Nutrient and Dissolved Oxygen TMDLs for Crooked Lake in McLean County, North Dakota

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1.0 INTRODUCTION AND DESCRIPTION OF THE WATERSHED

Crooked Lake, located 3 miles north of Turtle Lake, ND (Figure 1), is a 375 acre multipurpose natural lake formed as the result of glacial melting and outwash (NDDoH, 1993).

The recreational opportunities on Crooked Lake include fishing, boating, hiking, and swimming. Crooked Lake's recreational area is public friendly with a picnic area, outdoor toilets, boat ramp, and parking (Figure 2). Public use of Crooked Lake is heavy in the summer, depending on water quality and the productivity of the fishery (NDDoH, 1993).

Table 1. General Characteristics of Crooked Lake and the Crooked Lake Watershed.

Legal Name	Crooked Lake
Major Drainage Basin	Missouri River Basin
Nearest Municipality	Turtle Lake, North Dakota
Assessment Unit ID	ND-10130101-003-L_00
County Location	McLean County
Physiographic Region	Missouri Coteau
Watershed Area	34,988 acres
Surface Area	375 acres
Average Depth	9.2 feet
Maximum Depth	17.6 feet
Tributaries	Unnamed Tributary
Type of Waterbody	Natural – glacial formed
Dam Type	None
Fishery Type	Northern Pike, Walleye, Bluegill, Smallmouth bass, Perch

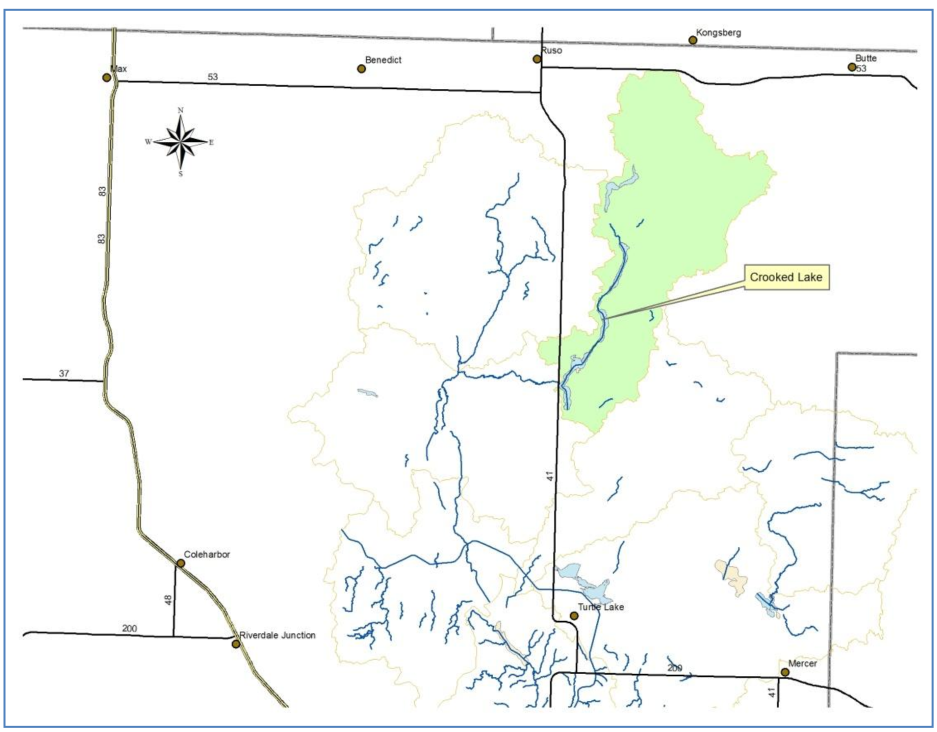

Figure 1. General Location of the Crooked Lake Watershed.

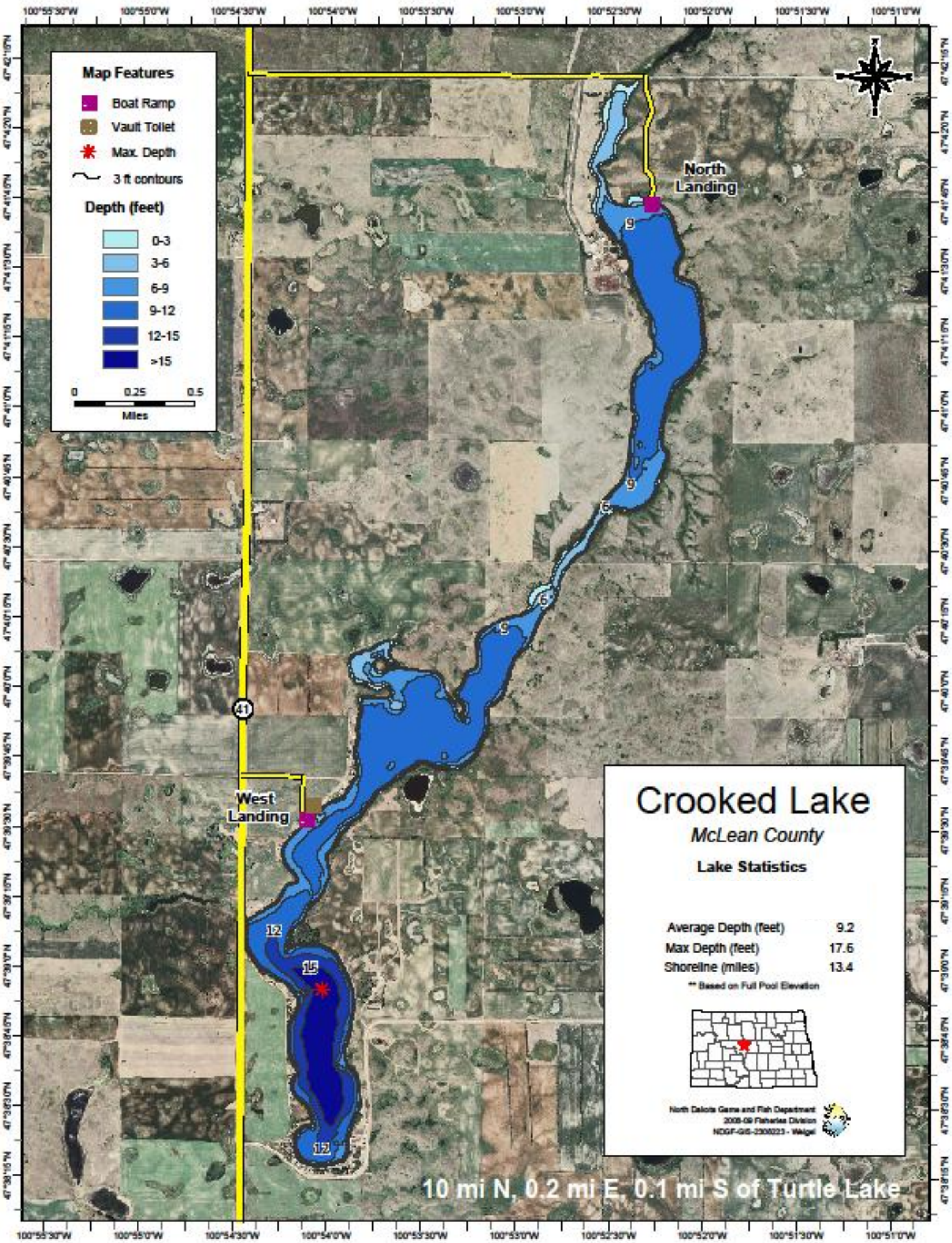

Figure 2. North Dakota Game and Fish Contour Map of Crooked Lake.

Crooked Lake and its watershed lie entirely within the Missouri Coteau level IV ecoregion (42a). The rolling hummocks of the Missouri Coteau enclose countless wetland depressions or potholes. During its slow retreat, the Wisconsinan glacier stalled on the Missouri escarpment for thousands of years, melting slowly beneath a mantle of sediment to create the characteristic pothole topography of the Missouri Coteau. The wetlands of the Missouri Coteau and the neighboring prairie pothole region are major waterfowl production areas in North America. Land use on the Missouri Coteau is a mixture of tilled agriculture in flatter areas and grazing land on steeper slopes (USGS, 2006).

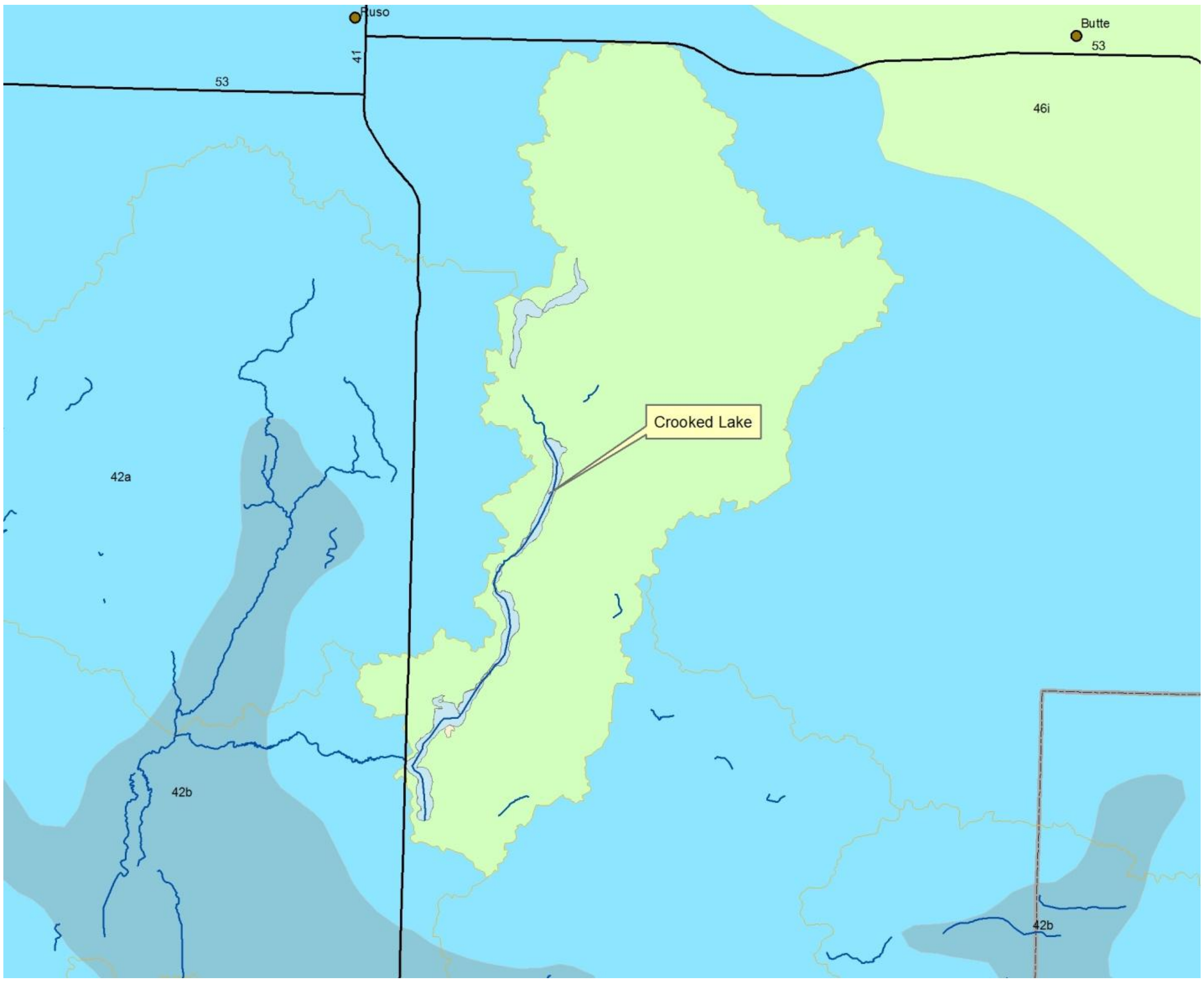

Figure 3. Level IV Ecoregions in the Crooked Lake Watershed.

1.1 Clean Water Act Section 303(d) Listing Information

As part of the 2012 Section 303(d) List of Impaired Waters Need Total Maximum Daily Loads (i.e., 2012 TMDL List), the North Dakota Department of Health (NDDoH) has assessed Crooked Lake as "fully supporting, but threatened" (i.e., impaired) for "fish and other aquatic biota" (i.e., aquatic life) and recreation uses (NDDoH, 2012). It should be noted that this assessment was first done for the 1998 Section 303(d) listing cycle using the 1991-1992 LWQA total phosphorus data as the primary trophic status indicator (Table 2). As described in the 2012 TMDL list, the causes of the aquatic life use impairment were described as "nutrient/eutrophication/biological indicators", and "low dissolved oxygen", while the cause of the recreation use impairment was described as only "nutrient/eutrophication/biological indicators." North Dakota's 2012 TMDL list did not provide information on any potential sources of these impairments. This TMDL report addresses both the aquatic life and recreation impairments caused by "nutrient/eutrophication/biological indicators" and the aquatic life impairment caused by "low dissolved oxygen."

Crooked Lake has been classified as a Class 3 warm water fishery, "Waters capable of supporting natural reproduction and growth of warm water fishes (e.g., largemouth bass and bluegill) and associated aquatic biota. Some cool water species may also be present." (NDDoH, 2011).

Table 2. Crooked Lake Section 303(d) Listing Information (NDDoH, 2012).

Assessment Unit ID	ND-10130101-003-L_00
Waterbody Name	Crooked Lake
Class	Class 3, Warm water fishery
Impaired Uses	Fish and Other Aquatic Biota, Recreation (Fully supporting, but threatened)
Causes	Nutrient/Eutrophication Biological Indicators and Low Dissolved Oxygen
Priority	High
First Appeared on 303(d) list	1998

1.2 Land Use/Land Cover

Land use in the Crooked Lake watershed is primarily agricultural. According to the 2010 National Agricultural Statistical Service (NASS) land survey data, approximately 57 percent of the the contributing watershed is pasture/grassland, 19 percent active cropland, 16 percent water/wetlands, three (3) percent developed/open space, and one (1) percent forest, and three (3) percent in other land uses. The majority of the crops grown consist of spring wheat, flax, sunflower, canola, peas, and durum wheat (Figure 4).

1.3 Climate and Precipitation

McLean County has a subhumid climate characterized by warm summers with frequent hot days and occasional cool days. Winters are very cold influenced by blasts of arctic air surging over the area. Precipitation occurs primarily during the warm period and is normally heavy in late spring and early summer. Total average annual precipitation for McLean County is about 17.13 inches. Average seasonal snowfall is approximately 35 inches. Figure 5 shows the average monthly precipitation for McLean County from 1912-2011.

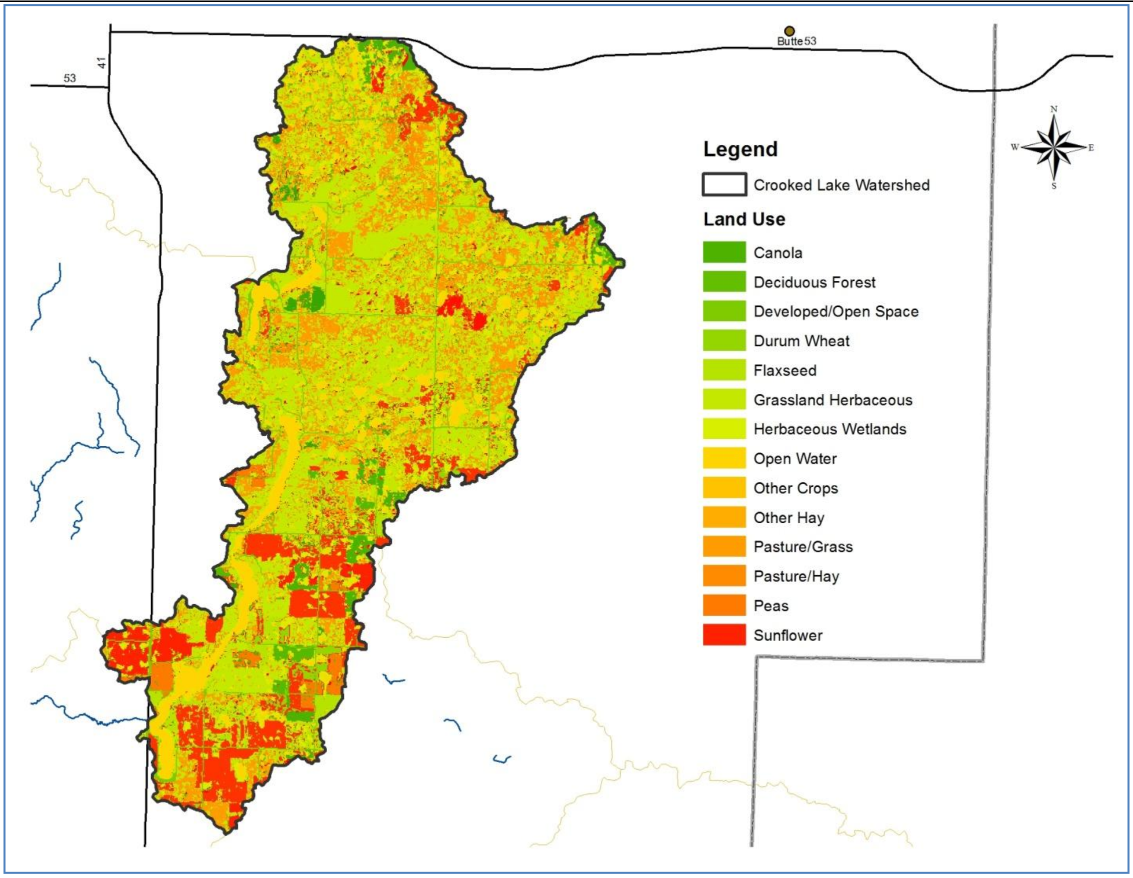

Figure 4. Crooked Lake Watershed Land Use Map (Based on the 2010 National Agricultural Statistical Survey).

