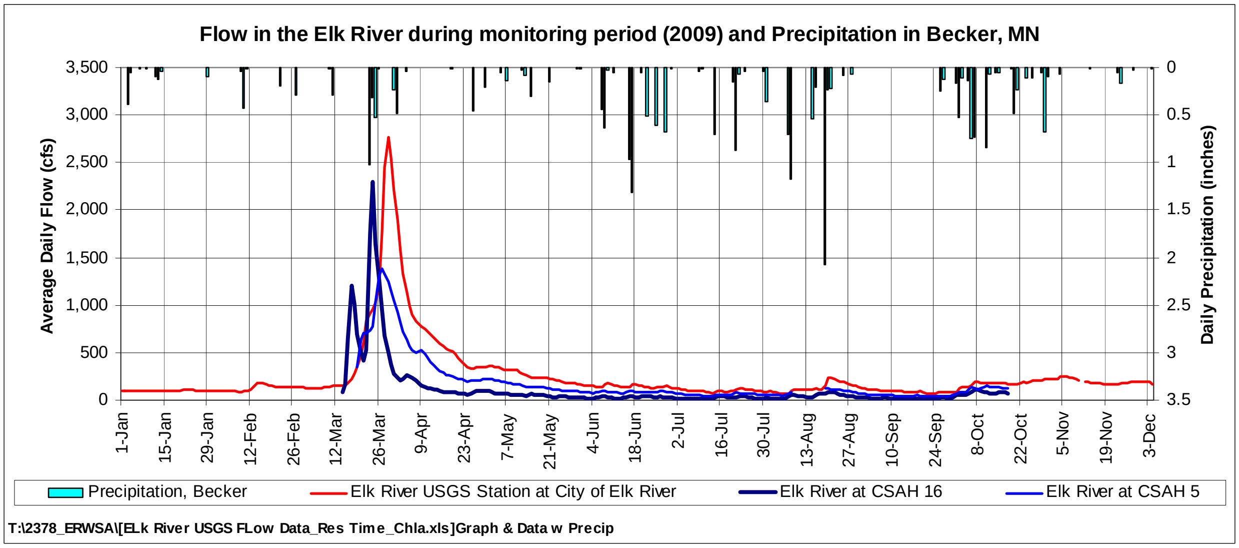
Figure 3.26 displays the basic hydrology for surface water in the watershed and the location of the USGS station. Water also enters the system through groundwater and precipitation runoff from the surrounding watershed.

Figure 3.26: Surface water flow in Elk River reach 579 watershed.



The monitoring year, 2009 was slightly below average year with respect to watershed runoff. The hydrograph for 2009 is shown in Figure 3.27, along with precipitation. Flow for the USGS station at the City of Elk River, and the two other monitoring stations where continuous flow was measured.

Figure 3.27: Flow and precipitation in the watershed in 2009



T:\2378_ERWSA\[ELk River USGS FLow Data_Res Time_Chla.xls]Graph & Data w Precip

3.2.3 Recreational Uses

Mayhew Lake and Big Elk Lake provide a variety of recreational uses, including fishing and boating. Mayhew Lake has one county owned gravel public access on the southwest corner of the lake. Improvements have been made recently to the county park on the west side of the lake which offers a fishing pier and picnic area. The park is well maintained and encourages shore fishing. Big Elk Lake has one DNR owned concrete public access on the east side of the lake off of County Road 88.

3.2.4 Fish Community

Mayhew Lake

A review of the most recent fish population assessment developed by the DNR reveals that the fish community of Mayhew Lake has fluctuated over time. Mayhew Lake has produced a stable black crappie fishery but populations of species such as walleye, bluegill or northern pike have been less stable. Walleyes do not naturally reproduce within Mayhew Lake and populations have been sustained with various levels of stocking efforts overtime. The 2008 walleye catch was significantly lower than 2002 and below the management goals of the lake. Walleye fingerlings were most recently stocked in 2009. Northern pike numbers have largely decreased since the 2002 survey in which northern pike population was larger than desirable. The 2008 northern pike population fell within the normal range for the lake class. High perch numbers were also documented in the lake and as an important prey species for both walleye and northern pike may help increase walleye and northern pike numbers. Although some perch fishing has been reported in recent years, the lake is best known for black crappie fishing. A large number of black crappie were caught as part of the 2008 panfish assessment and the lake management goal for black crappie was met. Bluegill and sunfish were less abundant. The assessment also found a high number of black bullhead as well as some yellow bullhead. Black bullhead is more prevalent in turbid water which may be an indicator of the lake water quality.

Carp are not easily sampled by gears traditionally used for DNR population estimates, and it is common for carp to be more prevalent in a lake than is indicated by the DNR surveys. The majority of the carp in the 2002 survey were caught in trapnets which were not used in the 2008 survey. The DNR indicates that common carp have a significant presence within the lake from direct observations and electrofishing. Common carp can present significant management problems, especially in shallow, eutrophic basins such as Mayhew Lake. Carp are a long lived species, with adults reaching ages of more than 50 years in some systems. Common carp are bottom-feeders that uproot aquatic macrophytes during feeding and spawning, re-suspending bottom sediments and nutrients. These activities can lead to increased nutrients in the water column, ultimately resulting in increased nuisance algal blooms. Addressing the presence of common carp in Mayhew Lake may be an important factor when attempting to improve water quality within the lake.

Big Elk Lake

The primary management species in Big Elk Lake are northern pike and walleye. Both species were stocked frequently during the 1960s and 1970s. Walleye have not been stocked in Big Elk Lake since 1980, however the Briggs Lake Chain Association was granted a permit to privately stock in 2009. Private stocking includes fish purchased by the DNR for stocking and fish purchased and stocked by private citizens and sporting groups. The most recent DNR survey indicates that both walleyes and northern pike are successfully reproducing in the system either within the lake itself or within the Elk River. The populations of walleye and northern pike are now self-sustaining and have an adequate forage base provided by the minnow and white sucker community. The catch rate for northern pike has increased significantly since the 1999 survey and anglers can expect success for northern pike. The panfish population (bluegill, black & white crappie, pumpkinseed and yellow perch) is low, likely due to the lack of stable submerged aquatic vegetation which provides spawning habitat, feeding areas and a refuge from predators. Big Elk Lake has a significant rough fish community that includes black bullhead and common carp. Riverine fish species are also common and white sucker catch rates have been high in each of the past five fish surveys.

3.2.5 Aquatic Plants

Mayhew Lake

A 2009 plant survey conducted by MPCA and ERWSA staff showed that Mayhew Lake lacks the typical aquatic plant community expected in the vegetated portion of the lake system. The DNR lake management plan states that the greatest depth of submerged plant growth was three feet. Based on a review of the lake depth contours, this indicates the area of the lake with submerged plant growth is very limited. Additionally, livestock with access to the lake in pastured areas have altered shoreline conditions causing a loss of emergent vegetation and bank erosion.

Improved water clarity within the lake would likely increase the percentage of the lake with submerged plant growth. An increase in the submerged aquatic plant base in Mayhew Lake may help to consume and remove nutrients in the water column as well as provide additional habitat for fish and wildlife as long as the plant community is native and not dominated by plants shown to degrade water quality such as curly leaf pond weed.

<u>Big Elk Lake</u>

A review of the lake management plan developed by the DNR reveals that Big Elk Lake lacks the typical aquatic plant community expected in a shallow lake system. Vegetation surveys conducted by the DNR in 1986, 1999, and 2009 indicated that most of the basin is devoid of submerged vegetation. A low number of native submerged species are present in the lake including coontail, sago pondweed and bushy pondweed. These species were mainly limited to depths of 2 to 5 feet in the shallow bays along the north and west shores of the lake near the stream inlets. The exotic species curly leaf pondweed was also observed in both the 1986, 1999 and 2009 surveys, but its distribution across the lake is limited. It does not appear to be expanding in abundance. Emergent vegetation is sparse around the lake shore, again limited to the shallow bays and marsh areas near the stream inlets. The emergent species observed by the DNR include sedges, bulrush, arrowhead and needlerush. The lack of healthy aquatic vegetation in the basin is likely due to the high algal turbidity in the lake that limits light transparency. The basin has a long fetch, and with its overall shallow depth, the absence of a stable root system from submerged aquatic vegetation may lead to some internal loading due to wind suspension of silty, organic sediments.

3.2.6 Shoreline Habitat Conditions

The shoreline areas are defined as the areas adjacent to the lakes edge with hydrophytic vegetation and water up to 1.5 feet deep or a water table within 1.5 feet from the surface. Shoreline areas should not be confused with shoreland areas which are defined as 1,000 feet upland from the ordinary high water level (OHWL). Natural shorelines provide water quality treatment, wildlife habitat, and increased biodiversity of plants and aquatic organisms. Natural shoreline areas also provide aesthetic values and important habitat to fisheries including spawning areas and refugia.

Buffering shorelines with native vegetation provide numerous benefits to both lakeshore owners and lake users including improved water quality, increased biodiversity, important habitat for both aquatic and terrestrial animals, and stabilizing erosion resulting in reduced maintenance of the shoreline. Identifying projects where natural shoreline habitats can be restored or protected will enhance the overall lake ecosystem.

The littoral zone is defined as that portion of the lake that is less than 15 feet in depth and is where the majority of the aquatic plants are found. The littoral zone of the lake also provides the essential spawning habitat for most warm water fishes (e.g. bass, walleye, and panfish). Mayhew Lake is 52% littoral and Big Elk Lake is 100% littoral. The definition of a shallow lake is any lake that has a maximum depth of 15 feet or less or that is 80 percent or more littoral. Based on this criteria, Big Elk Lake is considered a shallow lake while Mayhew lake is considered a deep lake.

Table 3.6 a and b provides a summary of shoreline conditions for each of the lakes based on the most recent surveys. Two tables are presented to account for the different classification categories used by different surveyors. In the 2002 lake survey data for Mayhew Lake, it was noted that, with some exception, cattle have access to the water.

Table 3.6a: Shoreline characteristics, DNR surveys

Lake Name	**Mayhew Lake (2002 DNR Survey)**	**Big Elk Lake (2009 DNR Survey)**
Forested	5%	37%
Marsh	-	28%
Residential	-	23%
Grassland	13%	8%
Pasture/Agricultural	80%	4%
County Park	2%	-

Table 3.6b: Shoreline characteristics, Metro Conservation Corps (MCC) survey

Classification	**Mayhew Lake (2009 MCC Survey)**
Mowed/ Lawn	**8%**
Natural Shoreland	**43%**
Natural Shoreland w/Adjacent Agricultural Use Adjacent	**40%**
Pasture	**8%**

3.2.7 Stream Bank Conditions

The primary sources of sediment in streams are sediment conveyed from the landscape and soil particles detached from the streambank. The amount of sediment conveyed from the landscape will vary based on general soil erodibility, land cover, slope, and conveyances to the stream. Streambank erosion is a natural process that can be accelerated significantly as a result of change in the watershed or to the stream itself. In Elk River reach 579, stream bank erosion is a minimal contributor to the total TSS load (~1.0% - 2.4%).

The annual soil loss by mile was estimated using field collected data and a method developed by the Natural Resources Conservation Service referred to as the “NRCS Direct Volume Method,” or the “Wisconsin method,” (Wisconsin NRCS 2003). Soil loss is calculated by:

1. measuring the amount of exposed streambank in a known length of stream;
2. multiplying that by a rate of loss per year;
3. multiplying that volume by soil density to obtain the annual mass for that stream length; and then
4. converting that mass into a mass per stream mile.

The Direct Volume Method is summarized in the following equation:

$$\frac{(\text{eroding area})\ (\text{lateral recession rate})\ (\text{density})}{2000\ \text{lbs/ton}} = \text{erosion in tons/year}$$

The eroding area is in square feet, the lateral recession rate is in feet/year, and density is in pounds/cubic feet (pcf). The eroding area is defined as that part of the streambank that is bare, rilled, or gullied, and showing signs of active erosion such as sloughed soil at the base. The length and width of the eroding face of the streambank is multiplied to calculate an eroded area.

The lateral recession rate is the thickness of soil eroded from a streambank face in a given year. Soil loss may occur at an even rate every year, but more often occurs unevenly as a result of large storm events, or significant land cover change in the upstream watershed. Historic aerial or other photographs, maps, construction records, or other information sources may be available to estimate the total recession over a known period of time, which can be converted into an average rate per year. However, these records are often not available, so the recession rate is estimated based on streambank characteristics that evaluate risk potential. Table 3.7 presents the categories of bank condition that are evaluated and the varying levels of condition and associated risk severity score.

Table 3.7: Bank condition severity rating

Category	Observed Condition	Score
Bank Stability	Do not appear to be eroding	0
	Erosion evident	1
	Erosion and cracking present	2
	Slumps and clumps sloughing off	3
Bank Condition	Some bare bank, few rills, no vegetative overhang	0
	Predominantly bare, some rills, moderate vegetative overhang	1
	Bare, rills, severe vegetative overhang, exposed roots	2
	Bare, rills and gullies, severe vegetative overhang, falling trees	3
Vegetation / Cover on Banks	Predominantly perennials or rock	0
	Annuals / perennials mixed or about 40% bare	1
	Annuals or about 70% bare	2
	Predominantly bare	3
Bank / Channel Slope	V-shaped channel, sloped banks	0
	Steep V- shaped channel, near vertical banks	1
	Vertical Banks, U-shaped channel	2
	U-shaped channel, undercut banks, meandering channel	3
Channel Bottom	Channel in bedrock / non-eroding	0
	Soil bottom, gravels or cobbles, minor erosion	1
	Silt bottom, evidence of active down cutting	2
Deposition	No evidence of recent deposition	1
	Evidence of recent deposits, silt bars	0

A Cumulative Rating score of 0-4 indicates a streambank at slight risk of erosion. A score of 5-8 indicates a moderate risk, and 9 or greater a severe risk. A field survey of the Elk River reach 579 was performed in fall 2009 to catalog the condition of the stream bank. Data collected during the field survey was used to calculate the annual soil loss within the reach. The majority of stream bank in the impaired Elk River reach was identified at a moderate risk of erosion with minimal areas indicating a severe risk. There were very few areas identified with active erosion during the field survey.