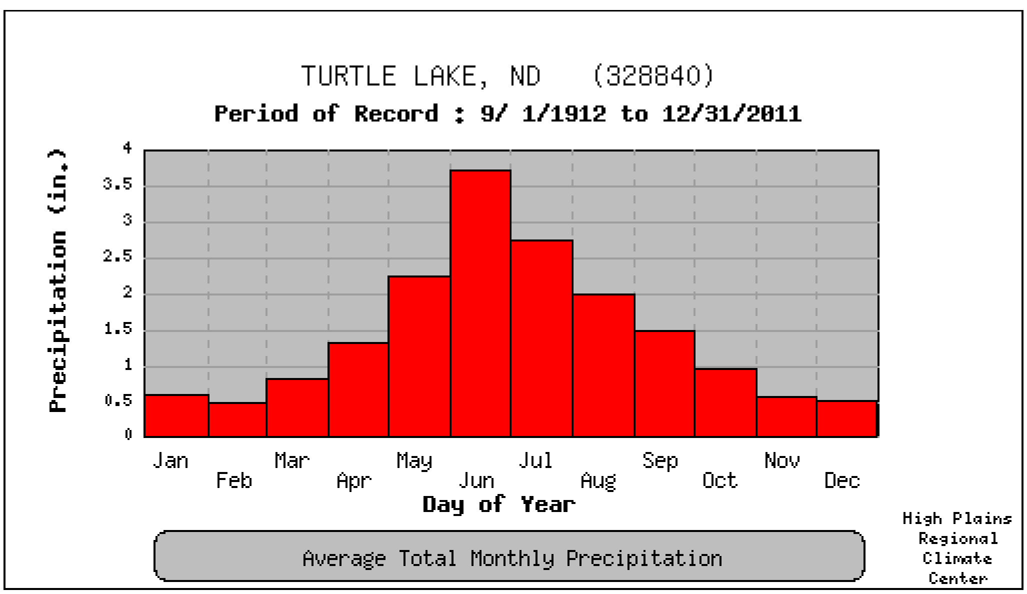

Figure 5. Average Total Monthly Precipitations at Turtle Lake, North Dakota from 1912-2011 (Data from the High Plains Regional Climate Center located at Turtle Lake, ND).

1.4 Available Water Quality Data

1.4.1 1991-1992 Lake Water Quality Assessment Project

In the early 1990's through a grant from the EPA Clean Lakes Program the NDDoH conducted a Lake Water Quality Assessment Project (LWQA) on 66 lakes and reservoirs in the state. The objective of the LWQA project was to describe the general physical and chemical condition of the state's lakes and reservoirs (NDDoH, 1993).

In cooperation with the North Dakota Game and Fish Department, lakes and reservoirs were targeted based on specific criteria. Those criteria consisted of geographic distribution, local and regional significance, fishing and recreational potential and relative trophic condition. Lakes received the highest priority if they had insufficient historical monitoring information (NDDoH, 1993).

Crooked Lake was one of the reservoirs targeted for the 1991-1992 LWQA. As such, monitoring consisted of two samples collected in the summer of 1991 and one during the winter of 1992. The samples were collected at one site located in the deepest area of the lake. The 1991-1992 LWQA Project characterized Crooked Lake as having mean surface concentration of total phosphorus of 0.10 mg/L, which exceeded the State's guideline goal for lake maintenance and improvement concentration of 0.02 mg/L. Nitrate + nitrite as N exhibited a volume weighted mean concentration of 0.008 mg/L, which suggests Crooked Lake was a nitrogen limited waterbody.

1.4.2 2010-2011 Crooked Lake TMDL Development and Watershed Assessment Project

The McLean County Soil Conservation District (SCD) conducted a TMDL development and watershed assessment of Crooked Lake from 2010-2011. Sampling was conducted at one inlet site (385552), at the outlet from Crooked Lake (385554), and at two in-lake sites located in the north basin (385553) and in the south basin (381030). (Table 3 and Figure 6).

Table 3. General Information for Water Sampling Sites for Crooked Lake.

Sample Site	Site ID	Dates Sampled		Latitude	Longitude
		Start	End		
Stream Sites					
Inlet	385552	May 2010	September 2011	47.70326	-100.87261
Outlet	385554	May 2010	September 2011	47.65276	-100.90787
Lake Sites					
North Site	385553	May 2010	September 2011	47.691	-100.87125
Deepest	381030	May 2010	September 2011	47.64673	-100.9002

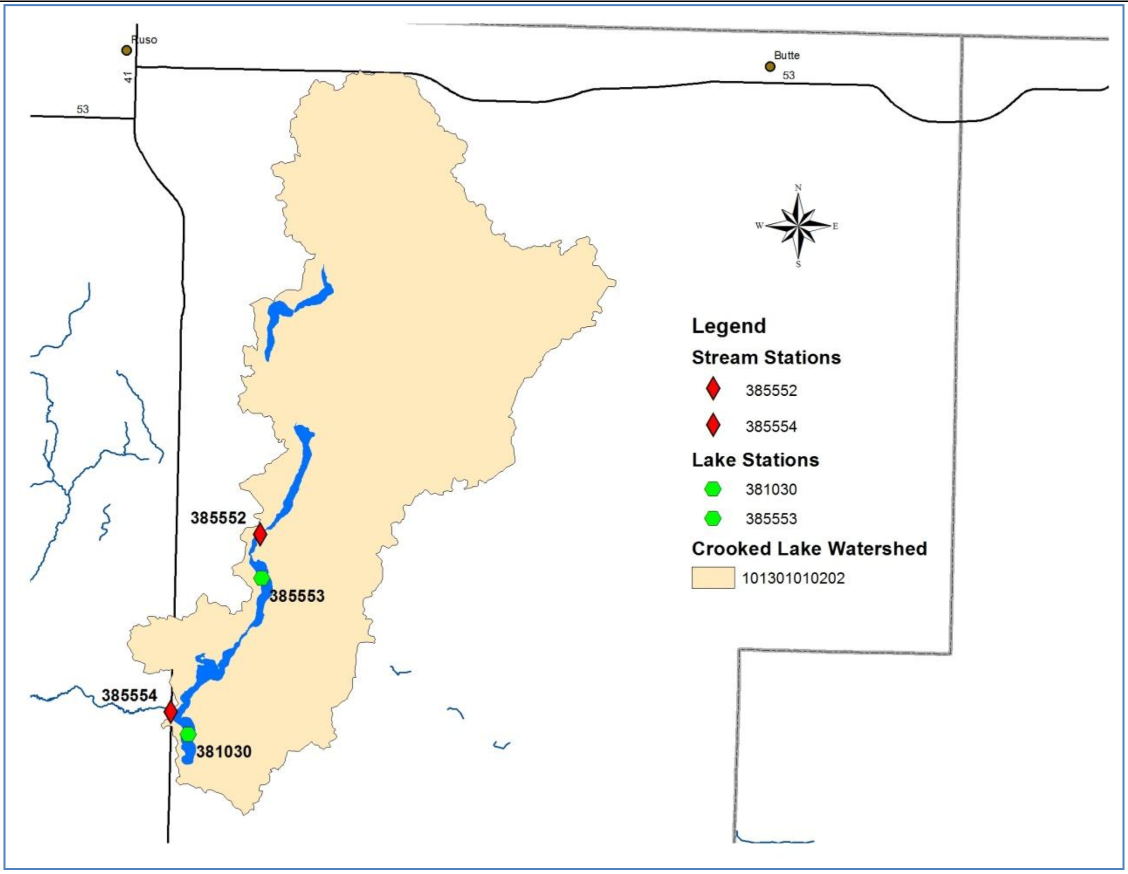

Figure 6. Stream and Lake Sampling Sites for Crooked Lake.

Stream Monitoring

Sampling frequency for the inlet and outlet sampling sites was stratified to coincide with the typical hydrograph for the region. This sampling design resulted in more frequent samples collected during spring and early summer, typically when stream discharge is greatest, and less frequent samples collected during the summer and fall. Sampling was discontinued during the winter ice cover period. Stream sampling was also terminated if the stream stopped flowing. If the stream began to flow again, water quality sampling was reinitiated.

Lake Monitoring

In order to accurately account for spatial and temporal variation in lake water quality, the lake was sampled at two locations twice per month during the open water season and monthly under ice cover conditions.

The McLean County SCD followed the methodology for water quality sampling found in the Quality Assurance Project Plan (QAPP) for the Turtle Creek, Crooked/Brush Lake TMDL Development and Watershed Assessment Project (NDDoH, 2010).

1.4.3 Water Quality Data

Water quality was monitored by the McLean County SCD in Crooked Lake at the north basin site (385553) and the south basin site (381030) between May 2010 and September 2011. Table 4 shows a summary of the resulting data used to develop the FLUX and BATHTUB models.

Table 4. Average 2010-2011 Growing Season Total Phosphorus, Total Nitrogen, Chlorophyll-a, and Secchi Disk Transparency Data for Sites 385553 and 381030.

Statistic	TP (µg/L)	TN (mg/L)	Chlorophyll-a (µg/L)	Secchi Depth (m)
n	66	66	28	18
Average	49.51	1.278	21.42	1.04

Dissolved oxygen results for sites 385553 and 381030 are presented in Figures 7 and 8. With the exception of two measurements taken near the lake's bottom in July and September 2011, all measurements were above the state's dissolved oxygen standards of 5 mg/L.

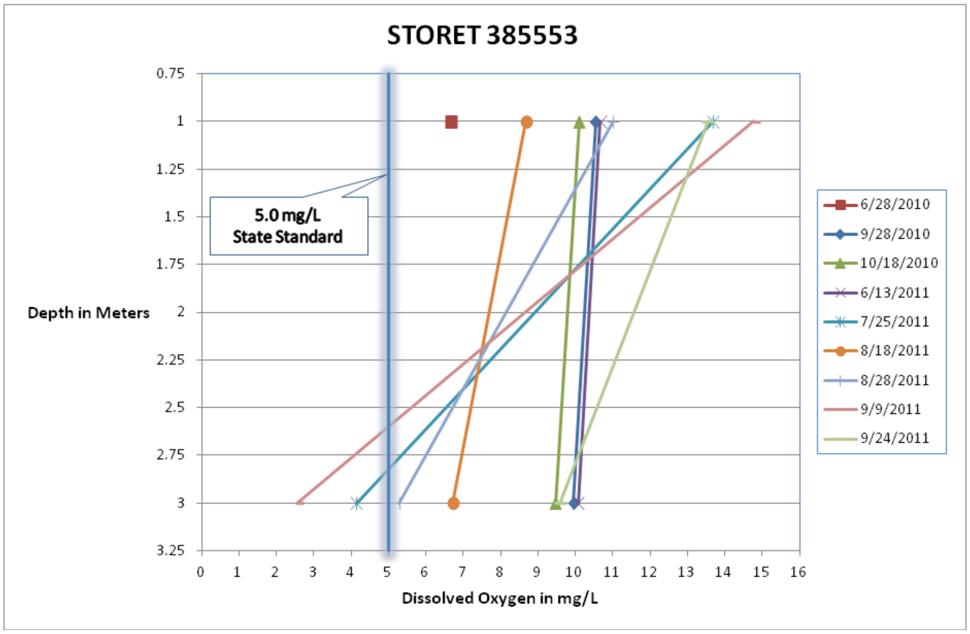

Figure 7. Dissolved Oxygen Profiles for North Basin Site 385553.

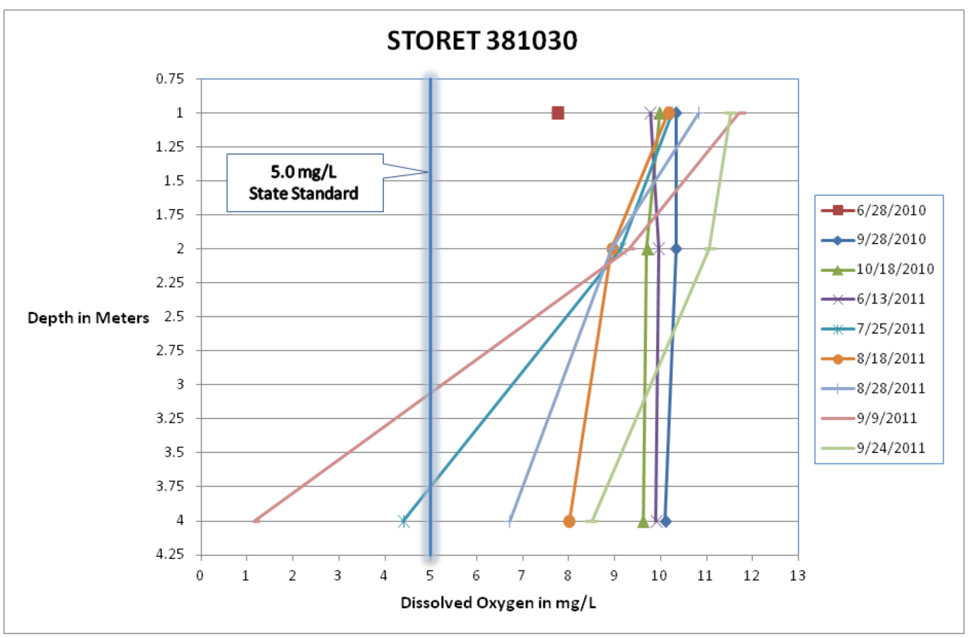

Figure 8. Dissolved Oxygen Profiles for South Basin Site 381030.

2.0 WATER QUALITY STANDARDS

The Clean Water Act requires that Total Maximum Daily Loads (TMDLs) be developed for waters on a state's Section 303(d) list. A TMDL is defined as "the sum of the individual wasteload allocations for point sources and load allocations for nonpoint sources and natural background" such that the capacity of the waterbody to assimilate pollutant loadings is not exceeded. The purpose of a TMDL is to identify the pollutant load reductions or other actions that should be taken so that impaired waters will be able to attain water quality standards. TMDLs are required to be developed with seasonal variations and must include a margin of safety that addresses the uncertainty in the analysis. Separate TMDLs are required to address each pollutant or cause of impairment (i.e., nutrients, sediment).

2.1 Narrative Water Quality Standards

The NDDoH has set narrative water quality standards, which apply to all surface waters in the state. The narrative standards pertaining to nutrient impairments are listed below (NDDoH, 2011).

- All waters of the state shall be free from substances attributable to municipal, industrial, or other discharges or agricultural practices in concentrations or combinations which are toxic or harmful to humans, animals, plants, or resident aquatic biota.

- No discharge of pollutants, which alone or in combination with other substances shall:
  1) Cause a public health hazard or injury to environmental resources;
  2) Impair existing or reasonable beneficial uses of the receiving waters; or
  3) Directly or indirectly cause concentrations of pollutants to exceed applicable standards of the receiving waters.

In addition to the narrative standards, the NDDoH has set a biological goal for all surface waters in the state. The goal states that "the biological condition of surface waters shall be similar to that of sites or waterbodies determined by the department to be regional reference sites," (NDDoH, 2011).

2.2 Numeric Water Quality Standards

Crooked Lake is classified as a Class 3 warm water fishery. Class 3 fisheries are defined as waterbodies "capable of supporting natural reproduction and growth of warm water fishes (i.e. largemouth bass and bluegill) and associated aquatic biota. Some cool water species may also be present" (NDDoH, 2011). All classified lakes in North Dakota are assigned aquatic life, recreation, irrigation, livestock watering, and wildlife beneficial uses. The North Dakota State Water Quality Standards (NDDoH, 2011) state that lakes shall use the same numeric criteria as Class 1 streams, including the "interim guideline limit" for dissolved nitrate as N, of 1.0 mg/L and State guideline nutrient goals for lakes and reservoirs (Table 5).

Table 5. Numeric Standards Applicable for North Dakota Lakes and Reservoirs (NDDoH , 2011).

State Water Quality Standard	Parameter	Guidelines	Limit
Numeric Standard for Class I and Classified Lakes	Nitrates (dissolved)	1.0 mg/L	Maximum allowed[1]
	Dissolved Oxygen	5 mg/L	Daily Minimum[2]
Guidelines for Goals in a Lake Improvement or Maintenance Program	NO3 as N	0.25 mg/L	Goal
	PO4 as P	0.02 mg/L	Goal

[1] "Up to 10% of samples may exceed"
2 "Up to 10% of representative samples collected during any three year period may be less than this value provided that lethal conditions are avoided."

3.0 TMDL TARGETS

A TMDL target is the value that is measured to judge the success of the TMDL effort. TMDL targets should be based on state water quality standards, but can also include site-specific values when no numeric criteria are specified in the standard. The following sections summarize water quality targets for Crooked Lake based on its beneficial uses. When the specific target is met, then the reservoir will meet the applicable water quality standards, including its designated beneficial uses.

3.1 TSI Target Based on Chlorophyll-a

The state's narrative water quality standards (see Section 2.1) form the basis for aquatic life and recreation use assessment for Section 305(b) reporting and Section 303(d) TMDL listing. In the case of this TMDL, the state's narrative water quality standards also form the basis for setting the TMDL target. State water quality standards contain narrative criteria that require lakes and reservoirs to be "free from" substances "which are toxic or harmful to humans, animals, plants, or resident aquatic biota" or are "in sufficient amounts to be unsightly or deleterious." Narrative standards also prohibit the "discharge of pollutants" (e.g., organic enrichment, nutrients, or sediment), "which alone or in combination with other substances, shall impair existing or reasonable beneficial uses of the receiving waters."

The chlorophyll-a trophic status indicator is used by the NDDoH as the primary means to assess whether a lake or reservoir is meeting the narrative standards (NDDoH, 2011). Trophic status is a measure of the productivity of a lake or reservoir and is directly related to the level of nutrients (i.e., phosphorus and nitrogen) entering the lake or reservoir from its watershed and/or from the internal recycling of nutrients. Highly productive lakes, termed "hypereutrophic," contain excessive phosphorus and are characterized by dense growths of weeds, blue-green algal blooms, low transparency, and low dissolved oxygen (DO) concentrations. These lakes experience frequent fish kills and are generally characterized as having excessive rough fish populations (carp, bullhead, and sucker) and poor sport fisheries (Table 6). Due to the frequent algal blooms and excessive weed growth, these lakes are also undesirable for recreational uses such as swimming and boating.