The Wisconsin NRCS used its field data from streams in Wisconsin to assign a lateral recession rate for each category (Table 3.8). Professional judgment is necessary to select a reasonable rate within the category. For Elk River reach 579 it was determined that assigning a range of values was appropriate to represent the stream bank. The applicable range of lateral recession rate was determined to be 0.1 – 0.3 feet per year.

Table 3.8: Estimated annual lateral recession rates per severity risk category

Lateral Recession Rate (ft/yr)	Category	Description
0.01 - 0.05 feet per year	Slight	Some bare bank but active erosion not readily apparent. Some rills but no vegetative overhang. No exposed tree roots.
0.06 - 0.15 feet per year	Moderate	Bank is predominantly bare with some rills and vegetative overhang. Some exposed tree roots but no slumps or slips.
0.16 - 0.3 feet per year	Severe	Bank is bare with rills and severe vegetative overhang. Many exposed tree roots and some fallen trees and slumps or slips. Some changes in cultural features such as fence corners missing and realignment of roads or trails. Channel cross section becomes U-shaped as opposed to V-shaped.
0.5+ feet per year	Very Severe	Bank is bare with gullies and severe vegetative overhang. Many fallen trees, drains and culverts eroding out and changes in cultural features as above. Massive slips or washouts common. Channel cross section is U-shaped and stream course may be meandering.

The assumed recession rate was multiplied by the total eroding area to obtain the estimated total annual volume of soil loss. To convert this soil loss to mass, soil texture or actual measured bulk dry density was used to establish a volume weight for the soil.

Using the WI NRCS method, the range of values for annual soil loss within the impaired reach was calculated to be 0.35-0.85 tons/mile or 8.06-19.66 tons/year for the 23.2 mile long reach. The annual TSS load, calculated at river mile 16.6 from the 2009 sampling data, was 827.5 tons.

3.3 SELECTION OF THE TURBIDITY SURROGATE

Data analysis to select a turbidity surrogate was conducted in accordance with the Turbidity TMDL Protocols and Submittal Requirements (MPCA 2007). This section documents selection of the turbidity surrogate.

Water quality data and field observations indicate that the nutrient impairment in Big Elk Lake was the driver of the turbidity impairment in the Elk River downstream of Big Elk Lake (Table 3.9). Upstream of Big Elk Lake, only 4 % of turbidity tube measurements indicate a violation of the standard, compared with 40% downstream measurements. Field staff observed that flows from the Elk River entering Big Elk Lake are clear and low in turbidity, yet the outflow from Big Elk Lake shows a significant increase in algal turbidity.

Table 3.9: Summary of historical transparency tube readings for the Elk River upstream of Big Elk Lake and within the listed reach (transparency tube measurements of less than 20 cm indicate a violation of standard)

Sample Location	Number of samples (n)	Meets Standard		Violates standard	
		n > 20 cm	% > 20 cm	n < 20 cm	% < 20 cm
Upstream of Big Elk Lake	391	376	96%	15	4%
Listed Reach of Elk River	396	239	60%	157	40%

Further, TP concentrations upstream of Big Elk Lake are not significantly different from TP concentrations downstream of Big Elk Lake. In 2009, average TP concentration was 100 ug/L upstream of Big Elk Lake and 115 ug/L downstream of Big Elk Lake.

The lack of observed turbidity (algal or watershed source) upstream of Big Elk Lake, combined with a field investigation of in-stream sources of turbidity (discussed in section 3.2.7 of this report) indicate that the source of the turbidity is the nutrient impairment in Big Elk Lake. Further, if the driver of the turbidity was solely the TP concentrations, one would expect that the upstream reach would also be impaired for algal turbidity.

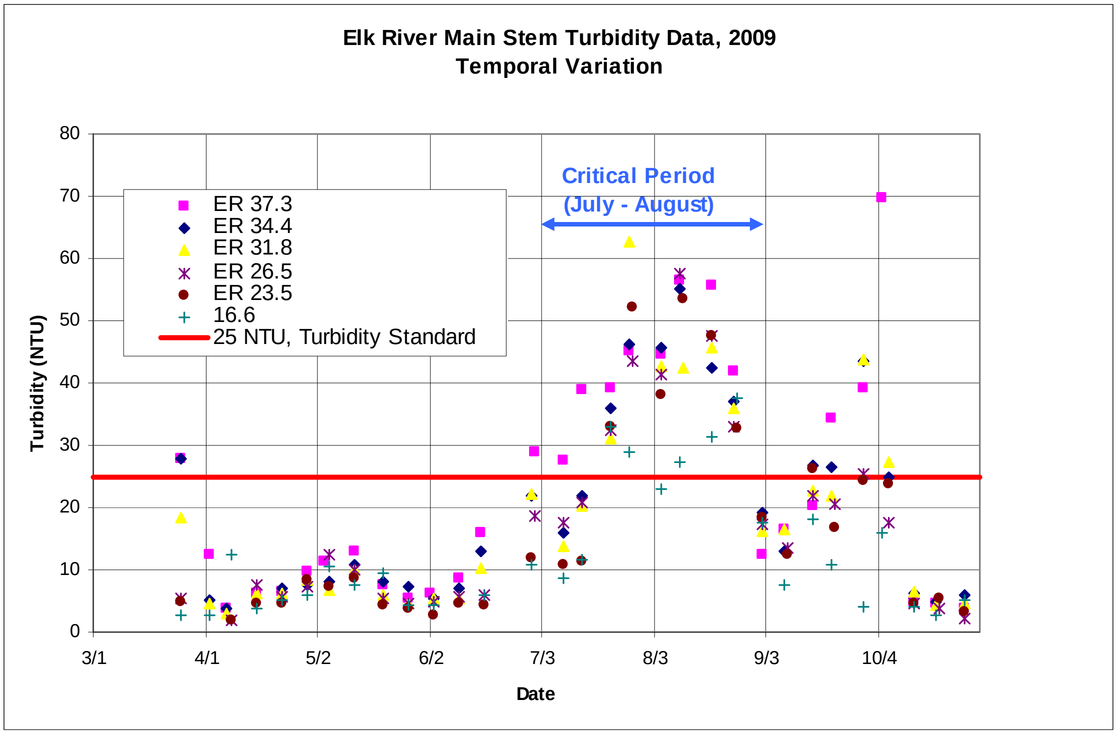
Big Elk Lake is a hyper-eutrophic shallow lake with total phosphorus and chlorophyll-a concentrations well above the state water quality standards. Big Elk Lake water clarity measured by Secchi depth also violates state standards and is typically 0.5 meters or less. Variation of turbidity, transparency, and VSS along the length of the Elk River illustrates the influence Big Elk Lake has on the water clarity within the Elk River (Figures 3.13 through 3.15). Further, seasonal variations of the 2009 turbidity, VSS and chlorophyll-a correlate with growing season algal blooms in Big Elk Lake (Figures 3.28- 3.30).

These data indicate that nutrient sources in tributary to Big Elk Lake, coupled with the lake dynamics are the driving factor in the turbidity impairment in the Elk River downstream of Big Elk Lake. Data and observations also indicate that algae thrive in the listed reach of the Elk River.

Given that the lake nutrient impairment is also driving a turbidity impairment, one must determine if meeting the lake nutrient standard will result in a sufficient improvement in downstream water quality to meet the turbidity standard. To that end, the analysis of in-stream data was conducted to determine the surrogate.

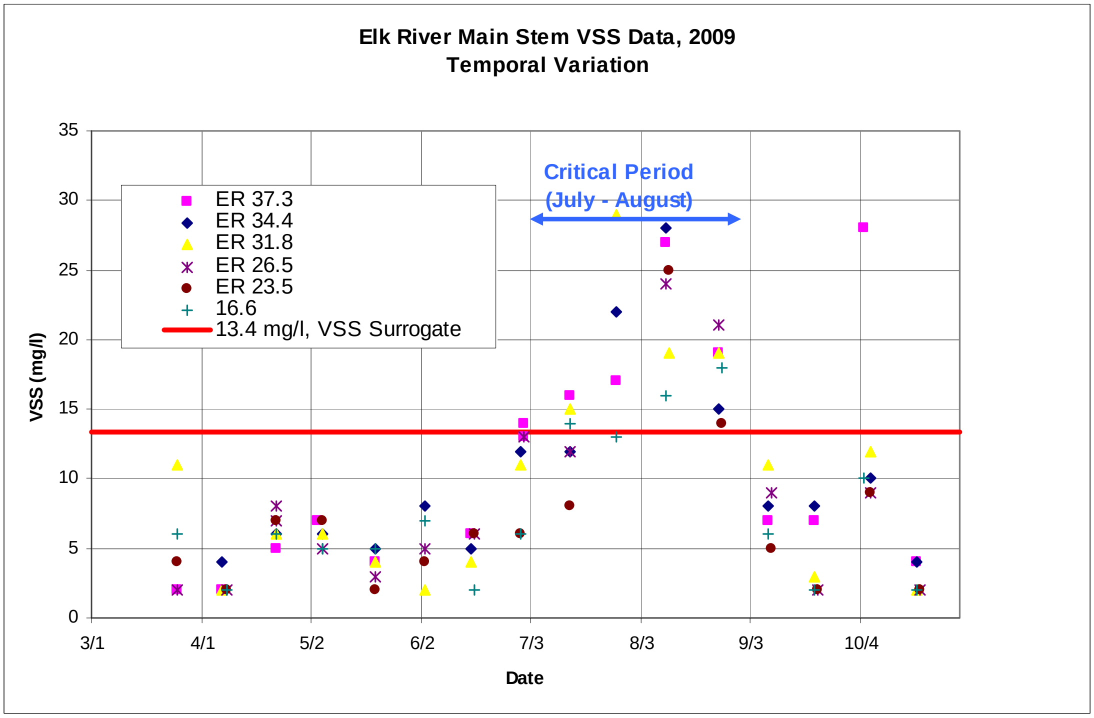
The in-stream surrogate with the highest correlation to measured turbidity was VSS, because VSS is an indicator of algal turbidity this further verifies that the impairment is driven by algal turbidity. The surrogate analysis for turbidity shown in Figure 3.31 was conducted in accordance with the Turbidity TMDL Protocols and Submittal Requirements (MPCA 2007).

Figure 3.28: Temporal variation in 2009 turbidity data



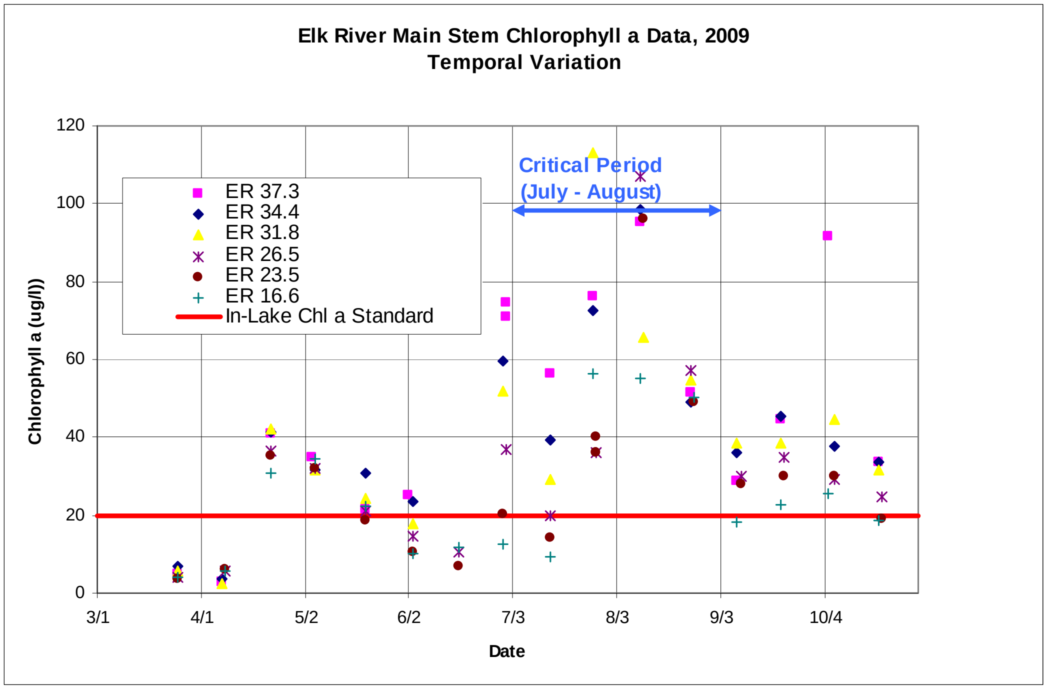
T:\2378_ERWSA\Elk River\Turbidity\[Critical Period for Reduction.xls]Temporal Variation (Turb)

Figure 3.29: Temporal variation in 2009 VSS data



T:\2378_ERWSA\Elk River\Turbidity\[Critical Period for Reduction.xls]Temporal Variation (VSS)

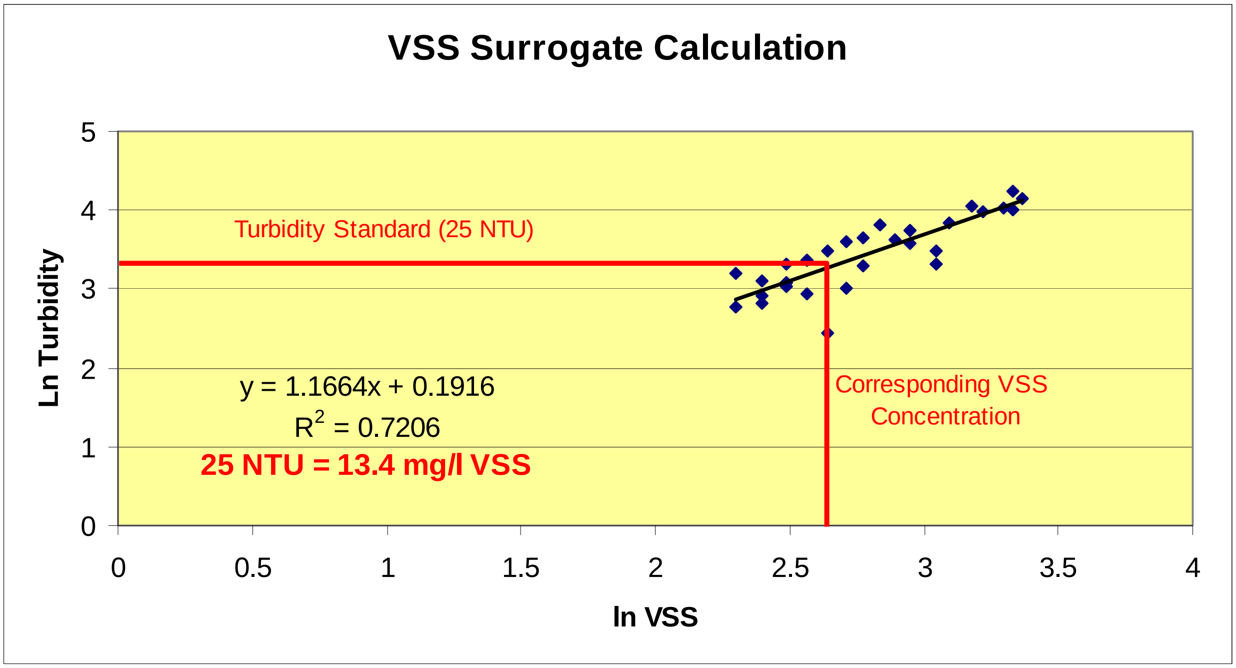
Figure 3.30: Temporal variation in 2009 chlorophyll-a data



T:\2378_ERWSA\Elk River\Turbidity\[Critical Period for Reduction.xls]Temporal Variation (Chl a)

Figure 3.31 shows that the VSS surrogate for the 25 NTU state standard is 13.4 mg/L VSS. That is to say, if we reduce in-stream VSS to 13.4 mg/L or lower, we will have achieved the state's 25 NTU standard.

Figure 3.31: VSS surrogate calculation



T:\2378_ERWSA\Elk River\Turbidity\[Surrogate calcs_mmb.xls]VSS

Based on the model of lake response to nutrient input, the hydrologically average year will result in an average summer TP concentration in Big Elk Lake of about 137 µg/L. Data and modeling for Big Elk Lake indicate that a 57% phosphorus load reduction to Big Elk Lake is needed to meet the nutrient TMDL.

Figures 5.5 through 5.7 in Section 5.2.3 of this report which show the correlations between in-stream VSS, TP and Chlorophyll-a. These relationships demonstrate that using the 60 µg/l endpoint of the Big Elk Lake nutrient TMDL is more conservative than using the calculated VSS surrogate endpoint of 13.4 mg/L. In other words, the load reduction required to meet the nutrient TMDL is greater than the load reduction to meet the turbidity impairment alone using the VSS surrogate.

Specifically, the in-stream VSS- TP relationship shows that the VSS surrogate of 13.4 mg/L corresponds to an in-stream TP concentration in excess of 100 ug/L. The state standard Big Elk Lake would require outflows from Big Elk Lake to equal 60 ug/L TP, which corresponds to a VSS concentration of around 5 mg/L or less (Figure 5.5). Since the outlet of Big Elk Lake is the upstream end of the impaired section and the critical reach for turbidity, lake outflow concentrations are essentially in-stream concentrations for the critical reach.

Further, comparing VSS and Chlorophyll-a in the Elk River shows that we begin to see exceedances of the VSS standard when chlorophyll-a concentrations exceed 40 ug/L. The state standard of 20 ug/L required for Big Elk Lake correlates with a much lower VSS concentration of about 6 ug/L (Figure 5.6). And the bulk of the exceedances of the turbidity standard of 25

NTU occur when chlorophyll-a is greater than 40 ug/L. The Big Elk Lake standard for Chlorophyll-a of 20 ug/L, provides a significant margin of safety (Figure 5.7).

In other words, the load reductions required to achieve the nutrient standard in Big Elk Lake will result in a more conservative turbidity TMDL for the Elk River than would be provided by using the VSS surrogate alone.

4.0 Pollutant Source Assessment

A key component to developing a TMDL is to understand the sources contributing to the impairment. This section provides a brief description of the potential sources in the watershed contributing to turbidity, *E.Coli* bacteria, and excess nutrients. Both permitted and non-permitted sources are present within the watershed.

4.1 PERMITTED SOURCES

Permitted sources can include industrial effluent, municipal wastewater treatment plants, construction runoff, concentrated animal feeding operations (CAFOs) and municipal stormwater. These can each be sources of turbidity, *E. Coli* bacteria (fecal coliform), and excess nutrients. The following is an inventory of the MPCA permitted sources in the TMDL watershed.

4.1.1 Facilities with NPDES Permits

Evaluation of point sources in the MPCA's Environmental Data Access (EDA) website showed four National Pollutant Discharge Elimination System (NPDES) permitted wastewater treatment facilities (WWTFs) are located within the impaired reach of the Elk River. NPDES permit holders discharging to the impaired reach of the Elk River are listed below.

Table 4.1: List of NPDES permitted WWTF's in the study area.

NPDES Permit Holder Name	NPDES Permit Number	Population[1] Served	MPCA Limits	Watershed Location
Foley WWTF	MN0023451-SD-1, -2, -3	2624	FC, TSS	ER 579, BEL
Gilman WWTF	MN6580021-SD-2	228	FC, TSS	ER 579, BEL
Becker WWTF	MN0025666-SD-1	4105	P,TSS	ER 579
Eagle View Commons WWTF	MN0063983	102[2]	NA	ER 579, BEL

FC= fecal colirorm; TSS= total suspended solids; P= phosphorus

ER 579= Elk River reach 579 watershed

1 League of MN Cities 2008

2 40 homes are served by the system, calculated from 2000 census average persons per household for Benton County

Foley WWTF is a class D facility consisting of two main lift stations and two stabilization ponds (Birch Pond and Golf Pond). Birch pond has a controlled discharge (SD001) which discharges to a marsh into Stoney Brook. Stoney Brook becomes Rice Creek prior to it's confluence with the Elk River. The pond has a detention time of 180 days at designed flow and treats up to 161,000 gallons per day (gpd). According to the MPCA permit, SD001 cannot discharge flow in the months of January through March, July and August. This discharge point must meet a fecal coliform limit of 200 colony forming units (cfu) per 100 ml limit as a calendar month geometric average and a total suspended solids (TSS) limit of 45 mg/L as a calendar month average. No phosphorus limit is required although phosphorus concentrations are recorded on the facilities discharge monitoring reports (DMR).

The second stabilization pond, Golf Pond, also has a controlled discharge (SD002) into a ditch to Stoney Brook. Golf Pond is designed to treat influent up to 210,300 gpd and has a detention time of 180 days at designed flow. The primary cells of Golf pond also have a manually controlled outlet control structure (SD003) which discharges to Stoney Brook. According to the MPCA permit SD002 can not discharge flow in the months of January through March, July and August. SD002 must meet a 200 cfu/ 100ml fecal coliform limit and a TSS limit of 45 mg/L. No phosphorus limit is required although concentrations are recorded on the facilities DMRs. SD003 is not regulated by any limits.

Gilman WWTF consists of a two cell stabilization pond. Both ponds have a detention time of 290 days at an average flow of .045 mgd. his facility treats domestic sewage and discharges to an unnamed ditch which flows to Bailey Creek which flows to the Elk River. According to the MPCA permit, the facility must meet a 200 cfu/ 100ml fecal coliform limit, a 45 mg/L TSS limit No P limit is required although P concentrations are recorded on the facilities DMRs. Discharge is prohibited from January through March, July and August.

Becker WWTF is a class A facility. Becker WWTF consists of two separate trains with a combine final discharge to the Elk River. One train treats water from the industrial park and the second treats domestic flow. Both trains currently use chemical application and a polymer addition for phosphorus and solids removal. Biosolids are mechanically thickened, go through a lime pasteurization process and are land applied. The Becker WWTF was designed to treat a combined average wet weather flow (AWW) of 850,000 gallons per day (GPD). The system was recently upgraded for an expanded flow which will allow it to treat an AWW flow of 2,150,000 gpd. Although the treatment capacity has increased, discharge limits remain the same and will be in effect until 2011. Effluent from the discharge has a 1 mg/L Phosphorus limit and 30 mg/L total suspended solids limit as calendar month averages based on a daily flow of 850,000 gallons. These limits are effective from January through December.

According to state rule, each facility is required to meet a discharge limit of 126 cfu/100ml *E.Coli* concentration and 1 mg/L phosphorus concentration. All permitted facilities are required to monitor their effluent to ensure that concentrations of specific pollutants remain within levels specified in the discharge permit. The MPCA regularly reviews the Discharge Monitoring reports to determine if violations have occurred.

Eagle View Commons WWTF is a Class C facility consisting of a gravity sewer system that discharges to one lift station, a cast in place tank constructed with three compartments in series with a total tank capacity of 38,779 gallons. One compartment is sized at 19,389 gallons and the other two compartments are sized at 9,695 gallons each. A splitter manhole to split flow between two lined subsurface flow forced aeration wetland treatment cells measuring 10,000 square feet each, a dosing manhole with a dosing siphon which periodically discharges wastewater to one 15,600 square foot unlined wetland that acts as an infiltration bed. This WWTF is designed to serve 40 homes; four bedroom homes with a contribution of 250 gallons per day (gpd) per home. The wetland treatment system has an average annual design flow of 10,000 gpd and a peak daily flow of 16,667 gpd. No commercial or industrial facilities are proposed to be served by the wastewater treatment system.

Impairment Contribution: *E.Coli*, excess nutrients, turbidity

4.1.2 MS4s

An evaluation of permit holders also revealed NPDES Phase II permits for small municipal separate storm sewer systems (MS4s). The unique permit numbers assigned to these permit holders are as follows:

Table 4.2: List of NPDES II permit holders in the TMDL study area

NPDES Phase II Permit Holder Name	NPDES II Permit Number	Watershed Location
Sherburne County	MS4400155	ER 579, BEL
Big lake Township	MS4400234	ER 579
City of Big Lake	MS4400249	ER 579
Benton County	MS4400067	ER 579, BEL, MAY
Sauk Rapids City	MS4400118	ER 579, BEL
Sauk Rapids Township	MS4400153	ER 579, BEL
St. Cloud City	MS4400052	ER 579, BEL
MNDOT Outstate District	MS4400180	ER 579, BEL
Haven Township	MS4400136	ER 579, BEL
Minden Township	MS400147	ER 579, BEL
Minnesota Correctional-St Cloud MS4	MS400179	ER 579, BEL
Watab Township MS4	MS400161	ER 579, BEL

Impairment Contribution: *E.Coli*, excess nutrients, turbidity

4.1.3 Construction Permits

The MPCA issues construction permits for any construction activities disturbing: 1) One acre or more of soil, 2) Less than one acre of soil if that activity is part of a “larger common plan of development or sale” that is greater than one acre or 3) Less than one acre of soil, but the MPCA determines that the activity poses a risk to water resources. The Environmental Protection

Agency (EPA) estimates a soil loss of 20 to 150 tons per acre per year from stormwater runoff at construction sites. Such sites vary in the number of acres they disturb.

Impairment contribution: excess nutrients, turbidity

4.1.4 Livestock Facilities with NPDES Permits

A Confined Animal Feeding Operation (CAFO) is a feedlot having 1,000 or more animal units, or a smaller feedlot with a direct man-made conveyance to surface water. A feedlot designated as a CAFO is required to operate in accordance with a NPDES permit. According to the MPCA Feedlot database there are two CAFOs located in the Sherburne County portion of Elk River reach 579 watershed. The CAFOs represent a total of 1456 animal units (AU) comprised of 1060 beef and 396 poultry AUs.

Table 4.3: List of CAFO NPDES permit holders in the TMDL study area that it drains to.

CAFO NPDES Permit Holder	Permit Number	AU's	Watershed Location
Goenner Poultry LLC	MNG441109	396	ER 579
Eiler Bros.	MNG440909	1060	ER 579

Impairment contribution: excess nutrients, *E.Coli,* turbidity

4.2 NON-PERMITTED SOURCES

Below is an inventory of the non-point sources in the Elk River watershed that have been identified as potential sources of nutrients, *E.Coli*, or turbidity.

The turbidity impairment in Elk River reach 579 has been identified to be the result of algal blooms caused by excess nutrients from Big Elk Lake. Big Elk Lake is addressed in this TMDL for Excess Nutrients (phosphorus) and reductions in nutrient loading to the lake will result in turbidity reductions in Elk River reach 579. As such, many of the sources of excess nutrients identified below are also listed as sources of turbidity.

4.2.1 Atmospheric Deposition

The atmosphere delivers phosphorus to water and land surfaces both in precipitation and dryfall (dust particles that are suspended by winds and later deposited). Such atmospheric inputs must be accounted for in development of a nutrient budget, though they are generally very small direct inputs to the lake and are impossible to control.

Impairment contribution: Excess nutrients, turbidity

4.2.2 Internal Phosphorus Release

Phosphorus accumulated in the lake sediments released under specific conditions is called internal loading. Internal loading can result from sediment anoxia where poorly bound phosphorus is released into the water column in a form readily available for phytoplankton production. The build up of phosphorus in lake-bottom sediments increases due to increased phosphorus loading from the watershed. Internal loading can also result from sediment re-suspension that may result from rough fish activity or prop wash from boat activity. Additionally, curly leaf pondweed can increase internal loading because it senesces and releases phosphorus during the summer growing season (late June to early July).

In-lake nutrient cycling is an important component of the whole-lake nutrient budget. Internal phosphorus release was first modeled, and then measured to validate the models. The 2009 data collection quantified watershed loads, these measured watershed loads, in-lake water quality, and periods of anoxia were used in combination with the Canfield-Bachmann lake response model to back-calculate sediment release rates. To validate the models, the sediment release rates were directly measured at Eau Galle Laboratories from lake cores collected in early 2010. The measured values validated the modeled results, indicating a high level of confidence in measured watershed loads, and lake water quality.