Table 6. Water Quality and Beneficial Use Changes That Occur as the Amount of Algae (expressed as Chlorophyll-a concentration) Changes Along the Trophic State Gradient (from Carlson and Simpson, 1996).

TSI Score	Chlorophyll-a (µg/L)	Secchi Disk Transparency (m)	Total Phosphorus (µg/L)	Attributes	Fisheries & Recreation
<30	<0.95	>8	<6	**Oligotrophy**: Clear water, oxygen throughout the year in the hypolimnion	Salmonid fisheries dominate
30-40	0.95-2.6	8-4	6-12	Hypolimnia of shallower lakes may become anoxic	Salmonid fisheries in deep lakes only
40-50	2.6-7.3	4-2	12-24	**Mesotrophy**: Water moderately clear; increasing probability of hypolimnetic anoxia during summer	Hypolimnetic anoxia results in loss of salmonids. Walleye may predominate
50-60	7.3-20	2-1	24-48	**Eutrophy**: Anoxic hypolimnia, macrophyte problems possible	Warm-water fisheries only. Bass may dominate.
60-70	20-56	0.5-1	48-96	Blue-green algae dominate, algal scums and macrophyte problems	Nuisance macrophytes, algal scums, and low transparency may discourage swimming and boating.
70-80	56-155	0.25-0.5	96-192	**Hypereutrophy**: (light limited productivity). Dense algae and macrophytes	
>80	>155	<0.25	192-384	Algal scums, few macrophytes	Rough fish dominate; summer fish kills possible

Mesotrophic and eutrophic lakes, on the other hand, generally have lower phosphorus concentrations, low to moderate levels of algae and aquatic plant growth, high transparency, and adequate DO concentrations throughout the year. Mesotrophic lakes do not experience algal blooms, while eutrophic lakes may occasionally experience algal blooms of short duration, typically a few days to a week (Table 7).

Therefore, for purposes of this TMDL report, it can be concluded that hypereutrophic lakes do not fully support a sustainable sport fishery and are limited in recreational uses, whereas eutrophic and mesotrophic lakes fully support both aquatic life and recreation use.

Due to the relationship between trophic status indicators and the aquatic community (as reflected by the fishery) or between trophic status indicators and the frequency of algal blooms, trophic status is an effective indicator of aquatic life and recreation use support in lakes and reservoirs (Table 7).

While the three trophic state indicators, chlorophyll-*a*, Secchi disk transparency, and total phosphorus, used in Carlson's TSI each independently estimate algal biomass and should produce the same index value for a given combination of variable values, often they do not. While transparency and phosphorus may co-vary with trophic state, many times the changes in observed in a lake's transparency are not caused by changes in algal biomass, but may be due to particulate sediment. Total phosphorus may or may not be strongly related to algal biomass due to light limitation and/or nitrogen and carbon limitation. Therefore, neither transparency nor phosphorus is an independent estimator of trophic state (Carlson and Simpson, 1996). For these reasons, the NDDoH gives priority to chlorophyll-*a* as the primary trophic state indicator because this variable is the most accurate of the three at predicting algal biomass (Carlson, 1980).

The same conclusion was also reached by a multi-state project team consisting of lake managers and water quality specialists from North Dakota, South Dakota, Montana, Wyoming and EPA Region 8. This group concluded that for lakes and reservoirs in the plains region of EPA Region 8, an average growing season chlorophyll-a concentration of 20 µg/L or less should be the basis for nutrient criteria development for lakes and reservoirs in the plains region (including North Dakota) and that this chlorophyll-a target would be protective of all of a lake or reservoir's beneficial uses, including recreation and aquatic life (Houston Engineering, 2011). The report, prepared by Houston Engineering, also concluded that most lakes and reservoirs in the plains region typically have high total phosphorus concentrations, but maintain relatively low productivity, and that due to this condition, chlorophyll-a is a better measure of a lake or reservoirs trophic status than is total phosphorus (Houston Engineering, 2011).

Water quality data collected in the lake in 2010 and 2011 showed an average chlorophyll-a concentration of 21.42 µg/l, an average total phosphorus concentration of 49.51 µg/l, an average Secchi Depth of 1.04 meters, and an average total nitrogen concentration of 1,277 µg/l. Based on these data, Crooked Lake is generally assessed as a eutrophic lake (Table 7, Figure 9).

Table 7. Carlson's Trophic State Indices for Crooked Lake.

Parameter	Relationship	Units	TSI Value	Trophic Status
Chlorophyll-a	TSI (Chl-a) = 30.6 + 9.81[ln(Chl-a)]	µg/L	60.66	Eutrophic
Total Phosphorus (TP)	TSI (TP) = 4.15 + 14.42[(ln(TP)]	µg/L	60.42	Eutrophic
Secchi Depth (SD)	TSI (SD) = 60 - 14.41[ln(SD)]	meters	59.47	Eutrophic
Total Nitrogen (TN)	TSI (TN) = 54.45 + 14.43[ln(TN)]	mg/L	57.59	Eutrophic

TSI < 30 - Oligotrophic (least productive) TSI 30-50 Mesotrophic
TSI 50-65 Eutrophic TSI > 65 - Hypereutrophic (most productive)

According to the phosphorus TSI value, Crooked Lake is a productive lake (eutrophic) trending towards hypereutrophic (Table 7). Carlson and Simpson (1996) suggest that if the phosphorus TSI value is equal to the chlorophyll-a and Secchi disk transparency TSI value, then algae dominates light attenuation as is the case with Crooked Lake (Table 8). Carlson and Simpson (1996) also state that a nitrogen index value might be a more universally applicable nutrient index than a phosphorus index, but it also means that a correspondence of the nitrogen index with the chlorophyll-a index cannot be used to indicate nitrogen limitation.

Table 8. Relationships Between TSI Variables and Conditions.

Relationship Between TSI Variables	Conditions
TSI(Chl) = TSI(TP) = TSI(SD)	Algae dominate light attenuation; TN/TP ~ 33:1
TSI(Chl) > TSI(SD)	Large particulates, such as *Aphanizomenon* flakes, dominate
TSI(TP) = TSI(SD) > TSI(CHL)	Non-algal particulates or color dominate light attenuation
TSI(SD) = TSI(CHL) > TSI(TP)	Phosphorus limits algal biomass (TN/TP >33:1)
TSI(TP) >TSI(CHL) = TSI(SD)	Algae dominate light attenuation but some factor such as nitrogen limitation, zooplankton grazing or toxics limit algal biomass.

As stated previously, the NDDoH has established an in-lake growing season average chlorophyll-a concentration goal of 20 µg/L for most lake and reservoir nutrient TMDLs, including this TMDL for Crooked Lake. This chlorophyll-a goal corresponds to a chlorophyll-a TSI of 60 which is in the eutrophic range and, as such, will be a trophic state sufficient to maintain both aquatic life and recreation uses of most lakes and reservoirs in the state, including Crooked Lake.

Through the use of a calibrated water quality model like BATHTUB (see Section 5.2), the average growing season TP load corresponding to an average growing season chlorophyll-a concentration of 20 µg/L can be estimated. For this TMDL, a 25 percent reduction in the observed total phosphorus load, or 127 kg, is estimated to be needed to achieve the TMDL goal for Crooked Lake.

3.2 Dissolved Oxygen TMDL Target

The North Dakota State Water Quality Standard for dissolved oxygen is "5 mg/L as a daily minimum", and where up to 10% of representative samples collected during any three year period may be less than this value provided that lethal conditions are avoided. This will be the dissolved oxygen TMDL target for Crooked Lake.

4.0 SIGNIFICANT SOURCES

There are no known point sources in Crooked Lake's contributing watershed. The pollutants of concern originate from non-point sources.

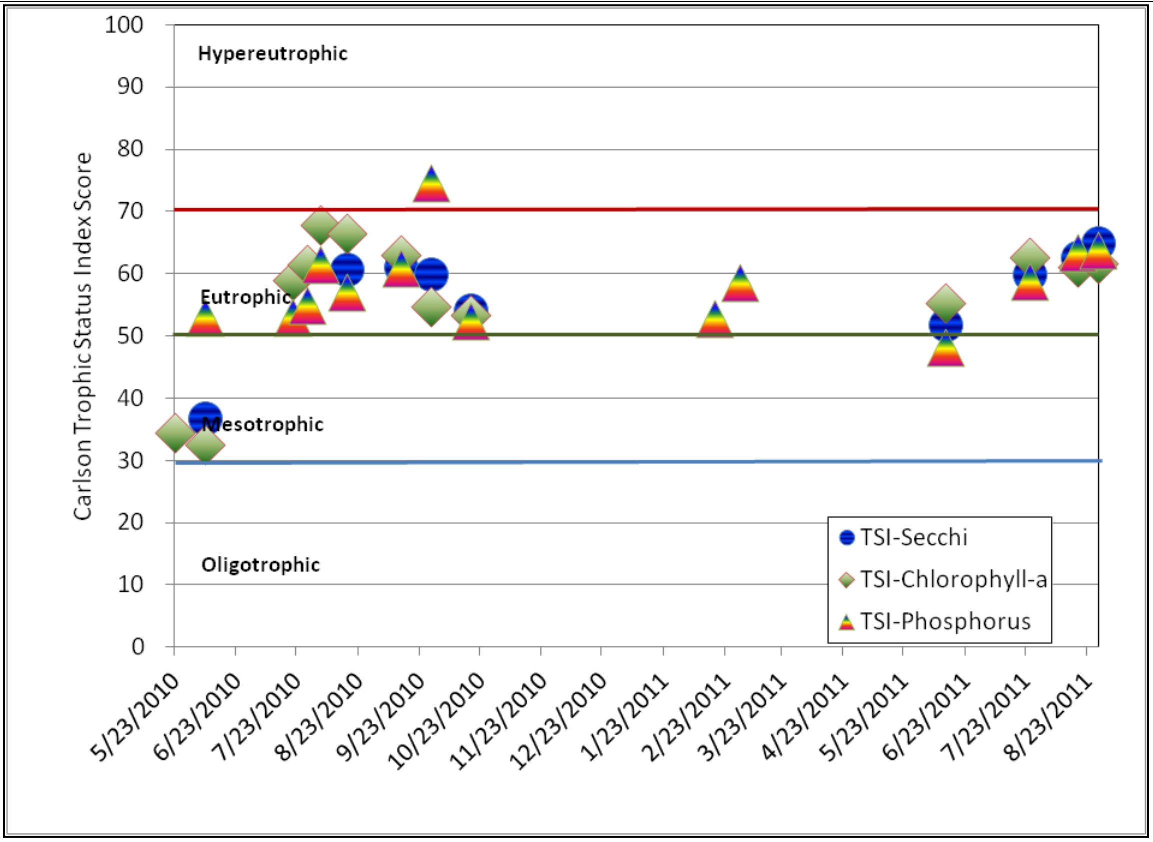

Figure 9. Temporal Distribution of Carlson's Trophic Status Index Scores for Crooked Lake (5/23/2010 though 9/24/2011).

5.0 TECHNICAL ANALYSIS

Establishing a relationship between in-stream water quality targets and pollutant source loading is a critical component of TMDL development. Identifying the cause-and-effect relationship between pollutant loads and the water quality response is necessary to evaluate the loading capacity of the receiving waterbody. The loading capacity is the amount of a pollutant that can be assimilated by the waterbody while still attaining and maintaining water quality standards. This section discusses the technical analysis used to estimate existing loads to Crooked Lake.

5.1 Tributary Load Analysis

To facilitate the analysis and reduction of tributary inflow and outflow water quality and flow data the FLUX program was employed. The FLUX program, developed by the US Army Corps of Engineers Waterways Experiment Station (Walker, 1996), uses six calculation techniques to estimate the average mass discharge or loading that passes through a given river or stream site. FLUX estimates loadings based on grab sample chemical concentrations and the continuous daily flow record. Load is therefore defined as the mass of a pollutant during a given time period (e.g., hour, day, month, season, year). The FLUX program allows the user, through various iterations, to select the most appropriate load calculation technique and data stratification scheme, either by flow or date, which will give a load estimate with the smallest statistical error, as represented by the coefficient of variation. Output from the FLUX program (Appendix A) is then provided as an input file to calibrate the BATHTUB eutrophication response model. For a complete description of the FLUX program the reader is referred to Walker (1996).

5.2 BATHTUB Trophic Response Model

The BATHTUB model (Walker, 1996) was used to predict and evaluate the effects of various nutrient load reduction scenarios on Crooked Lake BATHTUB performs steady-state water and nutrient balance calculations in a spatially segmented hydraulic network. The model accounts for advective and diffusive transport and nutrient sedimentation. Eutrophication related water quality conditions are predicted using empirical relationships previously developed and tested for reservoir applications.

The BATHTUB model is developed in three phases. The first two phases involve the analysis and reduction of the tributary and in-lake water quality data. The third phase involves model calibration. In the data reduction phase, the in-lake and tributary monitoring data collected as part of the project were summarized in a format which can serve as inputs to the model.

The tributary data were analyzed and reduced by the FLUX program. FLUX uses tributary inflow and outflow water quality and flow data to estimate average mass discharge or loading that passes a river or stream site using six calculation techniques. Load is therefore defined as the mass of a pollutant during a given unit of time. The FLUX model then allows the user to pick the most appropriate load calculation technique with the smallest statistical error. Output for the FLUX program is then used to calibrate the BATHTUB model.

The reservoir data were reduced in Excel using three computational functions. These include: 1) the ability to display concentrations as a function of depth, location, or date; 2) summary statistics (mean, median, etc.); and 3) evaluation of trophic status. The output data from the Excel program were then used to calibrate the BATHTUB model.

When the input data from FLUX and Excel programs are entered into the BATHTUB model the user has the ability to compare predicted conditions (model output) to actual conditions using general rates and factors. The BATHTUB model is then calibrated by combining tributary load estimates for the project period with in-lake water quality estimates. The model is termed calibrated when the predicted estimates for the trophic response variables are similar to observed estimates from the project monitoring data. BATHTUB then has the ability to predict total phosphorus concentration, chlorophyll-a concentration, and Secchi disk depth along with and the associated TSI scores as a means of expressing trophic response.

As stated above, BATHTUB can compare predicted vs. actual conditions. After calibration, the model then run to evaluate the effectiveness of a number of nutrient reduction alternatives including; (1) reducing externally derived nutrient loads; (2) reducing internally available nutrients; and (3) reducing both external and internal nutrient loads (See Appendix C for more detail).

BATHTUB modeled the trophic response of Crooked Lake. by reducing externally derived nutrient loads. External nutrient loads were addressed because they are known to cause eutrophication and because they are controllable through the implementation of watershed Best Management Practices (BMPs).

Predicted changes in Crooked Lake's trophic response were evaluated by reducing externally derived nutrient loads by 10, 25, 50, and 75 percent. These reductions were simulated in the model by reducing all species of phosphorus and nitrogen concentrations in the contributing tributary and other external delivery sources by 10, 25, 50, and 75 percent. Since there is no reliable means of estimating how much hydraulic discharge would be reduced through the implementation of BMPs, flow was held constant.

Table 9. Observed and Predicted Values for Selected Trophic Response Variables from a 10, 25, 50, and 75 Percent Reduction in External Phosphorus and Nitrogen Loading.

Variable	Observed	-10%	-25%	-50%	-75%
Total Phosphorus as P (µg/L)	49.51	47.75	45.11	40.72	36.33
Total Nitrogen as N (µg/L)	1276.63	1236.39	1176.41	1076.44	976.48
Chlorophyll-a (µg/L)	21.42	20.46	19.05	16.77	14.54
Secchi Disk Transparency (meters)	1.04	0.98	1.01	1.08	1.15
Carlson's TSI for Phosphorus	60.42	59.90	59.08	57.60	55.96
Carlson's TSI for Chlorophyll-a	60.66	60.21	59.51	58.26	56.86
Carlson's TSI for Secchi Disk	59.47	60.30	59.79	58.91	58.00

The model results indicate that with a 25% reduction in current total phosphorus loading, the mean growing season chlorophyll-a concentration would be reduced to 19.05 ug/L, which is below the TMDL target concentration of 20 ug/L. A 25% reduction in total phosphorus loading would also reduce the average growing season total phosphorus concentration to 45 ug/L and average Secchi disk transparency is estimated to be 1.01 meters (Table 9, Figure 9).

5.3 AnnAGNPS Watershed Model

The Annualized Agricultural NonPoint Source Pollution (AnnAGNPS) model was developed by the USDA Agricultural Research Service and Natural Resource Conservation Service (NRCS). The AnnAGNPS model consists of a system of computer models used to predict nonpoint source pollution (NPS) loadings within agricultural watersheds. The continuous simulation surface runoff model contains programs for: 1) input generation and editing; 2) "annualized" pollutant loading model; and 3) output reformatting and analysis.

The AnnAGNPS model uses batch processing, continual-simulation, and surface runoff pollutant loading to generate amounts of water, sediment, and nutrients moving from land areas (cells) and flowing into the watershed stream network at user specified locations (reaches) on a daily basis. The water, sediment, and chemicals travel throughout the specified watershed outlets. Feedlots, gullies, point sources, and impoundments are special components that can be included in the cells and reaches. Each component adds water, sediment, or nutrients to the reaches.

The AnnAGNPS model is able to partition soluble nutrients between surface runoff and infiltration. Sediment-attached nutrients are also calculated in the stream system.

Sediment is divided into five particle size classes (clay, silt, sand, small aggregate, and large aggregate) and are moved separately through the stream reaches.