Impairment contribution: Excess nutrients, turbidity

4.2.3 Groundwater

Groundwater can be a source or sink for water in a lake and contains varying levels of phosphorus. Therefore groundwater can contribute phosphorus and effect the hydraulic residence time of lakes. In the case of Mayhew and Big Elk Lakes, groundwater was determined to be recharging both lakes, and therefore constitute a source of water and phosphorus.

Groundwater contributions to the water and phosphorus budget of each lake were determined through direct measurement of the surficial water budget: Inflow and outflow volumes were measured in 2009. The surface expression of groundwater for each lake was determined to be the difference between the outflow and the sum of the inflows. To validate these measured values, the long term baseflow data for the Elk River at the City of Elk River were evaluated along with the regional hydrologic atlas, and published values for groundwater characteristics in the area.

Impairment contribution: Excess nutrients, turbidity

4.2.4 Subsurface Sewage Treatment Systems (SSTS)

The homes riparian to Big Elk Lake, Mayhew Lake and the Elk River are almost exclusively served by SSTS, as are several areas of the watershed. Failing SSTS can be a significant source of phosphorus to surface waters. Benton County staff indicates that, on average, 30 percent of the SSTS in the County are failing (pers. Communication between T. Determann and Sherburne County Staff in 2009). A 1991 Septic Leachate survey conducted on Big Elk Lake and the Briggs Chain of Lakes concluded that of the 504 residential units around the lakeshores, 10 percent exhibited indications of insufficiently treated septic leachate (Water Research & Management, Inc.). There are five homes with SSTS located on the lakeshore of Mayhew Lake.

In addition to phosphorus, *E.Coli* from humans can reach surface water through the pathways of SSTS. Failing or nonconforming SSTS can be a source of *E.coli* bacteria, especially during dry periods when these sources continue to discharge and runoff driven sources are not active. Poorly treated effluent can contain elevated concentrations of *E. coli* and is considered a threat to public health. Estimates from the Counties, past research conducted by Water Research and Management, Inc. (October 1991) and conservative estimates were used to approximate the external load that can be attributed to failing SSTS.

Impairment contribution: Excess nutrients, turbidity, *E.Coli*

4.2.5 Straight-pipe Septic Systems

Straight pipe septic systems are septic systems that deposit untreated raw sewage directly to rivers, lakes, drain tiles or ditches. For comparison, a properly functioning SSTS treats sewage with chemical, physical and biological processes using a septic tank and a soil treatment system. Straight-pipe septic systems are illegal and unpermitted, but do exist in the watershed.

Impairment contribution: Excess nutrients, turbidity, *E.Coli*

4.2.6 Rural and Urban Residential runoff

Runoff from the residential and urban riparian areas, lake shore property, and other areas of the watershed not covered under an MS4 Permit can be a major source of phosphorus, turbidity and *E. coli* loading to surface water. Lakeshore homes and other residential areas have the potential to transport materials such as grass clippings, leaves, car wash wastewater and animal waste to surface water. All of these materials contain phosphorus and bacteria which can impair local water quality. Lake shore property around Big Elk Lake and several lakes located upstream from the lake have dense residential populations.

Untreated urban stormwater has demonstrated fecal coliform concentrations as high as, or higher than grazed pasture runoff, cropland runoff, and feedlot runoff (USEPA 2001, Bannerman et al. 1993, 1996). There is relatively little urban area in the portion of the Elk River watershed listed for bacteria impairment, with urban and developed lands comprising approximately 7 percent of the total area. Consequently, urban stormwater is a relatively small proportion of the *E.Coli* load in this watershed.

Impairment contribution: Excess nutrients, turbidity, *E.Coli*

4.2.7 Non-CAFO Livestock Facilities and Riparian Pastures

Runoff from traditional and non-traditional livestock feedlots, pastures and land application of manure have the potential to be significant sources of nutrients and *E. Coli*.

There are numerous small to medium sized feedlots and riparian pastures scattered throughout the watershed which offer opportunities for manure to enter surface water directly; however, there is considerable variation in the type and density of livestock facilities across the watershed. The feedlot density is the highest in the upper portion of the watershed where Benton County is listed as having the highest density of broiler chickens and the 5th highest density of dairy cows in the state. To that point, runoff from feedlots may be a significant source of phosphorus and *E.Coli* contamination during periods of heavy precipitation. However, many small sized livestock operations have riparian pastures which lead to opportunities for manure to enter surface water directly during dry periods.

The MPCA registered feedlot data base lists 188 feedlots and approximately 29,330 AU's in the Elk River 579 watershed. The registered feedlots are mainly composed of dairy, beef and chicken. Other animals include horse, sheep, and swine. It is important to note that based on field observations and reports by SWCD staff, that registered feedlots comprise only a small percentage of total feedlots in Benton and Sherburne Counties.

Impairment contribution: Excess nutrients, turbidity, *E.Coli*

4.2.8 Agricultural Land Use

A high percentage of the land use in the watershed is agricultural consisting of row crops (corn, soybeans and small grains) and hay. Manure application on row crops and the type of manure application (surface vs. incorporated) of manure can contribute to *E.Coli* in waterways. In areas were surface manure is applied to crop fields, open tile inlets can serve as a transport mechanism to deliver bacteria to the Elk River and its tributaries.

Manure from animal feedlots including poultry, hot and dairy producers is applied to the landscape through one of two methods, surface application or liquid incorporation. Large hog or dairy feedlot operations typically have a liquid manure pit and these operations use liquid incorporation to apply manure. Small to medium sized beef, dairy and hog operations apply manure, typically starting in mid to late fall after harvesting is complete with surface manure applications continuing through the winter. Surface applied manure is worked into the soil with agriculture tillage equipment, which may take place immediately after application but may be delayed until the spring immediately prior to planting.

A recent survey of 187 soil test results in Benton County revealed that 93% of soil phosphorus tests conducted were greater than 21 ppm, the threshold where the MPCA begins to regulate land application of manure. A survey of 50 poultry manure tests and 30 manure spreader calibrations shows that on average, phosphorus is being applied at 604 pounds per acre with rates as high as 1,479 pounds per acre.

For Benton County, the combination of long, moderately steep slopes, easily erodible sandy loam soil that is inherently high in phosphorus, a high density of feedlots, and predominately agricultural land use in riparian areas leads to an extremely high potential to introduce large amounts of phosphorus, sediment, and bacteria to surface waters. Comparatively, soil types and flatter slopes mean overall slightly less risk of erodability in Sherburne County.

Impairment contribution: Excess nutrients, turbidity, *E.Coli*

4.2.9 Wildlife

Natural background loads for *E.coli* bacteria can be attributed to wildlife. The focus of this assessment was on deer and geese because they are known contributors of *E.coli* bacteria and are considered a good estimate of wildlife densities in general.

Wildlife populations were estimated utilizing past research and knowledge of the Department of Natural Resources. Deer populations in the Elk River Watershed are estimated to be 15-20 deer per square mile. Goose densities were estimated based on Metro area estimates and were reduced to half of those estimates based on MN DNR input (Fred Bengston pers. Comm.).

Table 4.4: Deer and goose population estimates.

Wildlife	Density (per sq mile)	Population (est.)
Deer	15-20	5025-6700
Geese	1.4	469

Impairment contribution: *E.Coli*

4.2.10 In-Stream sources

In-stream erosion sources (stream banks and bed) result from the instability of the stream channel. Channel instability can result from overgrazing and/or high or flashy flow events. The slope of the bank, amount of moisture in the soil, and the cohesiveness of the material all play a role in bank failure. A substantial portion of the sediment derived from banks and beds may have originally come from upland soil eroded years earlier and deposited in riparian areas.

Impairment contribution: Turbidity

5.0 Loading Capacity

5.1 MODELING APPROACH

5.1.1 Lake Nutrients

Lake response to nutrient loading was modeled using the BATHTUB suite of models and measured data including runoff volumes and water quality, internal loading, and in-lake water quality. BATHTUB is a series of empirical eutrophication models that predict the response to phosphorus inputs for morphological complex lakes and reservoirs (Army Corps of Engineers, 2009). Several models (subroutines) are available for use within the BATHTUB model.

The Canfield Bachman model within BATHTUB was used to predict the response of the lakes described herein to phosphorus loads and load reductions. The Canfield-Bachmann model was developed using data collected from 704 natural lakes to best describe the lake phosphorus sedimentation rate which is needed to predict the relationship between in-lake phosphorus concentrations and phosphorus load inputs. The phosphorus sedimentation rate is an estimate of net phosphorus loss from the water column through sedimentation to the lake bottom. The phosphorus sedimentation rate is used in concert with lake-specific characteristics such as annual phosphorus loading, mean depth, and hydraulic flushing rate to predict in-lake concentrations of phosphorus as they relate to phosphorus loading. These model predictions are compared to measured data to evaluate how well the model describes the lake system.

The Chlorophyll-a response model selected for this TMDL is Model 1 from the BATHTUB package, which accounts for nitrogen, phosphorus, light and flushing rate.

Measured, watershed specific data were used to apply the Canfield-Bachmann and Chlorophyll-a models to these lakes. Watershed runoff volumes, watershed loads, internal loads and groundwater loads were each measured for input to the models. A significant historical database was available for use in the modeling effort as well as data collected specifically for this study in 2009.

The models fit well compared to annual average lake water quality data. No calibration factors were used. In addition to the large dataset of measured input values, three years of measured in-lake water quality were used for calibration for Big Elk Lake and five years of data was used for Mayhew Lake. The differences between observed and model-predicted average in-lake concentrations were generally within the reported standard deviations for annual average TP for a given year providing a robust calibration (Appendix A).

5.1.2 Turbidity

Evaluation of water quality and flow data collected in the Elk River Watershed facilitated use of the load duration approach to evaluate the necessary load reductions to achieve the turbidity TMDL in the Elk River. The turbidity load duration evaluation, data analysis and modeling conducted for the Big Elk Lake nutrient TMDL showed that the nutrient TMDL for Big Elk Lake was the driver of the turbidity impairment, and was an appropriate surrogate for the turbidity impairment in Elk River reach 579. That is to say, a separate TMDL for turbidity is not necessary, because meeting the nutrient TMDL in Big Elk Lake will result in Elk River meeting the state standard for turbidity.

To correlate water quality in Big Elk Lake to the impaired reach, an in-stream VSS surrogate concentration equivalent to the 25 NTU State standard was calculated in accordance with the TMDL Protocol (March 2007) The in-stream VSS surrogate for the state standard is 13.4 µg/L . However, rather than setting a numerical TMDL utilizing this equivalent concentration, the direct relationship between in-lake and in-stream water quality was used to demonstrate that achieving the 60 µg/l total phosphorus concentration needed to meet the nutrient TMDL for Big Elk Lake (and subsequent reductions in chlorophyll-a and VSS concentrations in the outflow of the lake which is the upstream end of the impaired reach) will result in turbidity readings below the 25 NTU standard within the impaired river reach.

5.1.3 Bacteria

The TMDL was set using the load duration approach in accordance with the TMDL Protocols (MPCA 2009). The flow duration curves were developed using flow data from the USGS permanent flow gauging station located just downstream of the impaired reach at river mile 9.5 and flow measured upstream in 2009 for the project. These data were used in conjunction with the *E. Coli* standard to develop the TMDL. Monthly mean flows were used to develop a load duration curve.

Flow duration curves were developed from data collected in 2009 at the continuous flow monitoring stations at ER 37.3 and ER 16.6 and compared to a 2009 flow duration curve developed from the USGS station. The USGS station provided statistically significant range of flow conditions. Data collected at all three stations in 2009 were correlated. This correlation was used to develop the flow duration curves for the stations within the listed reach.

The load duration curve approach begins by ranking all of the recorded flows over time to determine a percentage of the time specific flow levels are exceeded. These flow values are then multiplied by the State standard for *E. Coli*, of 126 org/100 ml, to determine the allowable bacteria load across all flow regimes. The allowable loads are calculated as the total number of organisms/month of *E. Coli* bacteria that can be delivered to the river that will result in a concentration meeting the State standard. The calculated monthly loads are plotted as a continuous curve on a logarithmic scale which displays the bacteria load at the state standard across all flow regimes.

5.1.3.1 *E.Coli* Available for Runoff

The *E.Coli* produced in the watershed was divided into several source areas. It is important to note that this process assumes that all *E.Coli* produced in the watershed, remains in the watershed. The estimated amount of *E.Coli* potentially available each month for runoff is shown in Table 5.2. The daily production estimates for each animal unit or individual were based on literature values for fecal coliform (MPCA 2002) which were converted to be expressed in terms of *E.Coli.*

Table 5.2: Estimated monthly *E.Coli* bacteria available during runoff events

Category	**Source**	**Animal Units or Individuals in Subwatershed**	**E.Coli Organisms Produced Per Unit Per Month (10^9)***	**Total E.Coli Available (10^9)**	**Total E.Coli Available by Source (10^9)**	**Percent by Source**
Livestock	Riparian Livestock	8,732.3 Dairy AUs	1379.85	12,049,275	29,367,055	58.2%
		5,461.3 Beef AUs	2491.40	13,606,272		
		1,539 Swine AUs	1533.17	2,359,546		
		222 Horse AUs	8.05	1,787		
		2,072.1 Chicken AUs	651.60	1,350,176		
	Surface Applied Manure	4,924.9 Dairy AUs	1379.85	6,795,629	19,335,729	38.3%
		3,957.1 Beef AUs	2491.40	9,858,711		
		1,279 Swine AUs	1533.17	1,960,922		
		32 Horse AUs	8.05	258		
		1,105.3 Chicken AUs	651.60	720,210		
Human	Failing Septic Systems and Unsewered Communities	16,889 people	38.35	647,342	647,342	1.3%
Wildlife	Deer	5,869 deer	9.59	56,239	112,571	0.2%
	Geese	470 geese	0.20	94		
	Other Wildlife	Equivalent of Deer	9.59	56,239		
Urban Stormwater	Improperly Managed Pet Waste	10,250 dogs and cats	95.89	984,211	984,211	2.0%
Total					50,446,909	100%

* Derived from literature values in Mulla et. Al (2001), USEPA (2001), and Alderisio and DeLuca (1999)

Developing the delivery potential for each quantified source to reach surface waters is based on assigning risk values on a scale of 1-5 (1= very low risk and 5 = very high risk). These assumptions are divided into wet weather conditions and dry weather conditions to differentiate between those sources that are precipitation driven versus those which are not dependent on precipitation. The dry weather sources are septic systems, riparian livestock in pastures with direct access to the streams, and wildlife. Surface applied manure has been excluded as a dry weather source of bacteria in other TMDL studies. However, based on the agricultural conditions in the Elk River watershed it was determined that surface applied manure is assigned a very low delivery potential in dry weather conditions, and a low estimated delivery potential in wet weather relative to other sources.

Seasonality was accounted for in the amount available for wash off due to seasonal differences in application practices. Septic system delivery potential was not doubled here to reflect some of the variability in assessing failing septic systems. Some septic systems are considered failing due to interaction with the water table, but do not have a direct connection to surface waters. The delivery potential remains high though where drain tiling is present.

Table 5.2: *E.Coli* delivery potential

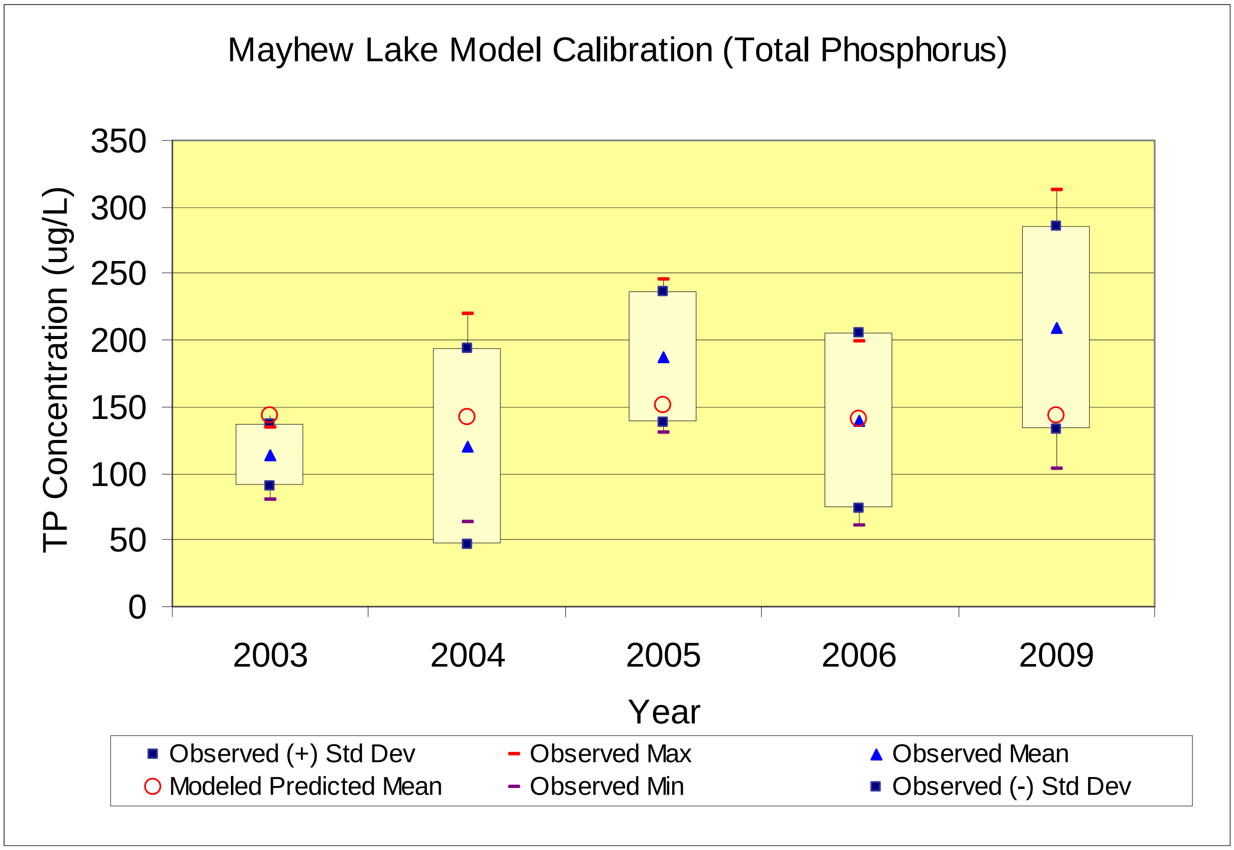
Source	**Estimated Delivery Potential**	
	Wet Conditions	**Dry Conditions**
Riparian Livestock	Very High	High
Surface Applied Manure	Low	Very Low
Failing Septic Systems	Moderate	Moderate
Unsewered Communities	Very Low	Very Low
Deer	Very Low	Very Low
Geese	Moderate	Moderate
Other Wildlife	Very Low	Very Low
Urban Stormwater Runoff	Moderate	N/A

5.2 MODEL CALIBRATION/VALIDATION RESULTS

5.2.1 Mayhew Lake Model

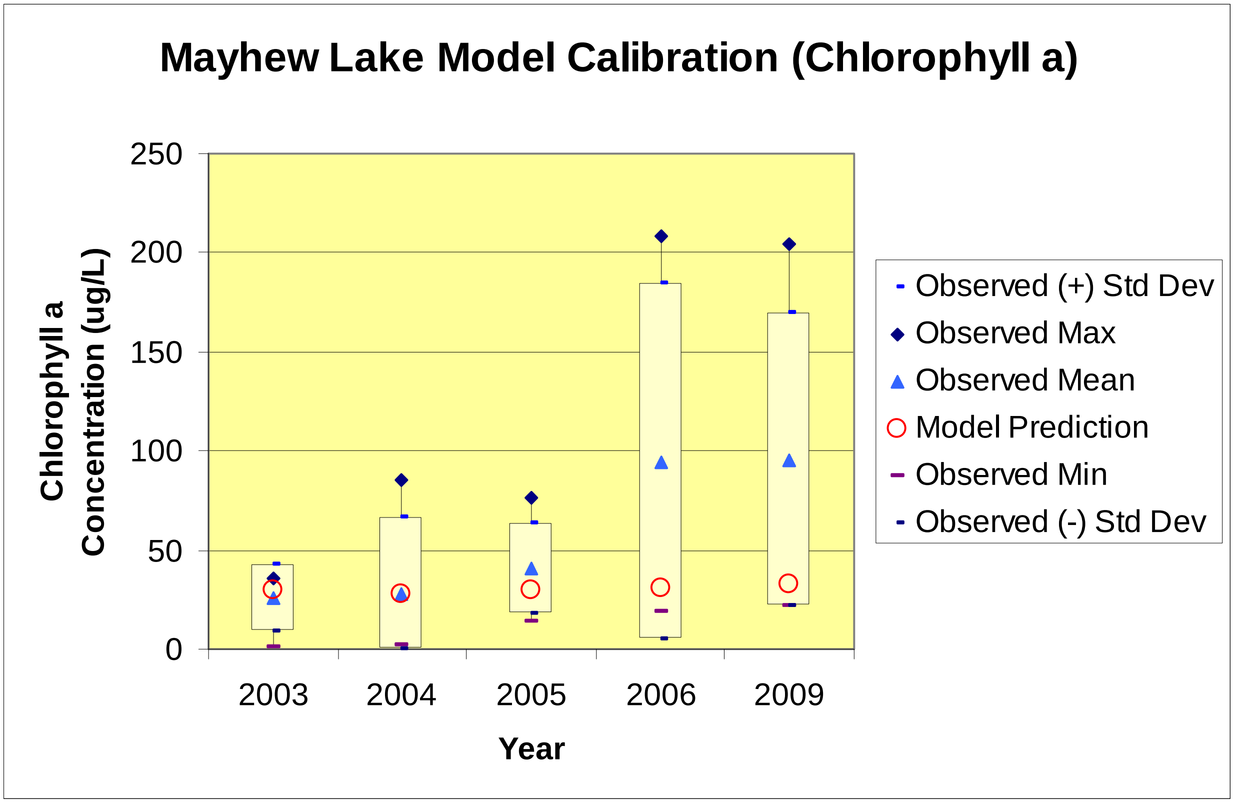
Water quality data was available for 2003-2006 and 2009. Each year was modeled utilizing the methods described in the previous section. The calibration of the modeling to recorded total phosphorous concentrations is presented in Figure 5.1. The calibration of the models to recorded chlorophyll-a concentrations is portrayed in Figure 5.2.

Figure 5.1: Mayhew Lake model calibration (total phosphorus)



T:\2378_ERWSA\Lake Response Model\[LRM Mayhew_mmb Calib 1.xls]TP Calibration Chart

Figure 5.2: Mayhew Lake model calibration (chlorophyll-a)

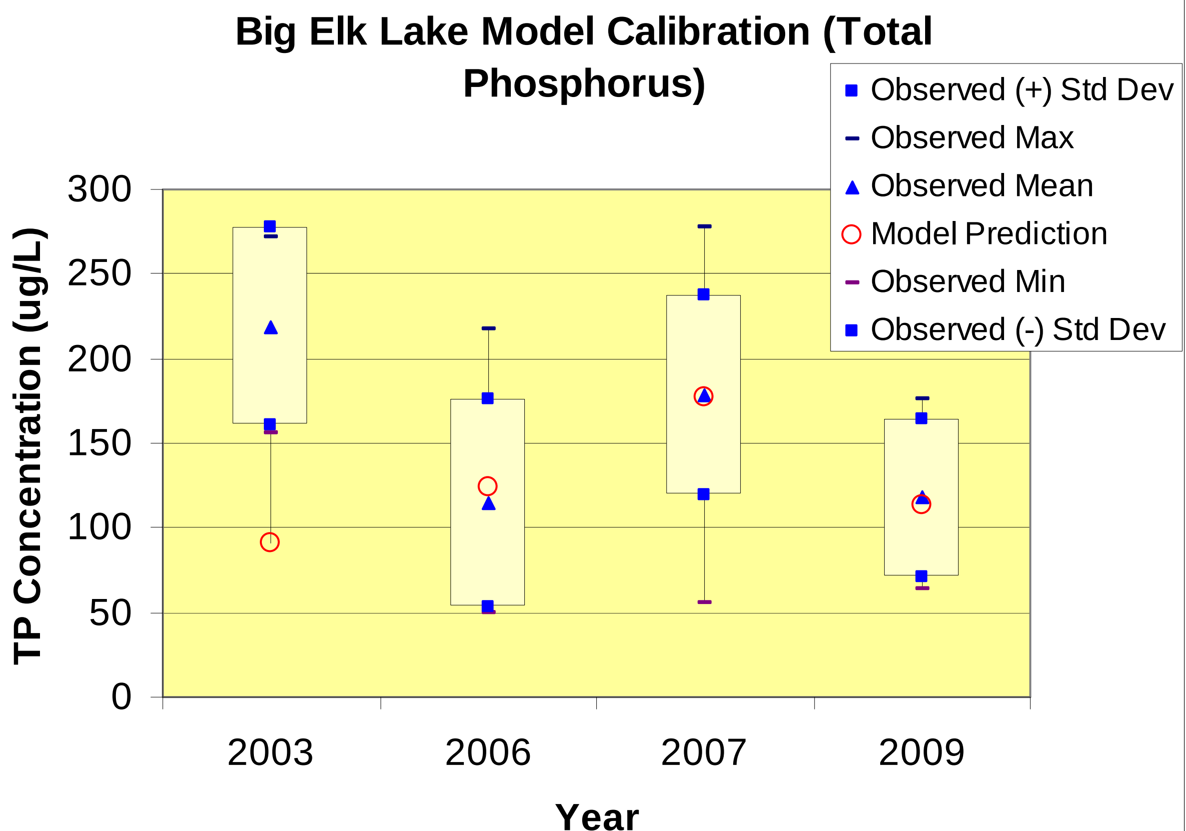


T:\2378_ERWSA\Lake Response Model\[LRM Mayhew_mmb Calib 1.xls]Chl-a Calibration Chart

5.2.2 Big Elk Lake Nutrient TMDL

Water quality data was available for 2003, 2006, 2007 and 2009. However, 2003 data was not used for the model calibration because the data collected did not characterize the growing season average. It represented three samples collected during late summer. Each year was modeled utilizing the methods described in the previous section. The calibration of the modeling to recorded total phosphorous concentrations is presented in Figure 5.3. The calibration of the models to recorded chlorophyll-a concentrations is portrayed in Figure 5.4.

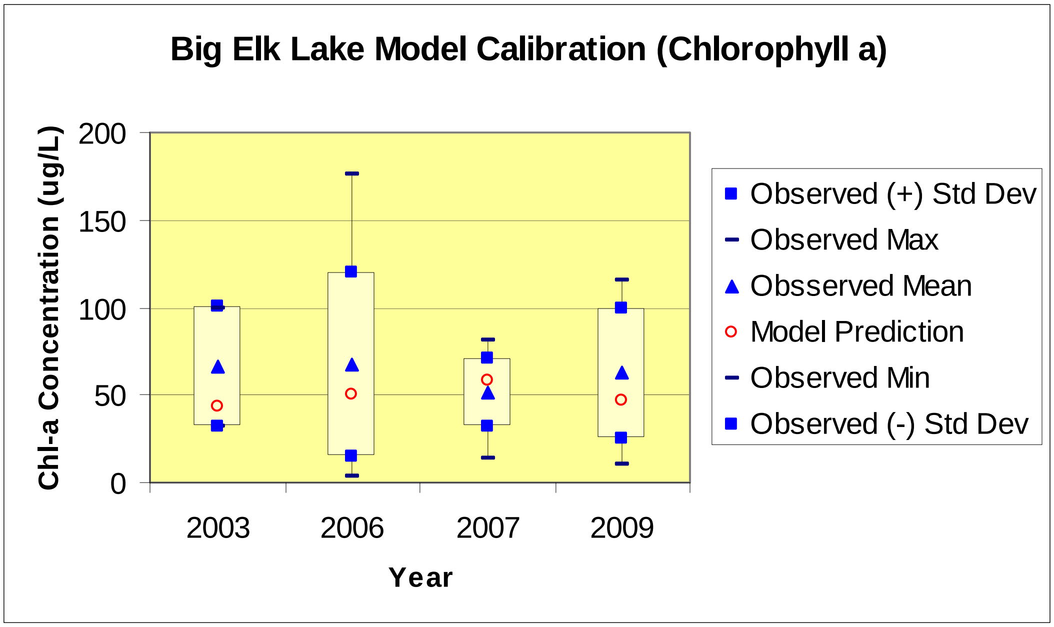
Figure 5.3: Big Elk Lake model calibration (total phosphorus)



*Lake surface water quality data collected in 2003 does not represent a true growing season average, it reflects 3 late late-summer measurements, the period of highest in-lake concentrations. As such it is not used in the calibration.