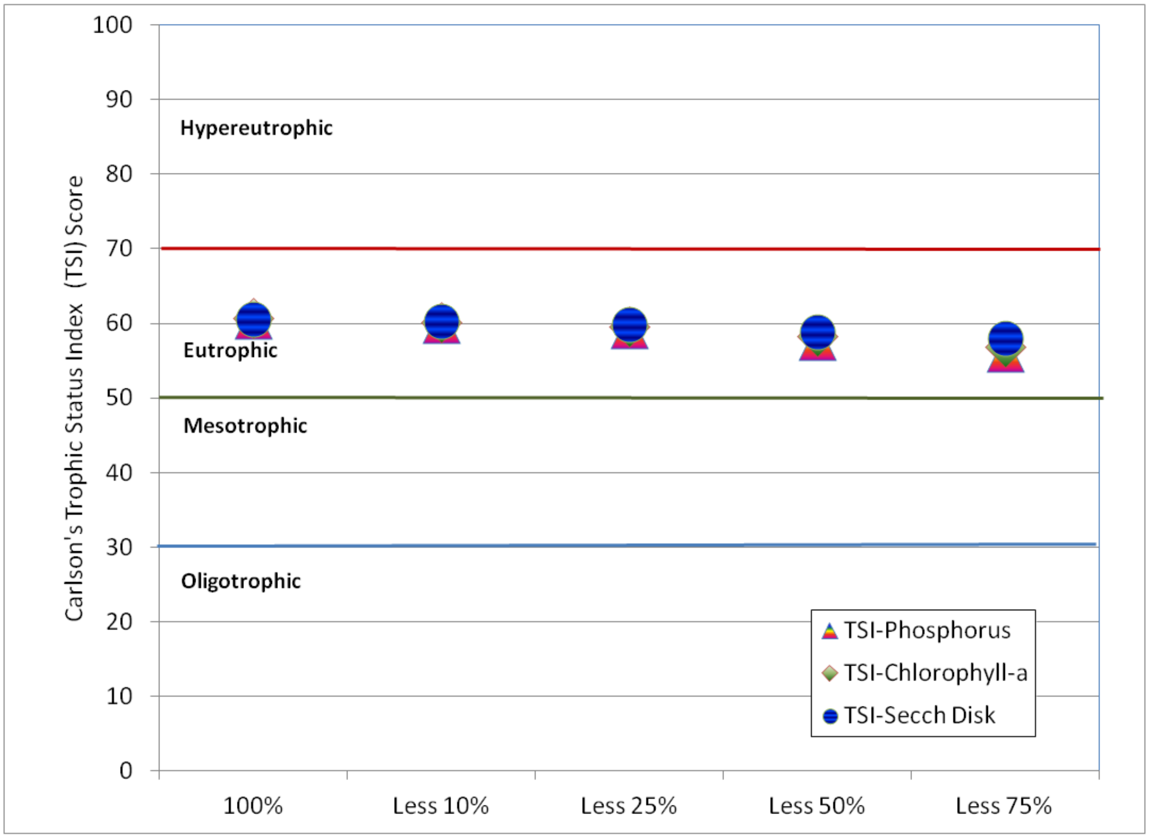

Figure 10. Predicted Change in Crooked Lake's Trophic Condition to Nutrient Load Reductions of 10, 25, 50, and 75 Percent.

AnnAGNPS uses various models to develop an annualized load in the watershed. These models account for surface runoff, soil moisture, erosion, nutrients, and reach routing. Each model serves a particular purpose and function in simulating the NPS processes occurring in the watershed.

To generate surface runoff and soil moisture, the soil profile is divided into two layers. The top layer is used as the tillage layer and has properties that change (bulk density etc.). While the remaining soil profile makes up the second layer with properties that remain static. A daily soil moisture budget is calculated based on rainfall, irrigation, and snow melt runoff, evapotranspiration, and percolation. Runoff is calculated using the NRCS Runoff Curve Number equation. These curve numbers can be modified based on tillage operations, soil moisture, and crop stage.

Overland sediment erosion was determined using a modified watershed-scale version of (Revised Universal Soil Loss Equation) RUSLE. (Geter and Theurer, 1998).

A daily mass balance for nitrogen (N), phosphorus (P), and organic carbon (OC) are calculated for each cell. Major components of N and P considered include plant uptake N and P, fertilization, residue decomposition, and N and P transport. Soluble and sediment absorbed N and P are also calculated. Nitrogen and phosphorus are then separated into organic and mineral phases. Plant uptake N and P are modeled through a crop growth stage index. (Bosch et. al. 1998)

The reach routing model moves sediment and nutrients through the watershed. Sediment routing is calculated based upon transport capacity relationships using the Bagnold stream power equation (Bagnold, 1966). Routing of nutrients through the watershed is accomplished by subdividing them into soluble and sediment attached components and are based on reach travel time, water temperature, and decay constant. Infiltration is also used to further reduce soluble nutrients. Both the upstream and downstream points of the reach are calculated for equilibrium concentrations by using a first order equilibrium model.

AnnAGNPS uses 34 different categories of input data and over 400 separate input parameters to execute the model. The input data categories can be split into five major classifications: climatic data, land characterization, field operations, chemical characteristics, and feedlot operations. Climatic data includes precipitation, maximum and minimum air temperature, relative humidity, sky cover, and wind speed. Land characterization consists of soil characterization, curve number, RUSLE parameters, and watershed drainage characterization. Field operations contain tillage, planting, harvest, rotation, chemical operations, and irrigation schedules. Finally, feedlot operations require daily manure rates, times of manure removal, and residue amount from previous operations.

Input parameters are used to verify the model. Some input parameters may be repeated for each cell, soil type, landuse, feedlot, and channel reach. Default values are available for some input parameters, others can be simplified because of duplication. Daily climatic input data can be obtained through weather generators, local data, and/or both. Geographical input data including cell boundaries, land slope, slope direction, and landuse can be generated by GIS or DEM (Digital Elevation Models).

Output data is expressed through an event based report for stream reaches and a source accounting report for land or reach components. Output parameters are selected by the user for the desired watershed source locations (specific cells, reaches, feedlots, point sources, or gullies) for any simulation period. Source accounting for land or reach components are calculated as a fraction of a pollutant load passing through any reach in the stream network that came from the user identified watershed source locations. Event based output data is defined as event quantities for user selected parameters at desired stream reach locations.

AnnAGNPS was utilized for the Crooked Lake TMDL Development and Watershed Assessment project. The Crooked Lake watershed delineation began with downloading a 30-meter digital elevation model (DEM) of Emmons County. Delineation is defined as drawing a boundary and dividing the land within the boundary into subwatersheds in such a matter that each subwatershed has uniformed hydrological parameters (land slope, elevation, etc.).

Land use and soil digital images were then used to extract the dominate identification of landuse and soil for each subwatershed. This process is achieved by overlaying Landsat and soil images over the subwatershed file. Each dominate soil is then further identified by its physical and chemical soil properties found in a database called National Soils Information System (NASIS) developed by the NRCS. Dominate landuse identification input parameters were obtained using Revised Universal Soil Loss Equation (RUSLE).

A five year simulation period was run on the Crooked Lake watershed at its present condition to provide a best estimation of the current land use practices applied to the soils and slopes of the watershed to obtain nutrient loads from the individual cells as well as the watershed as a whole. Major land use in the Crooked Lake watershed was identified as pasture/grassland (57 percent), cropland (19 percent), and water/wetlands (16 percent). The majority of the crops grown consist of spring wheat, flax, sunflower, canola, peas, and durum wheat (Figure 4).

Air seeders and conventional tillage were used in the cropland field operations. Crop rotations were determined from three years of land survey data from the National Agricultural Statistical Service (NASS). Typical planting of the fields was done in late April early May with fertilizer being applied at planting in specific amounts determined by crop type, harvest occurred in late September to mid October, spring tillage was done in early May with a chisel. Fertilizer application rates of metaphosphate, 16-52-0 (mono-ammonium phosphate), and multiple forms of anhydrous ammonia (i.e. 80-21-0, 80-26-0, etc.) were determined by the crop rotation and entered into the model.

The compiled data was used to assess the watershed to identify “critical cells” located in the watershed for potential best management practice (BMP) implementation (Figure 11). Critical cells were determined to be cells in the watershed providing an estimated annual phosphorus yield of 0.021 lbs/acre/year or greater.

5.4 Dissolved Oxygen

The cycling of nutrients in aquatic ecosystems is largely determined by oxidation-reduction (redox) potential and the distribution of dissolved oxygen and oxygen-demanding particles (Dodds, 2002). Dissolved oxygen gas has a strong affinity for electrons, and thus influences biogeochemical cycling and the biological availability of nutrients to primary producers such as algae. High levels of nutrients can lead to eutrophication, which is defined as the undesirable growth of algae and other aquatic plants. In turn, eutrophication can lead to increased biological oxygen demand and oxygen depletion due to the respiration of microbes that decompose the dead algae and other organic material.

Wetzel (1983) summarized, “The loading of organic matter to the hypolimnion and sediments of productive eutrophic lakes increases the consumption of dissolved oxygen. As a result, the oxygen content of the hypolimnion is reduced progressively during the period of summer stratification.”

Carpenter et al. (1998), has shown that nonpoint sources of phosphorous has lead to eutrophic conditions for many lake/reservoirs across the U.S. One consequence of eutrophication is oxygen depletions caused by decomposition of algae and aquatic plants. They also document that a reduction in nutrients will eventually lead to the reversal of eutrophication and attainment of designated beneficial uses. However, the rates of recovery are variable among lakes/reservoirs. This supports the Department of Health’s viewpoint that decreased nutrient loads at the watershed level will result in improved oxygen levels, the concern is that this process takes a significant amount of time (5-15 years).

In Lake Erie, heavy loadings of phosphorous have impacted the lake severely. Monitoring and research from the 1960's has shown that depressed hypolimnetic DO levels were responsible for large fish kills and large mats of decaying algae. Binational programs to reduce nutrients into the lake have resulted in a downward trend of the oxygen depletion rate since monitoring began in the 1970's. The trend of oxygen depletion has lagged behind that of phosphorous reduction, but this was expected (See: http://www.epa.gov/glnpo/lakeerie/dostory.html).

Nürnberg (1996), developed a model that quantified duration (days) and extent of lake oxygen depletion. The BATHTUB model indicates that excessive nutrient loading is responsible for the low dissolved oxygen depletion, referred to as an anoxic factor (AF). This model showed that AF is positively correlated with average annual total phosphorous (TP) concentrations. The AF may also be used to quantify response to watershed restoration measures which makes it very useful for TMDL development. Nürnberg (1996), developed several regression models that show nutrients control all trophic state indicators related to oxygen and phytoplankton in lakes/reservoirs. These models were developed from water quality characteristics using a suite of North American lakes. The morphometric parameters such as surface area (A_o = 375 acres; 1.52 km^2), mean depth (z = 9.2 feet; 2.8 meters) were calculated, and the ratio of mean depth to the surface area is ($z/A_o^{0.5}$ = 2.27) for Crooked Lake. This shows that these parameters are within the range of lakes used by Nürnberg. Based on this information, the Nürnberg's empirical nutrient-oxygen relationship holds true for North Dakota lakes and reservoirs.

6.0 MARGIN OF SAFETY AND SEASONALITY

6.1 Margin of Safety

Section 303(d) of the Clean Water Act and EPA's regulations require that "TMDLs shall be established at levels necessary to attain and maintain the applicable narrative and numerical water quality standards with seasonal variations and a margin of safety that takes into account any lack of knowledge concerning the relationship between effluent limitations and water quality." The margin of safety (MOS) can either be incorporated into conservative assumptions used to develop the TMDL (implicit) or added as a separate component of the TMDL (explicit). For the purposes of this nutrient TMDL, a MOS of 10 percent of the loading capacity will be used as an explicit MOS.

Assuming the existing annual phosphorus load to Crooked Lake from tributary sources and internal cycling is 169.4 kg/season and the TMDL reduction goal is a 25 percent reduction in total seasonal phosphorus loading, then this would result in a TMDL target total phosphorus loading capacity of 127.05 kg of total phosphorus per season. Based on a 10 percent explicit margin of safety, the MOS for the Crooked Lake TMDL would be 12.71 kg of phosphorus per season.

Monitoring and adaptive management during the implementation phase, along with post-implementation monitoring related to the effectiveness of the TMDL controls, will be used to ensure the attainment of the targets.

6.2 Seasonality

Section 303(d)(1)(C) of the Clean Water Act and the EPA's regulations require that a TMDL be established with seasonal variations. The Crooked Lake TMDL addresses seasonality because the FLUX, BATHTUB and AnnAGNPS models incorporate seasonal differences in their prediction of total phosphorus and nitrogen loadings.

7.0 TMDL

Table 9 summarizes the nutrient TMDL for Crooked Lake in terms of loading capacity, wasteload allocations, load allocations, and a margin of safety. The TMDL can be generically described by the following equation.

TMDL = LC = WLA + LA + MOS

where

LC loading capacity, or the greatest loading a waterbody can receive without violating water quality standards;

WLA wasteload allocation, or the portion of the TMDL allocated to existing or future point sources;

LA load allocation, or the portion of the TMDL allocated to existing or future non-point sources;

MOS margin of safety, or an accounting of the uncertainty about the relationship between pollutant loads and receiving water quality. The margin of safety can be provided implicitly through analytical assumptions or explicitly by reserving a portion of the loading capacity.

7.1 Nutrient TMDL

Table 10. Summary of the Phosphorus TMDL for Crooked Lake.

Category	Total Phosphorus (kg/yr)	Explanation
Existing Load	169.4	From observed data
Loading Capacity	127.05	25 percent total reduction based on BATHTUB modeling
Wasteload Allocation	0	No point sources
Load Allocation	114.34	Entire loading capacity minus MOS is allocated to non-point sources
MOS	12.71	10% of the loading capacity (kg/yr) is reserved as an explicit margin of safety

Based on data collected in 2010 thru 2011, the existing annual total phosphorus load to Crooked Lake is estimated at 169.4 kg. Assuming a 25 percent reduction in phosphorus loading will result in Crooked Lake reaching a total phosphorus concentration of 127.05 mg/L, resulting in an average growing season TMDL target chlorophyll-a concentration of 19.05 µg/L, the phosphorus TMDL or Loading Capacity is 127.05 kg per season. Assuming 10 percent of the loading capacity (12.71 kg/season) is explicitly assigned to the MOS and there are no point sources in the watershed all of the remaining loading capacity (114.34 kg/season) is assigned to the load allocation.

In November 2006 EPA issued a memorandum "Establishing TMDL "Daily" Loads in Light of the Decision by the U.S. Court of Appeals for the D.C. Circuit in Friends of the Earth, Inc. v. EPA et. al., No. 05-5015 (April 25, 2006) and Implications for NPDES Permits," which recommends that all TMDLs and associated load allocations and wasteload allocations include a daily time increment in conjunction with other appropriate temporal expressions that may be necessary to implement the relevant water quality standard. While the North Dakota Department of Health believes that the appropriate temporal expression for phosphorus loading to lakes and reservoirs is as an annual load, the phosphorus TMDL has also been expressed as a daily load. In order to express this phosphorus TMDL as a daily load the annual loading capacity of 127.05 kg/season was divided by 365 days. Based on this analysis, the phosphorus TMDL, expressed as an average daily load, is 0.35 kg/day with the load allocation equal to 0.31 kg/day and the MOS equal to 0.035 kg/day.

7.2 Dissolved Oxygen TMDL

As a result of the direct influence of eutrophication on increased biological oxygen demand and microbial respiration, it is anticipated that meeting the chlorophyll-a concentration target for Crooked Lake will address the dissolved oxygen impairment. A reduction in chlorophyll-a concentration due to the resulting lower algal biomass levels in the water column, would reduce the biological oxygen demand exerted by the decomposition of these primary producers. The reduction in biological oxygen demand is therefore assumed to result in attainment of the dissolved oxygen standard.

8.0 ALLOCATION

A 25 percent nutrient load reduction target was established for the entire Crooked Lake watershed. This reduction was set based on the BATHTUB model, which predicted that under similar hydraulic conditions, an external nutrient load reduction of 25 percent would lower Carlson's phosphorus TSI from 60.84 to 59.51.

Using the AnnAGNPS model, it was determined that cells with a phosphorus yield of 0.021 lbs/acre/yr or greater as priority areas in the watershed (Figure 10). These cells are the critical cells which should be examined by an implementation project to determine the necessity and types of BMP's to be implemented.

The TMDL in this report is a plan to improve water quality by implementing BMPs through a volunteer, incentive-based approach. This TMDL plan is put forth as a recommendation to what needs to be accomplished for Crooked Lake and its watershed to meet and protect its beneficial uses. Water quality monitoring should continue to assess the effects of recommendations made in this TMDL. Monitoring may indicate that loading capacity recommendations be adjusted.