T:\2378_ERWSA\Lake Response Model\[Seasonal LRM Big elk Lake_mmb Calib 3.xls]TP Calibration Chart

Figure 5.4: Mayhew lake model calibration (chlorophyll-a)

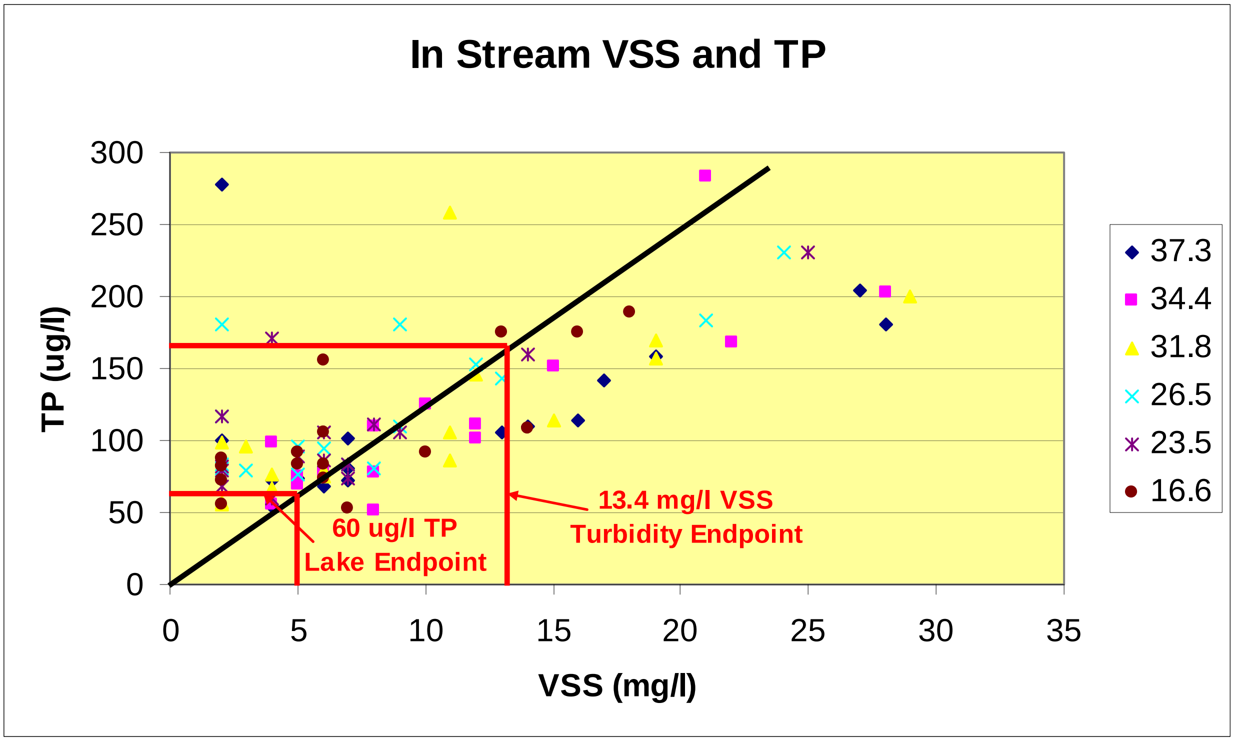


T:\2378_ERWSA\Lake Response Model\[Seasonal LRM Big elk Lake_mmb Calib 3.xls]Chl-a modeling

5.2.3 Elk River Reach 579 Turbidity TMDL

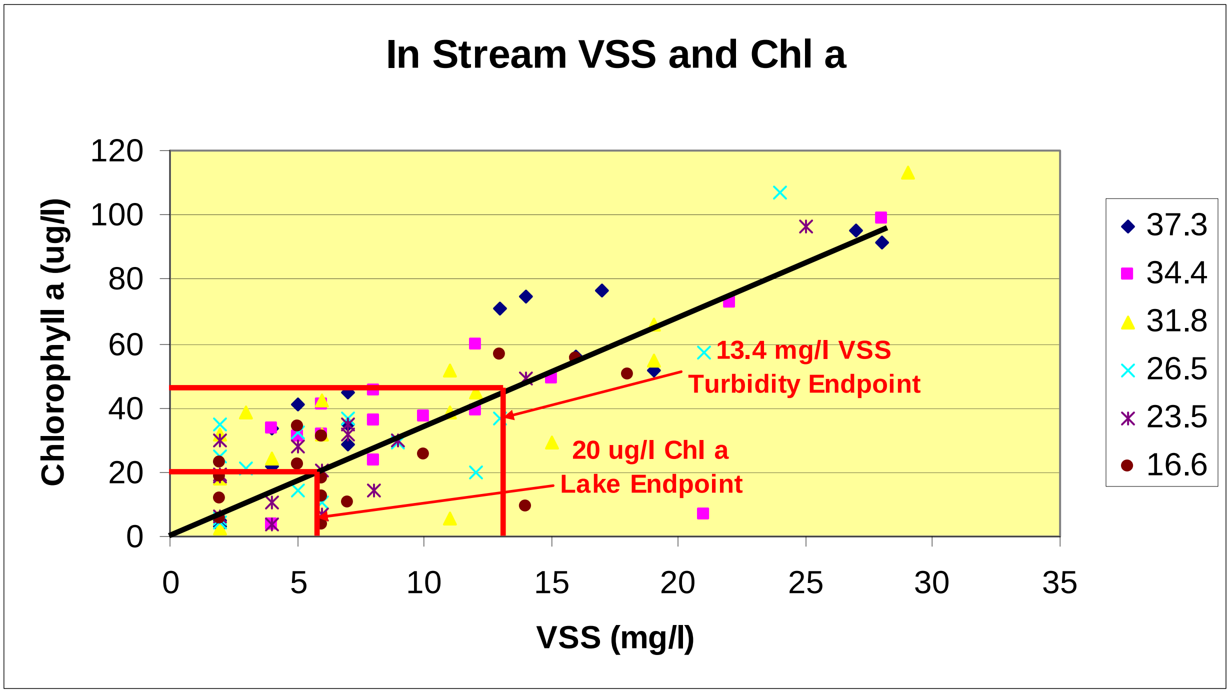
As previously discussed, achieving the endpoint of the Big Elk Lake nutrient TMDL will improve water clarity in the impaired reach. The following series of figures (Figures 5.5 – 5.7) provides additional supporting data that the Big Elk Lake nutrient TMDL is an appropriate surrogate for turbidity. A reduction in in-lake total phosphorus concentration will result in lower in-lake chlorophyll-a concentrations. In turn, this will lead to lower in-stream turbidity and improved water quality in the impaired reach.

Figure 5.5: In-stream VSS and total phosphorus



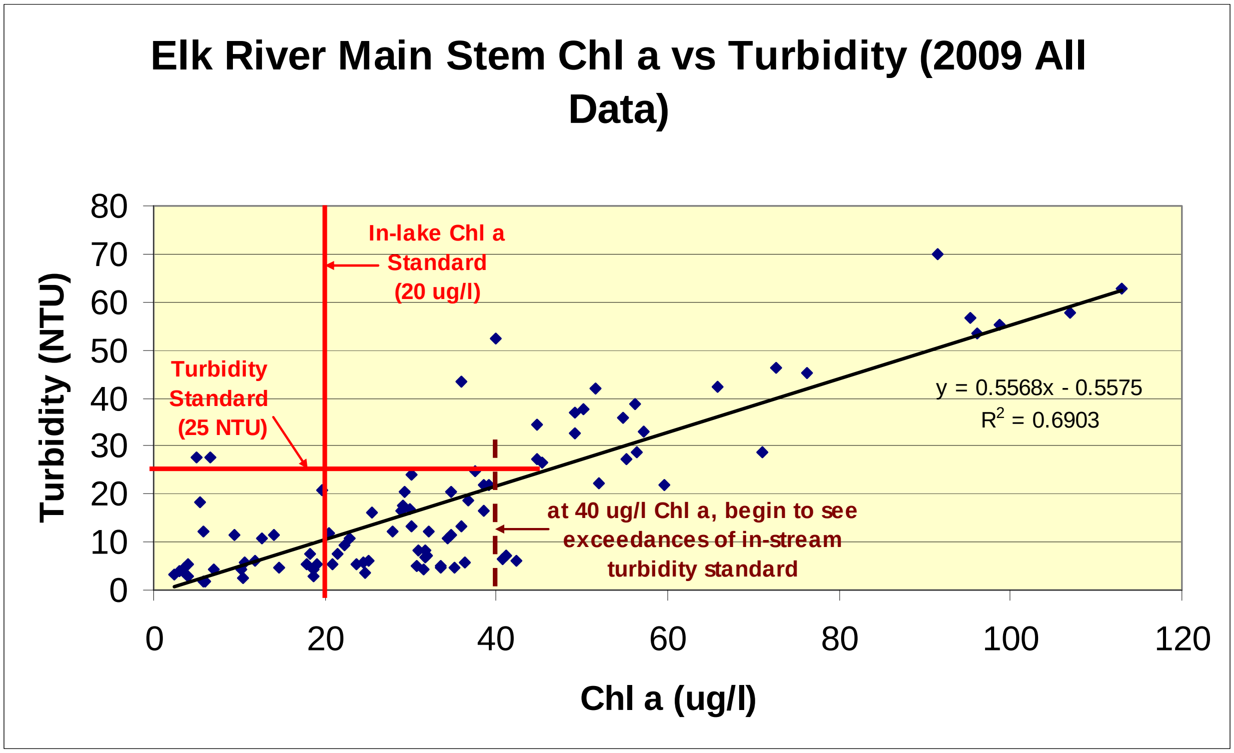
T:\2378_ERWSA\Elk River\Turbidity\[turbidity_mmb.xls]In Stream TSS, VSS, CHla

Figure 5.6: In-stream VSS and chlorophyll-a



T:\2378_ERWSA\Elk River\Turbidity\[turbidity_mmb.xls]In Stream TSS, VSS, CHla

Figure 5.7: In-stream chlorophyll-a and turbidity



T:\2378_ERWSA\Elk River\Turbidity\[Surrogate calcs_mmb.xls]Chl a

6.0 TMDL

6.1 ALLOCATION APPROACH

The TMDL is represented by the following equation:

$$\mathrm{TMDL} = \Sigma \mathrm{LA} + \Sigma \mathrm{WLA} + \mathrm{MOS} + \mathrm{RC}$$

Where:

ΣLA= Load Allocation, or the sum of the unpermitted sources including background sources such as precipitation and groundwater contribution as well as unpermitted watershed source like some agricultural, residential and urban land uses. Specifically, LA= Atmospheric Contribution +Groundwater+ Watershed Load + Tributary Loads +Internal Loads.

SWLA= Waste Load Allocation, or the sum of the permitted sources including WWTPs, MS4s, and permitted CAFOs.

MOS= Margin of Safety

RC= Reserve Capacity

6.1.1 Nutrients

Nutrient loads for the lake TMDLs are set for phosphorus, since this is typically the limiting nutrient for nuisance aquatic plants. This TMDL is written to solve the TMDL equation for the numeric target of 40 µg/l of total phosphorus for Mayhew Lake and 60 µg/l of total phosphorus for Big Elk Lake.

There are no known WWTPs which discharge in the Mayhew Lake watershed. There are three WWTPs which discharge in the Big Elk Lake watershed, none of which has a total phosphorus effluent discharge limit. These discharges will require a Waste Load Allocation, which will be included in the final TMDL report.

There are several permitted MS4s within the Big Elk Lake watershed, and one within Mayhew Lake watershed. It is recommended these MS4s be assigned a categorical wasteload allocation calculated from the permitted MS4 area and the total watershed area and expressed as a percentage (6.7% for Mayhew Lake and 29.7% for Big Elk Lake). This percentage will be applied to the TMDL to quantify the MS4 portion of the waste load.

The load allocation must be divided among existing permitted sources under state law. is charge from septic systems is not allowed by law and therefore the load allocation for septic systems will be zero. Relative proportions allocated to each source are based on reductions that can be achieved through Best Management Practices.

The loading capacity is the total maximum daily load of the impaired water. The daily load and waste load allocations for the average conditions in each lake are shown in Table 6.1. The overall load reduction required is based on the lake response model. The final partition of categorical loading allocations will change for the final report once the WLA is developed for the WWTPs.

Table 6.1: Total phosphorus load allocations expressed as daily loads (from lake response models and source watershed data)

Lake	Total Phosphorus TMDL (lbs/day)	Waste Load Allocation (lbs/day)	Load Allocation (lbs/day)	MOS
Mayhew	4.69	0.31	4.38	Implicit
Big Elk	25.1	7.46	17.65	Implicit

Draft load allocations by source for each lake are provided in Table 6.2. No reduction in atmospheric or groundwater loading is targeted because this source is impossible to control on a local basis. The remaining load reductions were applied based on understanding of the lakes, efficacy of proposed implementation strategies, as well as the model results.

Table 6.2: Partitioned Total Phosphorus Load Allocations Expressed as Daily Loads

Lake	Load Allocation	Direct Watershed	Tributary Inflows	Septic Systems	Atmospheric + Groundwater	Internal
Mayhew	4.38	0.02	0.50	0.00	0.59	3.26
Big Elk	17.65	0.02	2.74	0.00	3.74	11.15

Annual total maximum loads are provided in Tables 6.3 and 6.4. The values above are calculated from these annual loads. The loading capacity is based on average model predicted results for years in which lake water quality data was available (within the last 10 years).

Table 6.3: Total phosphorus load allocations expressed as annual loads

Lake	Total Phosphorus TMDL (lbs/year)	Waste Load Allocation (lbs/year)	Load Allocation (lbs/year)	MOS
Mayhew	1712	115	1597	Implicit
Big Elk	9163	2721	6442	Implicit

Table 6.4: Partitioned total phosphorus load allocations expressed as annual loads

Lake	Load Allocation	Direct Watershed	Tributary Inflows	Septic Systems	Atmospheric + Groundwater	Internal
Mayhew	1597	6	133	0	157	864
Big Elk	6442	7	1000	0	1365	4069

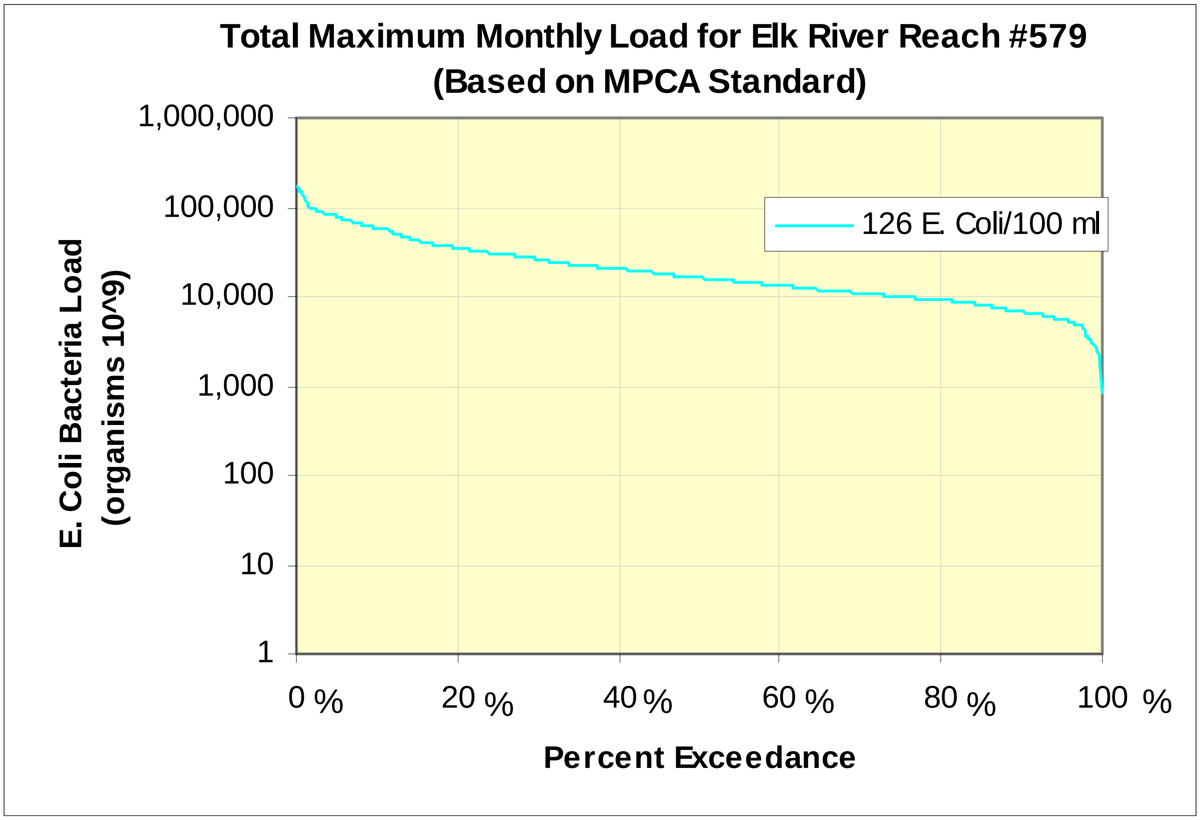
6.1.2 Turbidity

The numeric TMDL for the turbidity impairment in the Elk River reach 579 is the nutrient TMDL for Big Elk Lake. As discussed previously in this report, setting the nutrient TMDL in Big Elk Lake is an appropriate surrogate for a numeric turbidity TMDL. By achieving the nutrient goal in Big Elk Lake as allocated in the above section, water quality within the listed reach will improve and meet the State standard of 25 NTUs for turbidity. In addition to the load reduction for Big Elk Lake, existing sources will also be assigned categorical loading allocations in the Phase III Report.

6.1.3 Bacteria

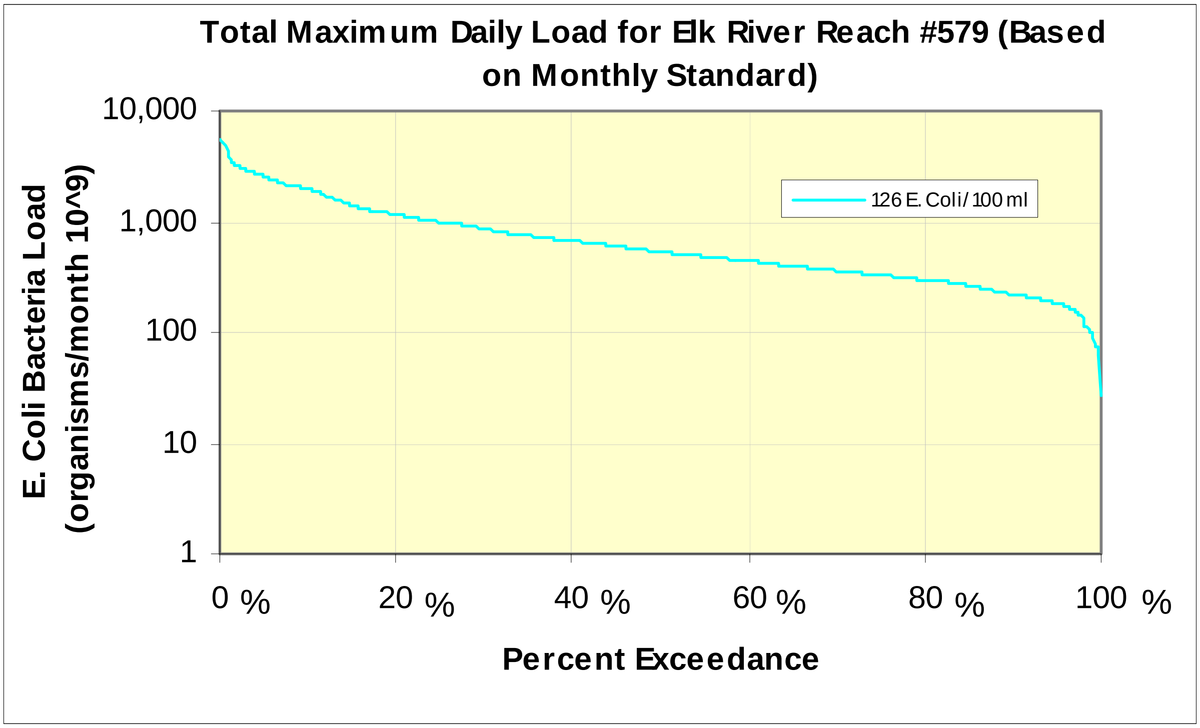
Because stream *E. Coli* concentrations are dependent upon the daily flow which is dynamic, it is appropriate to express the TMDL and load reduction by an allowable load across all flow conditions as is demonstrated in Figure 6.1 for monthly loads and 6.2 for daily loads. To determine acceptable loads under the critical flow regimes, chronic standard concentrations were multiplied by the flow at each interval. Monthly mean flow data was used to calculate the load duration curve. The daily loads were derived from the calculated monthly loads.

Figure 6.1: Total Maximum Daily Load for the listed segment of the Elk River, concentrations represent total monthly load based on 126 *E. Coli*/100 mL standard



T:\2378_ERWSA\Elk River\Bacteria\[Bacteria Load Calcs - Annual Flow.xls]Load Duration (Method 2)

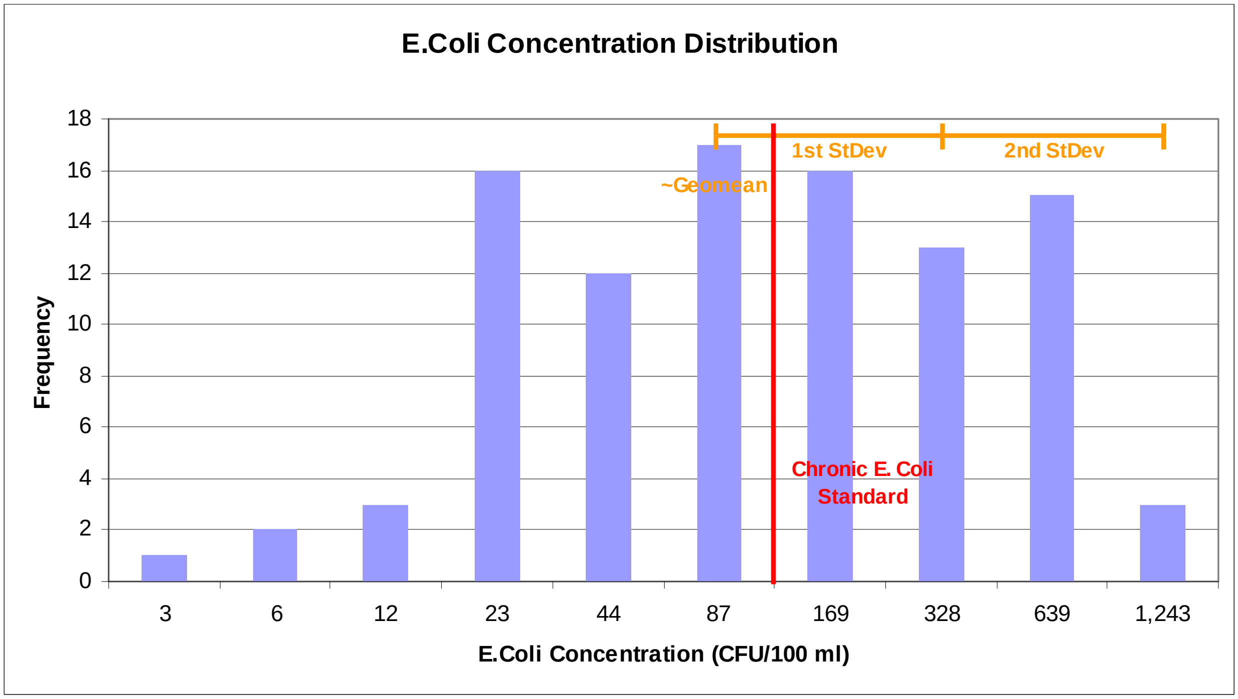
Figure 6.2 The Total Maximum Daily Load for the listed segment of the Elk River, concentrations represent Total Daily Load Derived from Monthly Load (Standard of 126 *E. Coli*/100 ml.)



T:\2378_ERWSA\Elk River\Bacteria\[Bacteria Load Calcs - Annual Flow.xls]Load Duration (Method 2)

To develop the TMDL equation, the seasonal mean discharge was calculated for each of five flow conditions. These data were then multiplied by the standard of 126 *E.Coli*/100 ml to establish the TMDL (Table 6.5). The Margin of Safety (MOS) was established using all existing watershed data to quantify uncertainty in the data. Figure 6.3 displays the distribution of the available data. The MOS was calculated from the difference between the geometric mean and the value two standard deviations above the geometric mean. The use of two standard deviations was applicable due to the data distribution and range of concentrations. The calculated MOS, expressed as a percentage of the state chronic standard (16%) and applied to the TMDL equation, is extremely conservative in this case.

Figure 6.3: Distribution of 2009 *E.Coli* concentrations



T:\2378_ERWSA\Elk River\[2009 WQ data.xls]Hist1

The wasteload allocation (WLA) was calculated using known discharges from the point sources within the watershed. The WLA is 213.21 x 10^9 for the wet condition. The load allocation (LA) assigned for the wet flow is the load remaining after the MOS and WLA are subtracted from the TMDL using the following calculation:

TMDL – MOS - WLA = LA
or
1072.70 x 10^9 *E. Coli* – 171.63 x 10^9 *E. Coli* – 213.21 x 10^9 *E. Coli* = 687.86 x 10^9 *E. Coli*

Under this scenario the load allocation is 64 percent of the TMDL at 126 *E. Coli*/100 ml and the MOS and WLA make up the remaining load. The TMDL loads for both daily loads and monthly loads based on the 126 *E. Coli* /100 ml daily standard are provided in Tables 6.5 and 6.6, respectively

Table 6.5: The TMDL expressed as daily loading capacity of *E. Coli* in the Elk River Reach # 579

Daily						
Reach	**Critical Condition**	**WWTF Wasteload Allocation (10^9 org)**	**MS4 Wasteload Allocation (10^9 org)**	**Load Allocation (10^9 org)**	**Margin of Safety (10^9 org)**	**TMDL (10^9 org)**
Elk River 579	High Flow	8.90	539.75	1817.25	450.65	2816.55
	Wet	8.90	204.31	687.86	171.63	1072.70
	Mid-Range	8.90	102.16	343.95	86.67	541.67
	Dry	8.90	61.33	206.49	52.71	329.43
	Low Flow	8.90	30.27	101.93	26.88	167.98

Table 6.6: The TMDL Expressed as Monthly Loading Capacity of *E. Coli* in the Elk River Reach # 579

Monthly						
Reach	**Critical Condition**	**WWTF Wasteload Allocation (10^9 org)**	**MS4 Wasteload Allocation (10^9 org)**	**Load Allocation (10^9 org)**	**Margin of Safety (10^9 org)**	**TMDL (10^9 org)**
Elk River 579	High Flow	270.80	16419.29	55280.68	13708.72	85679.49
	Wet	270.80	6215.01	20924.79	5221.07	32631.67
	Mid-Range	270.80	3107.63	10462.81	2636.43	16477.67
	Dry	270.80	1865.67	6281.35	1603.39	10021.22
	Low Flow	270.80	920.94	3100.63	817.59	5109.96

While estimates of *E.Coli* contributions are derived from literature values and knowledge of the land practices, actual fecal coliform or *E. Coli* data is based on field monitoring. Load and wasteload allocations were based on thorough watershed wide monitoring of *E.Coli* from April 1 through October 31. This robust data set provided for a thorough seasonal evaluation of loads and consequently the magnitude of the exceedances and reductions needed to meet the standard.