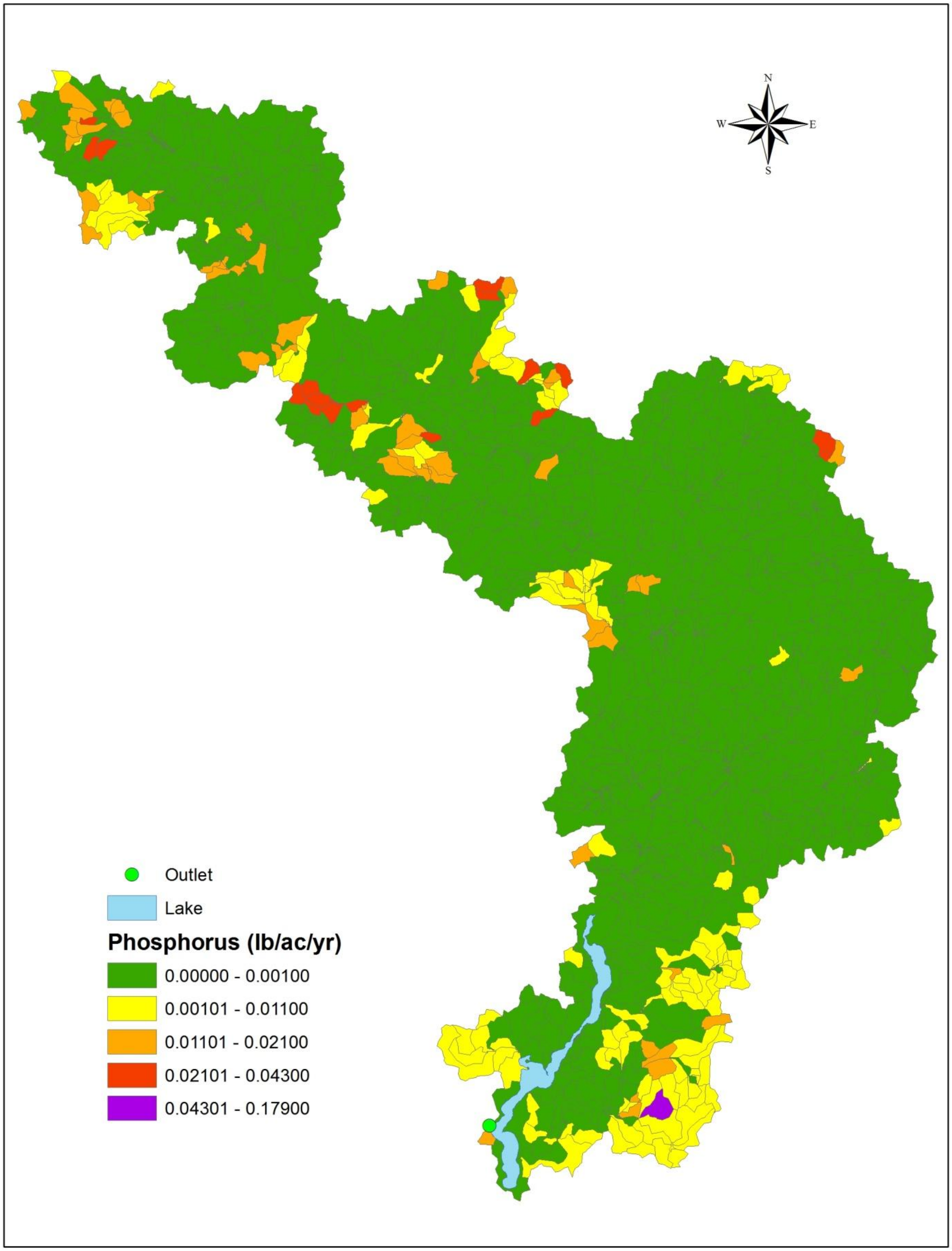

Figure 11. AnnAGNPS Model Identification of Critical Areas for BMP Implementation.

9.0 PUBLIC PARTICIPATION

To satisfy the public participation requirements of this TMDL, a letter was sent to the following participating agencies notifying them that the draft report was available for review and public comment. Those included in the mailing were as follows:

- McLean County Water Resource Board;
- South McLean Soil Conservation District;
- North Dakota Game and Fish Department;
- Natural Resource Conservation Service (State Office); and
- U.S. Environmental Protection Agency, Region VIII.

In addition to notifying specific agencies of this draft TMDL report's availability, the TMDL report was posted on the North Dakota Department of Health, Division of Water Quality web site at http://www.ndhealth.gov./WQ/SW/Z2 TMDL/TMDLs Under PublicComment/B Under Public Commment.html . A 30 day public notice soliciting comment and participation was also published in the McLean County Journal.

Comments were only received from US EPA Region 8, which were provided as part of their normal public notice review (Appendix D). The NDDoH's response to these comments are provided in Appendix E.

10.0 MONITORING

To insure that the BMPs implemented as a part of any watershed restoration plan will reduce phosphorus levels, water quality monitoring will be conducted in accordance with an approved Quality Assurance Project Plan (QAPP).

Specifically, monitoring will be conducted for all variables that are currently causing impairments to the beneficial uses of the waterbody. Once a watershed restoration plan (e.g. 319 PIP) is implemented, monitoring will be conducted in the lake/reservoir beginning two years after implementation and extending five years after the implementation project is complete.

11.0 TMDL IMPLEMENTATION STRATEGY

Implementation of TMDLs is dependent upon the availability of Section 319 NPS funds or other watershed restoration programs (e.g. USDA EQIP), as well as securing a local project sponsor and the required matching funds. Provided these three requirements are in place, a project implementation plan (PIP) is developed in accordance with the TMDL and submitted to the North Dakota Nonpoint Source Pollution Task Force and US EPA for approval. The implementation of the best management practices contained in the NPS PIP is voluntary. Therefore, success of any TMDL implementation project is ultimately dependent on the ability of the local project sponsor to find cooperating producers.

Monitoring is an important and required component of any PIP. As a part of the PIP, data are collected to monitor and track the effects of BMP implementation as well as to judge overall project success. Quality Assurance Project Plans (QAPPs) detail the strategy of how, when and where monitoring will be conducted to gather the data needed to document the TMDL implementation goal(s). As data are gathered and analyzed, watershed restoration tasks are adapted to place BMPs where they will have the greatest benefit to water quality.

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Appendix A
Flux Analysis

Crooked Lake Inlet 2010-2011 VAR=NH3 METHOD= 6 REG-3

STRATIFICATION SCHEME:

STR	DATE >=MIN	DATE < MAX	SEASON >=MIN	SEASON < MAX	FLOW >=MIN	FLOW < MAX
1			0	0	.00	1.87
2			0	0	1.87	11.20

STR	SAMPLES	EVENTS	FLOWS	VOLUME %
1	12	12	432	13.18
2	36	36	298	86.82
EXCLUDED	0	0	0	.00
TOTAL	48	48	730	100.00

Crooked Lake Inlet 2010-2011 VAR=NH3 METHOD= 6 REG-3

COMPARISON OF SAMPLED AND TOTAL FLOW DISTRIBUTIONS

STR	NQ	NC	NE	VOL%	TOTAL FLOW	SAMPLED FLOW	C/Q SLOPE	SIGNIF
1	432	12	12	13.2	.417	1.323	.406	.295
2	298	36	36	86.8	3.977	4.002	-.499	.020
***	730	48	48	100.0	1.870	3.332		

FLOW STATISTICS
FLOW DURATION = 730.0 DAYS = 1.999 YEARS
MEAN FLOW RATE = 1.870 HM3/YR
TOTAL FLOW VOLUME = 3.74 HM3
FLOW DATE RANGE = 20100101 TO 20111231
SAMPLE DATE RANGE = 20100413 TO 20110927

METHOD	MASS (KG)	FLUX (KG/YR)	FLUX VARIANCE	CONC (PPB)	CV
1 AV LOAD	201.5	100.8	.1539E+03	53.91	.123
2 Q WTD C	160.1	80.1	.1265E+03	42.83	.140
3 IJC	159.3	79.7	.1219E+03	42.62	.139
4 REG-1	156.6	78.4	.1092E+03	41.90	.133
5 REG-2	159.8	80.0	.1142E+03	42.76	.134
6 REG-3	156.0	78.1	.9068E+02	41.75	.122

Crooked Lake Inlet 2010-2011 VAR=NO3/NO2 METHOD= 5 REG-2

STRATIFICATION SCHEME:

	DATE		SEASON		FLOW	
STR	>=MIN	< MAX	>=MIN	< MAX	>=MIN	< MAX
1			0	0	.00	1.87
2			0	0	1.87	11.20

STR	SAMPLES	EVENTS	FLOWS	VOLUME %
1	12	12	432	13.18
2	36	36	298	86.82
EXCLUDED	0	0	0	.00
TOTAL	48	48	730	100.00

Crooked Lake Inlet 2010-2011 VAR=NO3/NO2 METHOD= 5 REG-2

COMPARISON OF SAMPLED AND TOTAL FLOW DISTRIBUTIONS

STR	NQ	NC	NE	VOL%	TOTAL FLOW	SAMPLED FLOW	C/Q SLOPE	SIGNIF
1	432	12	12	13.2	.417	1.323	.251	.536
2	298	36	36	86.8	3.977	4.002	-.141	.148
***	730	48	48	100.0	1.870	3.332		

FLOW STATISTICS
FLOW DURATION = 730.0 DAYS = 1.999 YEARS
MEAN FLOW RATE = 1.870 HM3/YR
TOTAL FLOW VOLUME = 3.74 HM3
FLOW DATE RANGE = 20100101 TO 20111231
SAMPLE DATE RANGE = 20100413 TO 20110927

METHOD	MASS (KG)	FLUX (KG/YR)	FLUX VARIANCE	CONC (PPB)	CV
1 AV LOAD	176.5	88.3	.4377E+02	47.22	.075
2 Q WTD C	130.4	65.3	.7635E+01	34.90	.042
3 IJC	130.3	65.2	.7506E+01	34.86	.042
4 REG-1	127.7	63.9	.9578E+01	34.17	.048
5 REG-2	129.6	64.9	.7063E+01	34.68	.041
6 REG-3	131.2	65.6	.7899E+01	35.09	.043

Crooked Lake Inlet 2010-2011 VAR=TN METHOD= 6 REG-3

STRATIFICATION SCHEME:

	---- DATE ----		-- SEASON --		-------- FLOW --------	
STR	>=MIN	< MAX	>=MIN	< MAX	>=MIN	< MAX
1			0	0	.00	1.87
2			0	0	1.87	11.20

STR	SAMPLES	EVENTS	FLOWS	VOLUME %
1	12	12	432	13.18
2	36	36	298	86.82
EXCLUDED	0	0	0	.00
TOTAL	48	48	730	100.00

Crooked Lake Inlet 2010-2011 VAR=TN METHOD= 6 REG-3

COMPARISON OF SAMPLED AND TOTAL FLOW DISTRIBUTIONS

STR	NQ	NC	NE	VOL%	TOTAL FLOW	SAMPLED FLOW	C/Q SLOPE	SIGNIF
1	432	12	12	13.2	.417	1.323	-.141	.469
2	298	36	36	86.8	3.977	4.002	-.279	.000
***	730	48	48	100.0	1.870	3.332		

FLOW STATISTICS
FLOW DURATION = 730.0 DAYS = 1.999 YEARS
MEAN FLOW RATE = 1.870 HM3/YR
TOTAL FLOW VOLUME = 3.74 HM3
FLOW DATE RANGE = 20100101 TO 20111231
SAMPLE DATE RANGE = 20100413 TO 20110927

METHOD	MASS (KG)	FLUX (KG/YR)	FLUX VARIANCE	CONC (PPB)	CV
1 AV LOAD	3981.1	1991.9	.1108E+05	1065.16	.053
2 Q WTD C	2888.0	1445.0	.1846E+04	772.71	.030
3 IJC	2882.3	1442.1	.1844E+04	771.17	.030
4 REG-1	2934.3	1468.1	.1546E+04	785.08	.027
5 REG-2	2926.6	1464.3	.1120E+04	783.03	.023
6 REG-3	2906.2	1454.1	.9901E+03	777.58	.022

Crooked Lake Inlet 2010-2011 VAR=TP METHOD= 5 REG-2

COMPARISON OF SAMPLED AND TOTAL FLOW DISTRIBUTIONS

STR	NQ	NC	NE	VOL%	TOTAL FLOW	SAMPLED FLOW	C/Q SLOPE	SIGNIF
1	730	48	48	100.0	1.870	3.332	-.240	.058
***	730	48	48	100.0	1.870	3.332		

FLOW STATISTICS
FLOW DURATION = 730.0 DAYS = 1.999 YEARS
MEAN FLOW RATE = 1.870 HM3/YR
TOTAL FLOW VOLUME = 3.74 HM3
FLOW DATE RANGE = 20100101 TO 20111231
SAMPLE DATE RANGE = 20100413 TO 20110927

METHOD	MASS (KG)	FLUX (KG/YR)	FLUX VARIANCE	CONC (PPB)	CV
1 AV LOAD	205.0	102.6	.9949E+02	54.86	.097
2 Q WTD C	115.1	57.6	.1845E+02	30.79	.075
3 IJC	114.8	57.4	.1860E+02	30.71	.075
4 REG-1	132.2	66.1	.2098E+02	35.37	.069
5 REG-2	120.3	60.2	.1322E+02	32.19	.060
6 REG-3	120.4	60.2	.1696E+02	32.21	.068

Crooked Lake Inlet 2010-2011 VAR=TDP METHOD= 5 REG-2

COMPARISON OF SAMPLED AND TOTAL FLOW DISTRIBUTIONS

STR	NQ	NC	NE	VOL%	TOTAL FLOW	SAMPLED FLOW	C/Q SLOPE	SIGNIF
1	730	48	48	100.0	1.870	3.332	-.240	.058
***	730	48	48	100.0	1.870	3.332		

FLOW STATISTICS
FLOW DURATION = 730.0 DAYS = 1.999 YEARS
MEAN FLOW RATE = 1.870 HM3/YR
TOTAL FLOW VOLUME = 3.74 HM3
FLOW DATE RANGE = 20100101 TO 20111231
SAMPLE DATE RANGE = 20100413 TO 20110927

METHOD	MASS (KG)	FLUX (KG/YR)	FLUX VARIANCE	CONC (PPB)	CV
1 AV LOAD	182.5	91.3	.7880E+02	48.83	.097
2 Q WTD C	102.4	51.2	.1462E+02	27.40	.075
3 IJC	102.2	51.1	.1474E+02	27.33	.075
4 REG-1	117.7	58.9	.1662E+02	31.48	.069
5 REG-2	107.1	53.6	.1047E+02	28.65	.060
6 REG-3	107.1	53.6	.1343E+02	28.67	.068

Crooked Lake Inlet 2010-2011 VAR=TSS METHOD= 4 REG-1

STRATIFICATION SCHEME:

	DATE		SEASON		FLOW	
STR	>=MIN	< MAX	>=MIN	< MAX	>=MIN	< MAX
1			0	0	.00	1.87
2			0	0	1.87	11.20

STR	SAMPLES	EVENTS	FLOWS	VOLUME %
1	12	12	432	13.18
2	36	36	298	86.82
EXCLUDED	0	0	0	.00
TOTAL	48	48	730	100.00

Crooked Lake Inlet 2010-2011 VAR=TSS METHOD= 4 REG-1

COMPARISON OF SAMPLED AND TOTAL FLOW DISTRIBUTIONS

STR	NQ	NC	NE	VOL%	TOTAL FLOW	SAMPLED FLOW	C/Q SLOPE	SIGNIF
1	432	12	12	13.2	.417	1.323	.866	.242
2	298	36	36	86.8	3.977	4.002	-.096	.141
***	730	48	48	100.0	1.870	3.332		

FLOW STATISTICS
FLOW DURATION = 730.0 DAYS = 1.999 YEARS
MEAN FLOW RATE = 1.870 HM3/YR
TOTAL FLOW VOLUME = 3.74 HM3
FLOW DATE RANGE = 20100101 TO 20111231
SAMPLE DATE RANGE = 20100413 TO 20110927

METHOD	MASS (KG)	FLUX (KG/YR)	FLUX VARIANCE	CONC (PPB)	CV
1 AV LOAD	33994.6	17008.9	.1886E+08	9095.49	.255
2 Q WTD C	22526.3	11270.9	.1773E+07	6027.07	.118
3 IJC	22577.9	11296.7	.1857E+07	6040.86	.121
4 REG-1	20479.4	10246.7	.2350E+06	5479.40	.047
5 REG-2	21914.8	10964.9	.1120E+07	5863.45	.097
6 REG-3	21301.1	10657.8	.6189E+06	5699.25	.074

Crooked Lake Inlet 2010-2011 VAR=INORG_N METHOD= 6 REG-3

STRATIFICATION SCHEME:

	DATE		SEASON		FLOW	
STR	>=MIN	< MAX	>=MIN	< MAX	>=MIN	< MAX
1			0	0	.00	1.87
2			0	0	1.87	11.20

STR	SAMPLES	EVENTS	FLOWS	VOLUME %
1	12	12	432	13.18
2	36	36	298	86.82
EXCLUDED	0	0	0	.00
TOTAL	48	48	730	100.00

Crooked Lake Inlet 2010-2011 VAR=INORG_N METHOD= 6 REG-3

COMPARISON OF SAMPLED AND TOTAL FLOW DISTRIBUTIONS

STR	NQ	NC	NE	VOL%	TOTAL FLOW	SAMPLED FLOW	C/Q SLOPE	SIGNIF
1	432	12	12	13.2	.417	1.323	.404	.167
2	298	36	36	86.8	3.977	4.002	-.413	.009
***	730	48	48	100.0	1.870	3.332		

FLOW STATISTICS
FLOW DURATION = 730.0 DAYS = 1.999 YEARS
MEAN FLOW RATE = 1.870 HM3/YR
TOTAL FLOW VOLUME = 3.74 HM3
FLOW DATE RANGE = 20100101 TO 20111231
SAMPLE DATE RANGE = 20100413 TO 20110927

METHOD	MASS (KG)	FLUX (KG/YR)	FLUX VARIANCE	CONC (PPB)	CV
1 AV LOAD	378.0	189.1	.2161E+03	101.13	.078
2 Q WTD C	290.5	145.3	.1414E+03	77.72	.082
3 IJC	289.6	144.9	.1365E+03	77.48	.081
4 REG-1	282.9	141.6	.1177E+03	75.70	.077
5 REG-2	289.4	144.8	.1222E+03	77.43	.076
6 REG-3	290.5	145.4	.1160E+03	77.73	.074

Crooked Lake Inlet 2010-2011   VAR=ORG_N   METHOD= 6 REG-3

STRATIFICATION SCHEME:

	DATE		SEASON		FLOW	
STR	>=MIN	< MAX	>=MIN	< MAX	>=MIN	< MAX
1			0	0	.00	1.87
2			0	0	1.87	11.20

STR	SAMPLES	EVENTS	FLOWS	VOLUME %
1	12	12	432	13.18
2	36	36	298	86.82
EXCLUDED	0	0	0	.00
TOTAL	48	48	730	100.00

Crooked Lake Inlet 2010-2011   VAR=ORG_N   METHOD= 6 REG-3

COMPARISON OF SAMPLED AND TOTAL FLOW DISTRIBUTIONS

STR	NQ	NC	NE	VOL%	TOTAL FLOW	SAMPLED FLOW	C/Q SLOPE	SIGNIF
1	432	12	12	13.2	.417	1.323	-.156	.451
2	298	36	36	86.8	3.977	4.002	-.284	.000
***	730	48	48	100.0	1.870	3.332		

FLOW STATISTICS
FLOW DURATION =   730.0 DAYS = 1.999 YEARS
MEAN FLOW RATE =   1.870 HM3/YR
TOTAL FLOW VOLUME =   3.74 HM3
FLOW DATE RANGE   = 20100101 TO 20111231
SAMPLE DATE RANGE = 20100413 TO 20110927

METHOD	MASS (KG)	FLUX (KG/YR)	FLUX VARIANCE	CONC (PPB)	CV
1 AV LOAD	3804.6	1903.6	.1027E+05	1017.94	.053
2 Q WTD C	2757.6	1379.7	.1790E+04	737.81	.031
3 IJC	2752.0	1376.9	.1788E+04	736.32	.031
4 REG-1	2806.4	1404.2	.1608E+04	750.88	.029
5 REG-2	2797.4	1399.6	.1156E+04	748.45	.024
6 REG-3	2775.9	1388.9	.1001E+04	742.70	.023

Crooked Lake Outlet 2010-2011 VAR=NH3 METHOD= 6 REG-3

COMPARISON OF SAMPLED AND TOTAL FLOW DISTRIBUTIONS

STR	NQ	NC	NE	VOL%	TOTAL FLOW	SAMPLED FLOW	C/Q SLOPE	SIGNIF
1	730	48	48	100.0	2.220	3.770	.000	1.000
***	730	48	48	100.0	2.220	3.770		

FLOW STATISTICS
FLOW DURATION = 730.0 DAYS = 1.999 YEARS
MEAN FLOW RATE = 2.220 HM3/YR
TOTAL FLOW VOLUME = 4.44 HM3
FLOW DATE RANGE = 20100101 TO 20111231
SAMPLE DATE RANGE = 20100413 TO 20110927

METHOD	MASS (KG)	FLUX (KG/YR)	FLUX VARIANCE	CONC (PPB)	CV
1 AV LOAD	226.1	113.1	.6017E+03	50.94	.217
2 Q WTD C	133.1	66.6	.3105E-04	30.00	.000
3 IJC	133.1	66.6	.4591E-05	30.00	.000
4 REG-1	133.1	66.6	.1324E-04	30.00	.000
5 REG-2	133.1	66.6	.4547E-04	30.00	.000
6 REG-3	133.1	66.6	.1502E-04	30.00	.000

Crooked Lake Outlet 2010-2011 VAR=NO3/NO2 METHOD= 6 REG-3

COMPARISON OF SAMPLED AND TOTAL FLOW DISTRIBUTIONS

STR	NQ	NC	NE	VOL%	TOTAL FLOW	SAMPLED FLOW	C/Q SLOPE	SIGNIF
1	730	48	48	100.0	2.220	3.770	.027	.200
***	730	48	48	100.0	2.220	3.770		

FLOW STATISTICS
FLOW DURATION = 730.0 DAYS = 1.999 YEARS
MEAN FLOW RATE = 2.220 HM3/YR
TOTAL FLOW VOLUME = 4.44 HM3
FLOW DATE RANGE = 20100101 TO 20111231
SAMPLE DATE RANGE = 20100413 TO 20110927

METHOD	MASS (KG)	FLUX (KG/YR)	FLUX VARIANCE	CONC (PPB)	CV
1 AV LOAD	348.5	174.4	.4323E+04	78.52	.377
2 Q WTD C	205.2	102.7	.9801E+03	46.24	.305
3 IJC	206.7	103.4	.1036E+04	46.58	.311
4 REG-1	202.3	101.2	.8998E+03	45.58	.296
5 REG-2	207.4	103.7	.1047E+04	46.72	.312
6 REG-3	161.7	80.9	.9841E+02	36.43	.123

Crooked Lake Outlet 2010-2011 VAR=TN METHOD= 3 IJC

STRATIFICATION SCHEME:

	---- DATE ----		-- SEASON --		-------- FLOW --------	
STR	>=MIN	< MAX	>=MIN	< MAX	>=MIN	< MAX
1			0	0	.00	1.11
2			0	0	1.11	4.44
3			0	0	4.44	19.64

STR	SAMPLES	EVENTS	FLOWS	VOLUME %
1	24	24	511	4.86
2	14	14	117	17.12
3	10	10	102	78.02
EXCLUDED	0	0	0	.00
TOTAL	48	48	730	100.00

Crooked Lake Outlet 2010-2011 VAR=TN METHOD= 3 IJC

COMPARISON OF SAMPLED AND TOTAL FLOW DISTRIBUTIONS

STR	NQ	NC	NE	VOL%	TOTAL FLOW	SAMPLED FLOW	C/Q SLOPE	SIGNIF
1	511	24	24	4.9	.154	.321	-.022	.340
2	117	14	14	17.1	2.372	2.412	.110	.330
3	102	10	10	78.0	12.399	13.950	-.185	.144
***	730	48	48	100.0	2.220	3.770		

FLOW STATISTICS
FLOW DURATION = 730.0 DAYS = 1.999 YEARS
MEAN FLOW RATE = 2.220 HM3/YR
TOTAL FLOW VOLUME = 4.44 HM3
FLOW DATE RANGE = 20100101 TO 20111231
SAMPLE DATE RANGE = 20100413 TO 20110927

METHOD	MASS (KG)	FLUX (KG/YR)	FLUX VARIANCE	CONC (PPB)	CV
1 AV LOAD	6011.3	3007.7	.4741E+05	1354.52	.072
2 Q WTD C	5209.3	2606.4	.3180E+04	1173.82	.022
3 IJC	5208.7	2606.1	.3026E+04	1173.67	.021
4 REG-1	5295.7	2649.7	.3433E+05	1193.29	.070
5 REG-2	5279.0	2641.3	.2342E+05	1189.52	.058
6 REG-3	5283.2	2643.4	.2192E+05	1190.46	.056

Crooked Lake Outlet 2010-2011 VAR=TP METHOD= 6 REG-3

COMPARISON OF SAMPLED AND TOTAL FLOW DISTRIBUTIONS

STR	NQ	NC	NE	VOL%	TOTAL FLOW	SAMPLED FLOW	C/Q SLOPE	SIGNIF
1	730	48	48	100.0	2.220	3.770	-.016	.622
***	730	48	48	100.0	2.220	3.770		

FLOW STATISTICS
FLOW DURATION = 730.0 DAYS = 1.999 YEARS
MEAN FLOW RATE = 2.220 HM3/YR
TOTAL FLOW VOLUME = 4.44 HM3
FLOW DATE RANGE = 20100101 TO 20111231
SAMPLE DATE RANGE = 20100413 TO 20110927

METHOD	MASS (KG)	FLUX (KG/YR)	FLUX VARIANCE	CONC (PPB)	CV
1 AV LOAD	243.5	121.8	.9316E+03	54.86	.251
2 Q WTD C	143.4	71.7	.5638E+02	32.31	.105
3 IJC	143.8	71.9	.5795E+02	32.40	.106
4 REG-1	144.6	72.3	.4707E+02	32.58	.095
5 REG-2	142.5	71.3	.6853E+02	32.10	.116
6 REG-3	150.4	75.2	.5034E+02	33.88	.094

Crooked Lake Outlet 2010-2011 VAR=TSS METHOD= 6 REG-3

COMPARISON OF SAMPLED AND TOTAL FLOW DISTRIBUTIONS

STR	NQ	NC	NE	VOL%	TOTAL FLOW	SAMPLED FLOW	C/Q SLOPE	SIGNIF
1	730	48	48	100.0	2.220	3.770	-.014	.661
***	730	48	48	100.0	2.220	3.770		

FLOW STATISTICS
FLOW DURATION = 730.0 DAYS = 1.999 YEARS
MEAN FLOW RATE = 2.220 HM3/YR
TOTAL FLOW VOLUME = 4.44 HM3
FLOW DATE RANGE = 20100101 TO 20111231
SAMPLE DATE RANGE = 20100413 TO 20110927

METHOD	MASS (KG)	FLUX (KG/YR)	FLUX VARIANCE	CONC (PPB)	CV
1 AV LOAD	63309.0	31676.2	.1149E+09	14265.39	.338
2 Q WTD C	37284.0	18654.8	.2162E+08	8401.21	.249
3 IJC	37539.5	18782.6	.2296E+08	8458.76	.255
4 REG-1	37565.1	18795.4	.2038E+08	8464.54	.240
5 REG-2	37072.2	18548.8	.2311E+08	8353.46	.259
6 REG-3	34158.1	17090.7	.4471E+07	7696.83	.124

Crooked Lake Outlet 2010-2011 VAR=TDP METHOD= 6 REG-3

COMPARISON OF SAMPLED AND TOTAL FLOW DISTRIBUTIONS

STR	NQ	NC	NE	VOL%	TOTAL FLOW	SAMPLED FLOW	C/Q SLOPE	SIGNIF
1	730	48	48	100.0	2.220	3.770	-.016	.622
***	730	48	48	100.0	2.220	3.770		

FLOW STATISTICS
FLOW DURATION = 730.0 DAYS = 1.999 YEARS
MEAN FLOW RATE = 2.220 HM3/YR
TOTAL FLOW VOLUME = 4.44 HM3
FLOW DATE RANGE = 20100101 TO 20111231
SAMPLE DATE RANGE = 20100413 TO 20110927

METHOD	MASS (KG)	FLUX (KG/YR)	FLUX VARIANCE	CONC (PPB)	CV
1 AV LOAD	216.7	108.4	.7379E+03	48.82	.251
2 Q WTD C	127.6	63.8	.4466E+02	28.75	.105
3 IJC	128.0	64.0	.4590E+02	28.84	.106
4 REG-1	128.7	64.4	.3729E+02	29.00	.095
5 REG-2	126.8	63.4	.5428E+02	28.57	.116
6 REG-3	133.8	67.0	.3988E+02	30.15	.094

Crooked Lake Outlet 2010-2011 VAR=INORG_N METHOD= 6 REG-3

COMPARISON OF SAMPLED AND TOTAL FLOW DISTRIBUTIONS

STR	NQ	NC	NE	VOL%	TOTAL FLOW	SAMPLED FLOW	C/Q SLOPE	SIGNIF
1	730	48	48	100.0	2.220	3.770	.018	.194
***	730	48	48	100.0	2.220	3.770		

FLOW STATISTICS
FLOW DURATION = 730.0 DAYS = 1.999 YEARS
MEAN FLOW RATE = 2.220 HM3/YR
TOTAL FLOW VOLUME = 4.44 HM3
FLOW DATE RANGE = 20100101 TO 20111231
SAMPLE DATE RANGE = 20100413 TO 20110927

METHOD	MASS (KG)	FLUX (KG/YR)	FLUX VARIANCE	CONC (PPB)	CV
1 AV LOAD	574.5	287.5	.7080E+04	129.46	.293
2 Q WTD C	338.4	169.3	.9801E+03	76.24	.185
3 IJC	339.8	170.0	.1036E+04	76.58	.189
4 REG-1	335.1	167.6	.8902E+03	75.50	.178
5 REG-2	340.8	170.5	.1056E+04	76.78	.191
6 REG-3	299.3	149.7	.1449E+03	67.44	.080

Crooked Lake Outlet 2010-2011 VAR=ORG_N METHOD= 3 IJC

COMPARISON OF SAMPLED AND TOTAL FLOW DISTRIBUTIONS

STR	NQ	NC	NE	VOL%	TOTAL FLOW	SAMPLED FLOW	C/Q SLOPE	SIGNIF
1	511	24	24	4.9	.154	.321	-.021	.352
2	117	14	14	17.1	2.372	2.412	.108	.349
3	102	10	10	78.0	12.399	13.950	-.219	.115
***	730	48	48	100.0	2.220	3.770		

FLOW STATISTICS
FLOW DURATION = 730.0 DAYS = 1.999 YEARS
MEAN FLOW RATE = 2.220 HM3/YR
TOTAL FLOW VOLUME = 4.44 HM3
FLOW DATE RANGE = 20100101 TO 20111231
SAMPLE DATE RANGE = 20100413 TO 20110927

METHOD	MASS (KG)	FLUX (KG/YR)	FLUX VARIANCE	CONC (PPB)	CV
1 AV LOAD	5776.3	2890.1	.4344E+05	1301.56	.072
2 Q WTD C	5003.5	2503.5	.4584E+04	1127.44	.027
3 IJC	5002.0	2502.7	.4498E+04	1127.10	.027
4 REG-1	5101.0	2552.3	.3076E+05	1149.41	.069
5 REG-2	5083.5	2543.5	.2240E+05	1145.46	.059
6 REG-3	5088.3	2545.9	.2111E+05	1146.54	.057

Appendix B
BATHTUB Results

CASE: Crooked Lake Calibrated 2010-11

HYDRAULIC AND DISPERSION PARAMETERS:

SEG	OUT	NET INFLOW HM3/YR	RESIDENCE TIME YRS	OVERFLOW RATE M/YR	MEAN VELOCITY KM/YR	----DISPERSION----- ESTIMATED KM2/YR	NUMERIC KM2/YR	EXCHANGE RATE HM3/YR
1	0	2.34	1.87178	1.8	2.1	1000.	4.	0.
2	1	.00	.00000	.0	1.0	1000.	0.	181.

CASE: Crooked Lake Calibrated 2010-11

GROSS WATER BALANCE:

ID	T	LOCATION	DRAINAGE AREA KM2	---- FLOW (HM3/YR) ---- MEAN	VARIANCE	CV	RUNOFF M/YR
1	1	Inlet 385552	186.766	1.870	.000E+00	.000	.010
2	4	Outlet 385554	223.908	2.220	.000E+00	.000	.010
3	1	TRIBUTARIES	34.605	.604	.000E+00	.000	.017
		PRECIPITATION	2.537	1.471	.866E-01	.200	.580
		TRIBUTARY INFLOW	221.371	2.474	.000E+00	.000	.011
		***TOTAL INFLOW	223.908	3.945	.866E-01	.075	.018
		GAUGED OUTFLOW	223.908	2.220	.000E+00	.000	.010
		ADVECTIVE OUTFLOW	.000	.000	.354E+00	9.990	-114.349
		***TOTAL OUTFLOW	223.908	2.220	.354E+00	.268	.010
		***EVAPORATION	.000	1.725	.268E+00	.300	.000

GROSS MASS BALANCE BASED UPON OBSERVED CONCENTRATIONS

COMPONENT: CONSERV

ID	T	LOCATION	----- LOADING ---- KG/YR	%(I)	--- VARIANCE --- KG/YR**2	%(I)	CV	CONC MG/M3	EXPORT KG/KM2
1	1	Inlet 385552	.0	.0	.000E+00	.0	.000	.0	.0
2	4	Outlet 385554	.0	.0	.000E+00	.0	.000	.0	.0
3	1	TRIBUTARIES	.0	.0	.000E+00	.0	.000	.0	.0

OVERFLOW RATE M/YR	HYDRAULIC RESIDENCE TIME YRS	------ CONSERV ------ POOL CONC MG/M3	RESIDENCE TIME YRS	TURNOVER RATIO -	RETENTION COEF -
.88	3.1988	.0	.0000	.0000	.0000

GROSS MASS BALANCE BASED UPON OBSERVED CONCENTRATIONS

COMPONENT: TOTAL P

ID	T	LOCATION	LOADING KG/YR	LOADING %(I)	VARIANCE KG/YR**2	VARIANCE %(I)	CV	CONC MG/M3	EXPORT KG/KM2
1	1	Inlet 385552	60.2	35.5	.130E+02	.9	.060	32.2	.3
2	4	Outlet 385554	75.2	44.4	.500E+02	3.4	.094	33.9	.3
3	1	TRIBUTARIES	33.1	19.6	.000E+00	.0	.000	54.9	1.0
		PRECIPITATION	76.1	44.9	.145E+04	99.1	.500	51.7	30.0
		TRIBUTARY INFLOW	93.3	55.1	.130E+02	.9	.039	37.7	.4
		***TOTAL INFLOW	169.4	100.0	.146E+04	100.0	.226	42.9	.8
		GAUGED OUTFLOW	88.8	52.4	.000E+00	.0	.000	40.0	.4
		ADVECTIVE OUTFLOW	.0	.0	.567E+03	38.8	9.999	40.0	-4574.0
		***TOTAL OUTFLOW	88.8	52.4	.567E+03	38.8	.268	40.0	.4
		***RETENTION	80.6	47.6	.203E+04	138.8	.559	.0	.0

OVERFLOW RATE M/YR	HYDRAULIC RESIDENCE TIME YRS	TOTAL P POOL CONC MG/M3	TOTAL P RESIDENCE TIME YRS	TOTAL P TURNOVER RATIO -	TOTAL P RETENTION COEF -
.88	3.1988	49.5	2.0752	.4819	.4759

GROSS MASS BALANCE BASED UPON OBSERVED CONCENTRATIONS

COMPONENT: TOTAL N

ID	T	LOCATION	LOADING KG/YR	LOADING %(I)	VARIANCE KG/YR**2	VARIANCE %(I)	CV	CONC MG/M3	EXPORT KG/KM2
1	1	Inlet 385552	1454.1	31.4	.102E+04	.1	.022	777.6	7.8
2	4	Outlet 385554	2605.5	56.2	.299E+04	.2	.021	1173.7	11.6
3	1	TRIBUTARIES	643.3	13.9	.000E+00	.0	.000	1065.0	18.6
		PRECIPITATION	2537.0	54.7	.161E+07	99.9	.500	1724.1	1000.0
		TRIBUTARY INFLOW	2097.3	45.3	.102E+04	.1	.015	847.8	9.5
		***TOTAL INFLOW	4634.3	100.0	.161E+07	100.0	.274	1174.6	20.7
		GAUGED OUTFLOW	3037.0	65.5	.000E+00	.0	.000	1368.0	13.6
		ADVECTIVE OUTFLOW	.4	.0	.663E+06	41.2	9.999	1368.0	********
		***TOTAL OUTFLOW	3037.4	65.5	.663E+06	41.2	.268	1368.0	13.6
		***RETENTION	1597.0	34.5	.227E+07	141.2	.944	.0	.0