6.2 MARGIN OF SAFETY

A Margin of Safety has been incorporated into this TMDL by use of conservative modeling approaches to account for an inherently imperfect understanding of lake systems and to ultimately ensure that the nutrient reduction strategy is protective of the water quality standard.

The Canfield Bachman model was used to predict the response of the lakes described herein to phosphorus loads and load reductions. Canfield-Bachmann is an empirical model developed using data collected from 704 natural lakes to best describe the lake phosphorus sedimentation rate which is needed to predict the relationship between in-lake phosphorus concentrations and phosphorus load inputs. The phosphorus sedimentation rate is an estimate of net phosphorus loss from the water column through sedimentation to the lake bottom. The phosphorus sedimentation rate is used in concert with lake-specific characteristics such as annual phosphorus loading, mean depth, and hydraulic flushing rate to predict in-lake concentrations of phosphorus as they relate to phosphorus loading. These model predictions are compared to measured data to evaluate how well the model describes the lake system.

To apply the Canfield-Bachmann model to these lakes measured watershed specific data were used: measured watershed runoff volumes, concentrations, overall loads, internal loads, and groundwater concentrations were used instead of modeled watershed hydrology and phosphorus load export. Further, no calibration factors were used.

The models fit well compared to annual average lake water quality data. Three to five years of data were compared for Mayhew and Big Elk Lakes respectively, and differences between observed and model-predicted average in-lake concentrations were generally within the reported standard deviations for annual average TP for a given year. The fit of the model ensures that the loads, and necessary load reductions predicted by the model are sufficient to achieve the in lake standards.

As discussed elsewhere in this report, the nutrient TMDL for Big Elk Lake is used as a surrogate for the turbidity TMDL in the Elk River. As such, the MOS for the Big Elk Lake nutrient TMDL also applies for the Turbidity TMDL. However, the data shows that based on the relationship between in-stream turbidity in lake water quality, using the lake nutrient TMDL for Big Elk Lake provides an additional MOS for the turbidity TMDL. Correlations between TP, Chlorophyll-a, and in stream VSS and turbidity indicate that a reduction in chlorophyll-a concentrations of 25 to 49% is needed to meet the standard. The target water quality goals provides a reduction on the order of 57%. Therefore, the turbidity TMDL will be achieved in advance of the lake nutrient TMDL for Big Elk Lake.

For the bacteria TMDL an explicit (quantified variability across the flow regime) margin of safety has been used. The explicit MOS of 16% was calculated from the distribution of available data as discussed in the previous section. This MOS accounts for the variation in flow for each flow regime as well as the distribution of recorded *E.Coli* concentrations.

6.3 RESERVE CAPACITY

The subwatersheds to the listed reach are located within Benton and Sherburne Counties. Both counties have experienced rapid growth due to the proximity to two of the fastest growing population centers in the state, St. Cloud and the Twin Cities.

In 2007, the Minnesota State Demographic Center reported that the population in the County is expected to double by the year 2030. The city of Becker, which is located in a subwatershed which directly drains to the listed reach, experienced a 54% growth over 6 years, the 2006 population reported by the Minnesota Office of the State Demographer was 4,105 compared to the 2000 census population of 2,673. Although Sherburne County was experiencing rapid residential growth, due to recent economic conditions development has slowed and the above population estimates may have been over-projected. The Sherburne County auditor has estimated the 2030 population to be only a 55.8% increase from the current estimated population. Projected growth in the county is limited to urban areas and the Land Use Plan protects productive farmlands and agri-business operations. Housing in agricultural areas is limited to 1 housing unit per 40 acres.

Benton County is also one of the fastest growing regions in the state. The Minnesota Department of Employment and Economic Development reported a population increase of 29% from 1990-2005 with a projected growth of another 32% by 2020 with a population of 51,490 people. The majority of the area within the subwatersheds to the listed reach is designated as agricultural land use. The 2005 Benton County Land Use Plan increased the number of allowable housing units in agricultural land use areas from 1 per 40 acres (set in 1999) to 4 per 40 acres to allow for growth. The Land Use Plan designates urban growth areas around the cities of Foley and Gilman within the subwatershed to the listed reach. These areas are targeted for annexation and municipal utilities. Development has slowed due to recent economic conditions and literature available regarding growth in Benton County has yet to be updated. The growth rates discussed above may have been over projected, and while future growth is inevitable in Benton County, it may not occur as rapidly as predicted in the future as it did in the early 2000s.

Load reduction targets to meet nutrient water quality goals in Mayhew and Big Elk Lakes are already aggressive, and so reserve capacity is not available given the current phosphorus budgets and required load reductions. As a result, planned developments must be undertaken to avoid increasing phosphorus loads to the lakes over existing conditions, and to decrease phosphorus loads where possible. The phosphorus load reductions required to meet water quality goals make stormwater BMPs and low impact development in these growth areas necessary. It will be one of the most cost effective methods to limit watershed phosphorus loads. Further, there are no planned WWTP expansions in the Mayhew or Big Elk Lake watersheds at this time, and it is unlikely given current MPCA policy that a WWTP would be permitted for an expansion if that expansion meant increased phosphorus discharges to either lake. This means that reserve capacity for growth is essentially zero with respect to phosphorus, in that nutrient export will need to decline with development rather than increase. This does not mean no growth, however growth must be accomplished without increasing phosphorus loads to impaired waters.

Growth within the urban areas of Benton and Sherburne Counties will result in bacteria from humans being treated at waste water treatment plants which already contribute to the listed reach of the Elk River. These WWTFs currently limit the concentration of bacteria discharged from the system and the quantity of discharge may increase with population growth. The Becker WWTF was recently expanded to increase treatment capacity however discharge concentration limits are still at the current permitted level (based on 845,000 GPD). The wasteload allocation for the TMDL was adjusted to account for the expansion as future permits may increase the allowable discharge limits.

Growth in the rural areas of the watershed will result in the installation of new SSTS systems to treat bacteria, since straight pipe septic systems are illegal. New SSTS systems will effectively treat bacteria and will not contribute to the bacteria load in the watershed. Changes in the human population should not change the load allocations provided in this TMDL. Additionally, loads from septic systems are not allowed under current law and it is unlikely that future sources will be permitted to discharge into the listed reach. Consequently no provisions for changes in human population have been identified in the load allocation of the TMDL.

Another source of *E.Coli* in the watershed is livestock. Some new large feedlot operations may occur in the future within the watershed. However, livestock facilities and practices are heavily scrutinized and often are permitted, especially in the case of new or expanding operations. Consequently, changes in animal numbers, practices, or facility size and type, will be associated with permits and mitigation practices to minimize export of *E.Coli*. Potential increases in *E.Coli* from livestock practices in the watershed should be mitigated. However, it is likely that the existing agricultural practices in the watershed will continue in their current manner. A provision with respect for *E.Coli* concentrations for an increase in livestock in the watersheds is not necessary at this time.

6.4 REASONABLE ASSURANCE

When establishing a TMDL, reasonable assurances must be provided demonstrating the ability to reach and maintain water quality endpoints. Several factors control reasonable assurances including a thorough knowledge of the ability to implement BMPs as well as the overall effectiveness of the BMPs. This TMDL establishes load reduction goals in the Elk River watershed so that impaired waters can meet state standards.

The Elk River Watershed Association has the jurisdictional capabilities to implement TMDLs. They have existing watershed programs targeting water quality improvements. The necessary load reductions will amount to an expansion of the existing programs, leveraging to the maximum extent in place programs and introduction of new projects, and programs as identified in the implementation plan. Further, TMDL implementation will take place on an iterative basis, with interim evaluations and milestones so that implementation course corrections based on annual monitoring and reevaluation can adjust the strategies to meet the standards.

6.5 SEASONAL VARIATION

The daily load reduction targets for the nutrient TMDLs are calculated from the current phosphorus budget for each lake. The budget is an average of several years of monitoring data and includes both wet years and dry years to account for annual variation. The BMPs to address excess loads to the lakes will be designed for average conditions; however, the performance will be protective of all conditions. In dry years the watershed load will be naturally lower allowing internal loading to comprise a larger portion of the overall phosphorus budget. Consequently, averaging across several modeled years addresses annual variability in lake loading.

Seasonal variation is accounted for through the use of annual loads in Mayhew Lake and seasonal loads in Big Elk Lake and developing targets for the summer period where the frequency and severity of nuisance algal growth will be the greatest. Although the critical period is the summer, lakes are not sensitive to short term changes in water quality, rather lakes respond to long-term changes such as changes in the annual load. Therefore the seasonal variation is accounted for in annual loads. Additionally by setting the TMDL to meet targets established for the most critical period (summer), the TMDL will inherently be protective of water quality during all other seasons.

Seasonal variation for the bacteria TMDL was addressed in accounting of *E.Coli* sources, and the use of the flow duration curve. *E.Coli* sources potentially available for runoff were varied seasonally to reflect the seasonality of practices in manure application and handling. Additionally, load and wasteload allocations were varied seasonally to reflect changes in stream loads and concentrations among seasons. The winter season is not included because the standard is for April 1 through October 31.

7.0 Public Participation

Public participation is critical to the process of implementing these TMDLs to meet water quality standards. The public participation conducted for this TMDL was an extension of work already underway by stakeholders concerned over declining water quality prior to the TMDL framework.

In 1994, a Joint Powers Board, the Elk River Watershed Association (ERWSA), was formed as a result of local water planning efforts in Sherburne and Benton Counties. Concerned citizens identified the water quality of the Elk River and lakes in the Elk River Watershed as priorities for improvement. Thus, the two Counties determined that a watershed approach would be the most effective way to improve water quality. The Joint Powers Board was formed by the Sherburne and Benton SWCDs and Counties for the purpose of coordinating efforts within the Elk River Watershed.

Public participation is underway and to date, has been addressed through multiple TAC meetings, articles in watershed association newsletters, informational pieces at annual watershed association meetings, newspaper articles, and one public meeting at the local town hall to inform citizens about impaired waters and the TMDL process. Public input has been instrumental in guiding the decision making process and has been critical to the establishment of an effective plan that will guide the listed water bodies and the Elk River watershed's future.

8.0 References

Barr Engineering Company, February 2004 (updated in 2007). Phosphorus Sources to Minnesota Watersheds. Prepared for Minnesota Pollution Control Agency.

EPA 440/5-80-011, "Modeling Phosphorus Loading and Lake Response Under Uncertainty: A Manual and Compilation of Export Coefficients".

Dexter, M.H., editor. 2005. Status of Wildlife Populations, Fall 2005. Unpup. Rep., Division of Fish and Wildlife, Minn. Dept. Nat. Res, St. Paul, MN. 270pp.

Gerbert, W.A, Graczyk, D.J., and Krug, W.R., 1987 “Average Annual Runoff in the United States, 1951-1980” Edition 1.0 US Geological Survey Web Site

Heiskary, S.A. and C.B. Wilson. 2005. Minnesota lake water quality assessment report: Developing nutrient criteria. Minnesota Pollution Control Agency. St. Paul, Minnesota.

Heiskary, S.A. and C.B. Wilson. 2008. Minnesota’s approach to lake nutrient criteria development. Lake Reserv. Manage. 24:282-297.

Heiskary, S.A. and W.W. Walter, Jr. 1988. Developing Phosphorus Criteria for Minnesota Lakes. Lake and Reservoir Manage., 1988 4(1): 1-9.

Helgesen, J.O., et al., 1975. Water Resources of the Mississippi and Sauk Rivers Watershed, Central Minnesota. HA-534, U.S. Geological Survey.

Landon, M.K., and Delin, G.N., 1995. Ground-Water Quality in Agricultural Areas, Anoka Sand Plain, Central Minnesota, 1984-90. WRI Report 95-4024, U.S. Geological Survey.

McCollor and Heiskary. 1993. “Selected Water Quality Characteristics of Minimally Impacted Streams from Minnesota’s Seven Ecoregions.” Minnesota Pollution Control Agency Water Quality Division

Midje, H.C., et al. c. 1966. “Hydrology Guide for Minnesota”. U.S. Department of Agriculture Soil Conservation Service.

Minnesota DNR, Fall 2005. “Status of Wildlife Populations” http://www.dnr.state.mn.us/publications/wildlife/populationstatus2005.html

Minnesota DNR, 1996. “Minnesota Land Use and Land Cover- A 1990’s Census of the Land”

Minnesota Pollution Control Agency, March 2007 *Turbidity TMDL Protocols and Submittal Requirements*

Minnesota Pollution Control Agency, 2009 *Bacteria TMDL Protocols and Submittal Requirements*

Minnesota Pollution Control Agency, March 2007 *Lake Nutrient TMDL Protocols and Submittal Requirements*

Nurnberg, G. K. 2005. Quantification of Internal Phosphorus Loading in Polymictic Lakes. *SIL, Verh. Internat. Verein. Limnol.* vol. 29.

Nurnberg, G. K. 1995. Quantifying anoxia in lakes. *Limnol. Oceanogr*. vol. 40, no. 6

Nurnberg, G. K. 1988. Prediction of Phosphorus Release Rate from Total and Reductant-Soluble Phosphorus in Anoxic Lake Sediments. *Canadian Journal of Fisheries and Aquatic Sciences*. vol 45.

MPCA 2004 "Guidance Manual for Assessing the Quality of Minnesota Surface Waters"

MPCA, May 1999. Phosphorus in Minnesota's Ground Water. Minnesota Pollution Control Agency information sheet.

Spatial Climate Analysis Services, 2000. Oregon State University. "http:www.ocs.orst.edu/pub/map/precipitation/Total/States/MN/

Stumm, W., and Stumm-Zollinger, E., 1972. The Role of Phosphorus in Eutrophication. Chapter 2 in Mitchell, R., ed., 1972, *Water Pollution Microbiology*, Wiley-Interscience, New York.

USDA, c. 1966. Hydrology Guide for Minnesota. U.S. Department of Agriculture, Soil Conservation Service, St. Paul