OVERFLOW RATE M/YR	HYDRAULIC RESIDENCE TIME YRS	TOTAL N POOL CONC MG/M3	TOTAL N RESIDENCE TIME YRS	TOTAL N TURNOVER RATIO -	TOTAL N RETENTION COEF -
.88	3.1988	1278.6	1.9596	.5103	.3446

CASE: Crooked Lake Calibrated 2010-11

OBSERVED AND PREDICTED DIAGNOSTIC VARIABLES
RANKED AGAINST CE MODEL DEVELOPMENT DATA SET

SEGMENT: 1 Lower 381030

VARIABLE	VALUES OBSERVED	VALUES ESTIMATED	RANKS (%) OBSERVED	RANKS (%) ESTIMATED
TOTAL P MG/M3	40.00	49.51	42.1	51.5
TOTAL N MG/M3	1368.00	1275.87	68.7	64.7
C.NUTRIENT MG/M3	37.21	43.79	52.1	60.1
CHL-A MG/M3	13.87	21.40	69.4	85.8
SECCHI M	1.33	1.06	60.8	49.2
ORGANIC N MG/M3	1263.00	1148.31	97.3	95.9
TP-ORTHO-P MG/M3	31.00	36.19	51.4	57.8
ANTILOG PC-1	400.99	602.36	64.7	75.4
ANTILOG PC-2	11.25	12.42	85.6	89.5
(N - 150) / P	30.45	22.74	80.4	66.5
INORGANIC N / P	11.67	9.57	17.4	12.7
TURBIDITY 1/M	.41	.41	32.2	32.2
ZMIX * TURBIDITY	2.10	2.10	30.0	30.0
ZMIX / SECCHI	3.90	4.87	36.4	51.5
CHL-A * SECCHI	18.45	22.76	79.9	87.2
CHL-A / TOTAL P	.35	.43	81.5	89.3
FREQ(CHL-a>10) %	82.65	99.15	.0	.0
FREQ(CHL-a>20) %	8.53	53.03	.0	.0
FREQ(CHL-a>30) %	.33	10.10	.0	.0
FREQ(CHL-a>40) %	.01	1.27	.0	.0
FREQ(CHL-a>50) %	.00	.15	.0	.0
FREQ(CHL-a>60) %	.00	.02	.0	.0
CARLSON TSI-P	57.34	60.42	.0	.0
CARLSON TSI-CHLA	56.40	60.65	.0	.0
CARLSON TSI-SEC	55.89	59.11	.0	.0

SEGMENT: 2 Upper 385553

VARIABLE	VALUES OBSERVED	VALUES ESTIMATED	RANKS (%) OBSERVED	RANKS (%) ESTIMATED
TOTAL P MG/M3	60.00	49.49	59.9	51.5
TOTAL N MG/M3	1180.00	1276.94	60.1	64.8
C.NUTRIENT MG/M3	49.18	43.78	65.6	60.1
CHL-A MG/M3	29.76	21.40	93.3	85.8
SECCHI M	.71	.84	29.3	37.0
ORGANIC N MG/M3	1054.00	1180.40	94.1	96.3
TP-ORTHO-P MG/M3	47.00	41.13	68.2	63.0
ANTILOG PC-1	906.22	680.58	84.1	78.2
ANTILOG PC-2	11.46	10.63	86.4	83.0
(N - 150) / P	17.17	22.77	50.6	66.6
INORGANIC N / P	9.69	11.54	13.0	17.1
TURBIDITY 1/M	.66	.66	53.4	53.4
ZMIX * TURBIDITY	1.48	1.48	16.5	16.5
ZMIX / SECCHI	3.16	2.69	24.0	16.2
CHL-A * SECCHI	21.25	17.96	85.0	78.8
CHL-A / TOTAL P	.50	.43	92.8	89.3
FREQ(CHL-a>10) %	99.98	99.15	.0	.0
FREQ(CHL-a>20) %	88.00	53.02	.0	.0
FREQ(CHL-a>30) %	42.98	10.09	.0	.0
FREQ(CHL-a>40) %	12.80	1.27	.0	.0
FREQ(CHL-a>50) %	3.01	.15	.0	.0
FREQ(CHL-a>60) %	.64	.02	.0	.0
CARLSON TSI-P	63.19	60.41	.0	.0
CARLSON TSI-CHLA	63.89	60.65	.0	.0
CARLSON TSI-SEC	64.85	62.53	.0	.0

SEGMENT: 3 AREA-WTD MEAN

VARIABLE		VALUES OBSERVED	VALUES ESTIMATED	RANKS (%) OBSERVED	RANKS (%) ESTIMATED
TOTAL P	MG/M3	49.51	49.50	51.5	51.5
TOTAL N	MG/M3	1278.63	1276.38	64.8	64.7
C.NUTRIENT	MG/M3	42.90	43.79	59.1	60.1
CHL-A	MG/M3	21.42	21.40	85.8	85.8
SECCHI	M	1.04	.96	47.9	43.7
ORGANIC N	MG/M3	1163.65	1163.57	96.1	96.1
TP-ORTHO-P	MG/M3	38.61	38.54	60.5	60.4
ANTILOG PC-1		605.56	636.27	75.5	76.7
ANTILOG PC-2		12.29	11.59	89.1	86.9
(N - 150) / P		22.80	22.75	66.7	66.6
INORGANIC N / P		10.55	10.29	14.9	14.3
TURBIDITY	1/M	.52	.52	43.3	43.3
ZMIX * TURBIDITY		1.99	1.99	27.7	27.7
ZMIX / SECCHI		3.66	3.96	32.4	37.5
CHL-A * SECCHI		22.22	20.48	86.4	83.8
CHL-A / TOTAL P		.43	.43	89.4	89.3
FREQ(CHL-a>10)	%	99.16	99.15	.0	.0
FREQ(CHL-a>20)	%	53.16	53.03	.0	.0
FREQ(CHL-a>30)	%	10.16	10.10	.0	.0
FREQ(CHL-a>40)	%	1.28	1.27	.0	.0
FREQ(CHL-a>50)	%	.15	.15	.0	.0
FREQ(CHL-a>60)	%	.02	.02	.0	.0
CARLSON TSI-P		60.42	60.42	.0	.0
CARLSON TSI-CHLA		60.66	60.65	.0	.0
CARLSON TSI-SEC		59.47	60.63	.0	.0

CASE: 25% Crooked Lakes Stream Inputs

HYDRAULIC AND DISPERSION PARAMETERS:

SEG	OUT	NET INFLOW HM3/YR	RESIDENCE TIME YRS	OVERFLOW RATE M/YR	MEAN VELOCITY KM/YR	DISPERSION ESTIMATED KM2/YR	DISPERSION NUMERIC KM2/YR	EXCHANGE RATE HM3/YR
1	0	2.34	1.87178	1.8	2.1	1000.	4.	0.
2	1	.00	.00000	.0	1.0	1000.	0.	181.

CASE: 50% Crooked Lakes Stream Inputs

GROSS WATER BALANCE:

ID	T	LOCATION	DRAINAGE AREA KM2	FLOW (HM3/YR) MEAN	FLOW (HM3/YR) VARIANCE	FLOW (HM3/YR) CV	RUNOFF M/YR
1	1	Inlet 385552	186.766	1.870	.000E+00	.000	.010
2	4	Outlet 385554	223.908	2.220	.000E+00	.000	.010
3	1	TRIBUTARIES	34.605	.604	.000E+00	.000	.017
		PRECIPITATION	2.537	1.471	.866E-01	.200	.580
		TRIBUTARY INFLOW	221.371	2.474	.000E+00	.000	.011
		***TOTAL INFLOW	223.908	3.945	.866E-01	.075	.018
		GAUGED OUTFLOW	223.908	2.220	.000E+00	.000	.010
		ADVECTIVE OUTFLOW	.000	.000	.354E+00	9.990	-114.349
		***TOTAL OUTFLOW	223.908	2.220	.354E+00	.268	.010
		***EVAPORATION	.000	1.725	.268E+00	.300	.000

GROSS MASS BALANCE BASED UPON OBSERVED CONCENTRATIONS

COMPONENT: CONSERV

ID	T	LOCATION	LOADING KG/YR	LOADING %(I)	VARIANCE KG/YR**2	VARIANCE %(I)	CV	CONC MG/M3	EXPORT KG/KM2
1	1	Inlet 385552	.0	.0	.000E+00	.0	.000	.0	.0
2	4	Outlet 385554	.0	.0	.000E+00	.0	.000	.0	.0
3	1	TRIBUTARIES	.0	.0	.000E+00	.0	.000	.0	.0

HYDRAULIC OVERFLOW RATE M/YR	HYDRAULIC RESIDENCE TIME YRS	CONSERV POOL CONC MG/M3	CONSERV RESIDENCE TIME YRS	CONSERV TURNOVER RATIO -	CONSERV RETENTION COEF -
.88	3.1988	.0	.0000	.0000	.0000

GROSS MASS BALANCE BASED UPON OBSERVED CONCENTRATIONS

COMPONENT: TOTAL P

ID	T	LOCATION	LOADING KG/YR	LOADING %(I)	VARIANCE KG/YR**2	VARIANCE %(I)	CV	CONC MG/M3	EXPORT KG/KM2
1	1	Inlet 385552	15.1	12.1	.816E+00	.1	.060	8.1	.1
2	4	Outlet 385554	75.2	60.5	.500E+02	3.4	.094	33.9	.3
3	1	TRIBUTARIES	33.1	26.7	.000E+00	.0	.000	54.9	1.0
PRECIPITATION			76.1	61.2	.145E+04	99.9	.500	51.7	30.0
TRIBUTARY INFLOW			48.2	38.8	.816E+00	.1	.019	19.5	.2
***TOTAL INFLOW			124.3	100.0	.145E+04	100.0	.306	31.5	.6
GAUGED OUTFLOW			88.8	71.4	.000E+00	.0	.000	40.0	.4
ADVECTIVE OUTFLOW			.0	.0	.567E+03	39.1	9.999	40.0	-4574.0
***TOTAL OUTFLOW			88.8	71.5	.567E+03	39.1	.268	40.0	.4
***RETENTION			35.5	28.5	.202E+04	139.1	1.265	.0	.0

OVERFLOW RATE M/YR	HYDRAULIC RESIDENCE TIME YRS	TOTAL P POOL CONC MG/M3	TOTAL P RESIDENCE TIME YRS	TOTAL P TURNOVER RATIO -	TOTAL P RETENTION COEF -
.88	3.1988	49.5	2.8288	.3535	.2855

GROSS MASS BALANCE BASED UPON OBSERVED CONCENTRATIONS

COMPONENT: TOTAL N

ID	T	LOCATION	LOADING KG/YR	LOADING %(I)	VARIANCE KG/YR**2	VARIANCE %(I)	CV	CONC MG/M3	EXPORT KG/KM2
1	1	Inlet 385552	363.5	10.3	.640E+02	.0	.022	194.4	1.9
2	4	Outlet 385554	2605.5	73.5	.299E+04	.2	.021	1173.7	11.6
3	1	TRIBUTARIES	643.3	18.2	.000E+00	.0	.000	1065.0	18.6
PRECIPITATION			2537.0	71.6	.161E+07	100.0	.500	1724.1	1000.0
TRIBUTARY INFLOW			1006.8	28.4	.640E+02	.0	.008	406.9	4.5
***TOTAL INFLOW			3543.8	100.0	.161E+07	100.0	.358	898.2	15.8
GAUGED OUTFLOW			3037.0	85.7	.000E+00	.0	.000	1368.0	13.6
ADVECTIVE OUTFLOW			.4	.0	.663E+06	41.2	9.999	1368.0	********
***TOTAL OUTFLOW			3037.4	85.7	.663E+06	41.2	.268	1368.0	13.6
***RETENTION			506.4	14.3	.227E+07	141.2	2.977	.0	.0

OVERFLOW RATE M/YR	HYDRAULIC RESIDENCE TIME YRS	TOTAL N POOL CONC MG/M3	TOTAL N RESIDENCE TIME YRS	TOTAL N TURNOVER RATIO -	TOTAL N RETENTION COEF -
.88	3.1988	1278.6	2.5626	.3902	.1429

CASE: 50% Crooked Lakes Stream Inputs

HYDRAULIC AND DISPERSION PARAMETERS:

SEG	OUT	NET INFLOW HM3/YR	RESIDENCE TIME YRS	OVERFLOW RATE M/YR	MEAN VELOCITY KM/YR	DISPERSION ESTIMATED KM2/YR	DISPERSION NUMERIC KM2/YR	EXCHANGE RATE HM3/YR
1	0	2.34	1.87178	1.8	2.1	1000.	4.	0.
2	1	.00	.00000	.0	1.0	1000.	0.	181.

CASE: 25% Crooked Lakes Stream Inputs
OBSERVED AND PREDICTED DIAGNOSTIC VARIABLES
RANKED AGAINST CE MODEL DEVELOPMENT DATA SET

SEGMENT: 1 Lower 381030

VARIABLE	VALUES OBSERVED	VALUES ESTIMATED	RANKS (%) OBSERVED	RANKS (%) ESTIMATED
TOTAL P MG/M3	40.00	36.30	42.1	37.9
TOTAL N MG/M3	1368.00	975.12	68.7	48.3
C.NUTRIENT MG/M3	37.21	32.10	52.1	44.7
CHL-A MG/M3	13.87	14.52	69.4	71.4
SECCHI M	1.33	1.30	60.8	59.7
ORGANIC N MG/M3	1263.00	881.52	97.3	88.8
TP-ORTHO-P MG/M3	31.00	26.02	51.4	44.0
ANTILOG PC-1	400.99	335.01	64.7	59.4
ANTILOG PC-2	11.25	11.13	85.6	85.1
(N - 150) / P	30.45	22.73	80.4	66.5
INORGANIC N / P	11.67	9.10	17.4	11.7
TURBIDITY 1/M	.41	.41	32.2	32.2
ZMIX * TURBIDITY	2.10	2.10	30.0	30.0
ZMIX / SECCHI	3.90	3.98	36.4	37.8
CHL-A * SECCHI	18.45	18.90	79.9	80.8
CHL-A / TOTAL P	.35	.40	81.5	86.9
FREQ(CHL-a>10) %	82.65	86.28	.0	.0
FREQ(CHL-a>20) %	8.53	11.17	.0	.0
FREQ(CHL-a>30) %	.33	.51	.0	.0
FREQ(CHL-a>40) %	.01	.02	.0	.0
FREQ(CHL-a>50) %	.00	.00	.0	.0
FREQ(CHL-a>60) %	.00	.00	.0	.0
CARLSON TSI-P	57.34	55.95	.0	.0
CARLSON TSI-CHLA	56.40	56.85	.0	.0
CARLSON TSI-SEC	55.89	56.20	.0	.0

SEGMENT: 2 Upper 385553

VARIABLE	VALUES OBSERVED	VALUES ESTIMATED	RANKS (%) OBSERVED	RANKS (%) ESTIMATED
TOTAL P MG/M3	60.00	36.36	59.9	38.0
TOTAL N MG/M3	1180.00	977.98	60.1	48.5
C.NUTRIENT MG/M3	49.18	32.17	65.6	44.8
CHL-A MG/M3	29.76	14.56	93.3	71.5
SECCHI M	.71	.98	29.3	44.9
ORGANIC N MG/M3	1054.00	915.14	94.1	90.1
TP-ORTHO-P MG/M3	47.00	31.02	68.2	51.4
ANTILOG PC-1	906.22	389.50	84.1	63.8
ANTILOG PC-2	11.46	9.25	86.4	75.5
(N - 150) / P	17.17	22.77	50.6	66.6
INORGANIC N / P	9.69	11.76	13.0	17.6
TURBIDITY 1/M	.66	.66	53.4	53.4
ZMIX * TURBIDITY	1.48	1.48	16.5	16.5
ZMIX / SECCHI	3.16	2.30	24.0	10.5
CHL-A * SECCHI	21.25	14.26	85.0	68.2
CHL-A / TOTAL P	.50	.40	92.8	86.9
FREQ(CHL-a>10) %	99.98	86.47	.0	.0
FREQ(CHL-a>20) %	88.00	11.33	.0	.0
FREQ(CHL-a>30) %	42.98	.52	.0	.0
FREQ(CHL-a>40) %	12.80	.02	.0	.0
FREQ(CHL-a>50) %	3.01	.00	.0	.0
FREQ(CHL-a>60) %	.64	.00	.0	.0
CARLSON TSI-P	63.19	55.97	.0	.0
CARLSON TSI-CHLA	63.89	56.87	.0	.0
CARLSON TSI-SEC	64.85	60.29	.0	.0

SEGMENT: 3 AREA-WTD MEAN

VARIABLE		VALUES OBSERVED	VALUES ESTIMATED	RANKS (%) OBSERVED	RANKS (%) ESTIMATED
TOTAL P	MG/M3	49.51	36.33	51.5	37.9
TOTAL N	MG/M3	1278.63	976.48	64.8	48.4
C.NUTRIENT	MG/M3	42.90	32.13	59.1	44.8
CHL-A	MG/M3	21.42	14.54	85.8	71.5
SECCHI	M	1.04	1.15	47.9	53.2
ORGANIC N	MG/M3	1163.65	897.50	96.1	89.5
TP-ORTHO-P	MG/M3	38.61	28.39	60.5	47.7
ANTILOG PC-1		605.56	358.22	75.5	61.4
ANTILOG PC-2		12.29	10.26	89.1	81.3
(N - 150) / P		22.80	22.75	66.7	66.6
INORGANIC N / P		10.55	9.95	14.9	13.6
TURBIDITY	1/M	.52	.52	43.3	43.3
ZMIX * TURBIDITY		1.99	1.99	27.7	27.7
ZMIX / SECCHI		3.66	3.30	32.4	26.3
CHL-A * SECCHI		22.22	16.70	86.4	75.7
CHL-A / TOTAL P		.43	.40	89.4	86.9
FREQ(CHL-a>10) %		99.16	86.37	.0	.0
FREQ(CHL-a>20) %		53.16	11.24	.0	.0
FREQ(CHL-a>30) %		10.16	.52	.0	.0
FREQ(CHL-a>40) %		1.28	.02	.0	.0
FREQ(CHL-a>50) %		.15	.00	.0	.0
FREQ(CHL-a>60) %		.02	.00	.0	.0
CARLSON TSI-P		60.42	55.96	.0	.0
CARLSON TSI-CHLA		60.66	56.86	.0	.0
CARLSON TSI-SEC		59.47	58.00	.0	.0

CASE: 50% Crooked Lakes Stream Inputs

HYDRAULIC AND DISPERSION PARAMETERS:

SEG	OUT	NET INFLOW HM3/YR	RESIDENCE TIME YRS	OVERFLOW RATE M/YR	MEAN VELOCITY KM/YR	DISPERSION ESTIMATED KM2/YR	DISPERSION NUMERIC KM2/YR	EXCHANGE RATE HM3/YR
1	0	2.34	1.87178	1.8	2.1	1000.	4.	0.
2	1	.00	.00000	.0	1.0	1000.	0.	181.

CASE: 50% Crooked Lakes Stream Inputs

GROSS WATER BALANCE:

ID	T	LOCATION	DRAINAGE AREA KM2	FLOW (HM3/YR) MEAN	VARIANCE	CV	RUNOFF M/YR
1	1	Inlet 385552	186.766	1.870	.000E+00	.000	.010
2	4	Outlet 385554	223.908	2.220	.000E+00	.000	.010
3	1	TRIBUTARIES	34.605	.604	.000E+00	.000	.017
		PRECIPITATION	2.537	1.471	.866E-01	.200	.580
		TRIBUTARY INFLOW	221.371	2.474	.000E+00	.000	.011
		***TOTAL INFLOW	223.908	3.945	.866E-01	.075	.018
		GAUGED OUTFLOW	223.908	2.220	.000E+00	.000	.010
		ADVECTIVE OUTFLOW	.000	.000	.354E+00	9.990	-114.349
		***TOTAL OUTFLOW	223.908	2.220	.354E+00	.268	.010
		***EVAPORATION	.000	1.725	.268E+00	.300	.000

GROSS MASS BALANCE BASED UPON OBSERVED CONCENTRATIONS

COMPONENT: CONSERV

ID	T	LOCATION	LOADING KG/YR	LOADING %(I)	VARIANCE KG/YR**2	VARIANCE %(I)	CV	CONC MG/M3	EXPORT KG/KM2
1	1	Inlet 385552	.0	.0	.000E+00	.0	.000	.0	.0
2	4	Outlet 385554	.0	.0	.000E+00	.0	.000	.0	.0
3	1	TRIBUTARIES	.0	.0	.000E+00	.0	.000	.0	.0

OVERFLOW RATE M/YR	HYDRAULIC RESIDENCE TIME YRS	CONSERV POOL CONC MG/M3	CONSERV RESIDENCE TIME YRS	CONSERV TURNOVER RATIO -	CONSERV RETENTION COEF -
.88	3.1988	.0	.0000	.0000	.0000

GROSS MASS BALANCE BASED UPON OBSERVED CONCENTRATIONS

COMPONENT: TOTAL P

ID	T	LOCATION	LOADING KG/YR	LOADING %(I)	VARIANCE KG/YR**2	VARIANCE %(I)	CV	CONC MG/M3	EXPORT KG/KM2
1	1	Inlet 385552	30.1	21.6	.326E+01	.2	.060	16.1	.2
2	4	Outlet 385554	75.2	54.0	.500E+02	3.4	.094	33.9	.3
3	1	TRIBUTARIES	33.1	23.8	.000E+00	.0	.000	54.9	1.0
		PRECIPITATION	76.1	54.6	.145E+04	99.8	.500	51.7	30.0
		TRIBUTARY INFLOW	63.2	45.4	.326E+01	.2	.029	25.6	.3
		***TOTAL INFLOW	139.4	100.0	.145E+04	100.0	.273	35.3	.6
		GAUGED OUTFLOW	88.8	63.7	.000E+00	.0	.000	40.0	.4
		ADVECTIVE OUTFLOW	.0	.0	.567E+03	39.1	9.999	40.0	-4574.0
		***TOTAL OUTFLOW	88.8	63.7	.567E+03	39.1	.268	40.0	.4
		***RETENTION	50.5	36.3	.202E+04	139.1	.889	.0	.0

OVERFLOW RATE M/YR	HYDRAULIC RESIDENCE TIME YRS	TOTAL P POOL CONC MG/M3	TOTAL P RESIDENCE TIME YRS	TOTAL P TURNOVER RATIO -	TOTAL P RETENTION COEF -
.88	3.1988	49.5	2.5232	.3963	.3627

GROSS MASS BALANCE BASED UPON OBSERVED CONCENTRATIONS

COMPONENT: TOTAL N

ID	T	LOCATION	LOADING KG/YR	LOADING %(I)	VARIANCE KG/YR**2	VARIANCE %(I)	CV	CONC MG/M3	EXPORT KG/KM2
1	1	Inlet 385552	727.0	18.6	.256E+03	.0	.022	388.8	3.9
2	4	Outlet 385554	2605.5	66.7	.299E+04	.2	.021	1173.7	11.6
3	1	TRIBUTARIES	643.3	16.5	.000E+00	.0	.000	1065.0	18.6
		PRECIPITATION	2537.0	64.9	.161E+07	100.0	.500	1724.1	1000.0
		TRIBUTARY INFLOW	1370.3	35.1	.256E+03	.0	.012	553.9	6.2
		***TOTAL INFLOW	3907.3	100.0	.161E+07	100.0	.325	990.3	17.5
		GAUGED OUTFLOW	3037.0	77.7	.000E+00	.0	.000	1368.0	13.6
		ADVECTIVE OUTFLOW	.4	.0	.663E+06	41.2	9.999	1368.0	********
		***TOTAL OUTFLOW	3037.4	77.7	.663E+06	41.2	.268	1368.0	13.6
		***RETENTION	869.9	22.3	.227E+07	141.2	1.733	.0	.0

OVERFLOW RATE M/YR	HYDRAULIC RESIDENCE TIME YRS	TOTAL N POOL CONC MG/M3	TOTAL N RESIDENCE TIME YRS	TOTAL N TURNOVER RATIO -	TOTAL N RETENTION COEF -
.88	3.1988	1278.6	2.3242	.4303	.2226

CASE: 50% Crooked Lakes Stream Inputs

OBSERVED AND PREDICTED DIAGNOSTIC VARIABLES
RANKED AGAINST CE MODEL DEVELOPMENT DATA SET

SEGMENT: 1 Lower 381030

VARIABLE	VALUES OBSERVED	VALUES ESTIMATED	RANKS (%) OBSERVED	RANKS (%) ESTIMATED
TOTAL P MG/M3	40.00	40.71	42.1	42.8
TOTAL N MG/M3	1368.00	1075.37	68.7	54.4
C.NUTRIENT MG/M3	37.21	36.00	52.1	50.4
CHL-A MG/M3	13.87	16.75	69.4	77.4
SECCHI M	1.33	1.21	60.8	56.1
ORGANIC N MG/M3	1263.00	968.16	97.3	91.9
TP-ORTHO-P MG/M3	31.00	29.32	51.4	49.0
ANTILOG PC-1	400.99	414.56	64.7	65.6
ANTILOG PC-2	11.25	11.61	85.6	86.9
(N - 150) / P	30.45	22.73	80.4	66.5
INORGANIC N / P	11.67	9.41	17.4	12.4
TURBIDITY 1/M	.41	.41	32.2	32.2
ZMIX * TURBIDITY	2.10	2.10	30.0	30.0
ZMIX / SECCHI	3.90	4.27	36.4	42.4
CHL-A * SECCHI	18.45	20.33	79.9	83.5
CHL-A / TOTAL P	.35	.41	81.5	87.8
FREQ(CHL-a>10) %	82.65	94.18	.0	.0
FREQ(CHL-a>20) %	8.53	22.95	.0	.0
FREQ(CHL-a>30) %	.33	1.82	.0	.0
FREQ(CHL-a>40) %	.01	.11	.0	.0
FREQ(CHL-a>50) %	.00	.01	.0	.0
FREQ(CHL-a>60) %	.00	.00	.0	.0
CARLSON TSI-P	57.34	57.60	.0	.0
CARLSON TSI-CHLA	56.40	58.25	.0	.0
CARLSON TSI-SEC	55.89	57.21	.0	.0

SEGMENT: 2 Upper 385553

VARIABLE	VALUES OBSERVED	VALUES ESTIMATED	RANKS (%) OBSERVED	RANKS (%) ESTIMATED
TOTAL P MG/M3	60.00	40.74	59.9	42.9
TOTAL N MG/M3	1180.00	1077.63	60.1	54.5
C.NUTRIENT MG/M3	49.18	36.04	65.6	50.5
CHL-A MG/M3	29.76	16.78	93.3	77.5
SECCHI M	.71	.93	29.3	42.2
ORGANIC N MG/M3	1054.00	1001.30	94.1	92.9
TP-ORTHO-P MG/M3	47.00	34.30	68.2	55.6
ANTILOG PC-1	906.22	476.90	84.1	69.4
ANTILOG PC-2	11.46	9.76	86.4	78.6
(N - 150) / P	17.17	22.77	50.6	66.6
INORGANIC N / P	9.69	11.85	13.0	17.8
TURBIDITY 1/M	.66	.66	53.4	53.4
ZMIX * TURBIDITY	1.48	1.48	16.5	16.5
ZMIX / SECCHI	3.16	2.43	24.0	12.3
CHL-A * SECCHI	21.25	15.59	85.0	72.6
CHL-A / TOTAL P	.50	.41	92.8	87.9
FREQ(CHL-a>10) %	99.98	94.24	.0	.0
FREQ(CHL-a>20) %	88.00	23.10	.0	.0
FREQ(CHL-a>30) %	42.98	1.85	.0	.0
FREQ(CHL-a>40) %	12.80	.12	.0	.0
FREQ(CHL-a>50) %	3.01	.01	.0	.0
FREQ(CHL-a>60) %	.64	.00	.0	.0
CARLSON TSI-P	63.19	57.61	.0	.0
CARLSON TSI-CHLA	63.89	58.27	.0	.0
CARLSON TSI-SEC	64.85	61.06	.0	.0

SEGMENT: 3 AREA-WTD MEAN

VARIABLE	VALUES OBSERVED	VALUES ESTIMATED	RANKS (%) OBSERVED	RANKS (%) ESTIMATED
TOTAL P MG/M3	49.51	40.72	51.5	42.8
TOTAL N MG/M3	1278.63	1076.44	64.8	54.5
C.NUTRIENT MG/M3	42.90	36.02	59.1	50.4
CHL-A MG/M3	21.42	16.77	85.8	77.4
SECCHI M	1.04	1.08	47.9	49.9
ORGANIC N MG/M3	1163.65	983.91	96.1	92.4
TP-ORTHO-P MG/M3	38.61	31.69	60.5	52.3
ANTILOG PC-1	605.56	441.28	75.5	67.3
ANTILOG PC-2	12.29	10.75	89.1	83.6
(N - 150) / P	22.80	22.75	66.7	66.6
INORGANIC N / P	10.55	10.24	14.9	14.2
TURBIDITY 1/M	.52	.52	43.3	43.3
ZMIX * TURBIDITY	1.99	1.99	27.7	27.7
ZMIX / SECCHI	3.66	3.52	32.4	30.0
CHL-A * SECCHI	22.22	18.08	86.4	79.1
CHL-A / TOTAL P	.43	.41	89.4	87.8
FREQ(CHL-a>10) %	99.16	94.21	.0	.0
FREQ(CHL-a>20) %	53.16	23.03	.0	.0
FREQ(CHL-a>30) %	10.16	1.83	.0	.0
FREQ(CHL-a>40) %	1.28	.12	.0	.0
FREQ(CHL-a>50) %	.15	.01	.0	.0
FREQ(CHL-a>60) %	.02	.00	.0	.0
CARLSON TSI-P	60.42	57.60	.0	.0
CARLSON TSI-CHLA	60.66	58.26	.0	.0
CARLSON TSI-SEC	59.47	58.91	.0	.0

CASE: 75% Crooked Lakes Stream Inputs

HYDRAULIC AND DISPERSION PARAMETERS:

SEG	OUT	NET INFLOW HM3/YR	RESIDENCE TIME YRS	OVERFLOW RATE M/YR	MEAN VELOCITY KM/YR	----DISPERSION----- ESTIMATED KM2/YR	NUMERIC KM2/YR	EXCHANGE RATE HM3/YR
1	0	2.34	1.87178	1.8	2.1	1000.	4.	0.
2	1	.00	.00000	.0	1.0	1000.	0.	181.

CASE: 75% Crooked Lakes Stream Inputs

GROSS WATER BALANCE:

ID	T	LOCATION	DRAINAGE AREA KM2	---- FLOW (HM3/YR) ---- MEAN	VARIANCE	CV	RUNOFF M/YR
1	1	Inlet 385552	186.766	1.870	.000E+00	.000	.010
2	4	Outlet 385554	223.908	2.220	.000E+00	.000	.010
3	1	TRIBUTARIES	34.605	.604	.000E+00	.000	.017
		PRECIPITATION	2.537	1.471	.866E-01	.200	.580
		TRIBUTARY INFLOW	221.371	2.474	.000E+00	.000	.011
		***TOTAL INFLOW	223.908	3.945	.866E-01	.075	.018
		GAUGED OUTFLOW	223.908	2.220	.000E+00	.000	.010
		ADVECTIVE OUTFLOW	.000	.000	.354E+00	9.990	-114.349
		***TOTAL OUTFLOW	223.908	2.220	.354E+00	.268	.010
		***EVAPORATION	.000	1.725	.268E+00	.300	.000

GROSS MASS BALANCE BASED UPON OBSERVED CONCENTRATIONS

COMPONENT: CONSERV

ID	T	LOCATION	----- LOADING ---- KG/YR	%(I)	--- VARIANCE --- KG/YR**2	%(I)	CV	CONC MG/M3	EXPORT KG/KM2
1	1	Inlet 385552	.0	.0	.000E+00	.0	.000	.0	.0
2	4	Outlet 385554	.0	.0	.000E+00	.0	.000	.0	.0
3	1	TRIBUTARIES	.0	.0	.000E+00	.0	.000	.0	.0

OVERFLOW RATE M/YR	HYDRAULIC RESIDENCE TIME YRS	-------------- CONSERV -------------- POOL CONC MG/M3	RESIDENCE TIME YRS	TURNOVER RATIO -	RETENTION COEF -
.88	3.1988	.0	.0000	.0000	.0000

GROSS MASS BALANCE BASED UPON OBSERVED CONCENTRATIONS

COMPONENT: TOTAL P

ID	T	LOCATION	LOADING KG/YR	LOADING %(I)	VARIANCE KG/YR**2	VARIANCE %(I)	CV	CONC MG/M3	EXPORT KG/KM2
1	1	Inlet 385552	45.1	29.2	.734E+01	.5	.060	24.1	.2
2	4	Outlet 385554	75.2	48.7	.500E+02	3.4	.094	33.9	.3
3	1	TRIBUTARIES	33.1	21.5	.000E+00	.0	.000	54.9	1.0
		PRECIPITATION	76.1	49.3	.145E+04	99.5	.500	51.7	30.0
		TRIBUTARY INFLOW	78.3	50.7	.734E+01	.5	.035	31.6	.4
		***TOTAL INFLOW	154.4	100.0	.146E+04	100.0	.247	39.1	.7
		GAUGED OUTFLOW	88.8	57.5	.000E+00	.0	.000	40.0	.4
		ADVECTIVE OUTFLOW	.0	.0	.567E+03	39.0	9.999	40.0	-4574.0
		***TOTAL OUTFLOW	88.8	57.5	.567E+03	39.0	.268	40.0	.4
		***RETENTION	65.6	42.5	.202E+04	139.0	.686	.0	.0

OVERFLOW RATE M/YR	HYDRAULIC RESIDENCE TIME YRS	TOTAL P POOL CONC MG/M3	TOTAL P RESIDENCE TIME YRS	TOTAL P TURNOVER RATIO -	TOTAL P RETENTION COEF -
.88	3.1988	49.5	2.2775	.4391	.4247

GROSS MASS BALANCE BASED UPON OBSERVED CONCENTRATIONS

COMPONENT: TOTAL N

ID	T	LOCATION	LOADING KG/YR	LOADING %(I)	VARIANCE KG/YR**2	VARIANCE %(I)	CV	CONC MG/M3	EXPORT KG/KM2
1	1	Inlet 385552	1090.6	25.5	.576E+03	.0	.022	583.2	5.8
2	4	Outlet 385554	2605.5	61.0	.299E+04	.2	.021	1173.7	11.6
3	1	TRIBUTARIES	643.3	15.1	.000E+00	.0	.000	1065.0	18.6
		PRECIPITATION	2537.0	59.4	.161E+07	100.0	.500	1724.1	1000.0
		TRIBUTARY INFLOW	1733.8	40.6	.576E+03	.0	.014	700.8	7.8
		***TOTAL INFLOW	4270.8	100.0	.161E+07	100.0	.297	1082.5	19.1
		GAUGED OUTFLOW	3037.0	71.1	.000E+00	.0	.000	1368.0	13.6
		ADVECTIVE OUTFLOW	.4	.0	.663E+06	41.2	9.999	1368.0	********
		***TOTAL OUTFLOW	3037.4	71.1	.663E+06	41.2	.268	1368.0	13.6
		***RETENTION	1233.5	28.9	.227E+07	141.2	1.222	.0	.0

OVERFLOW RATE M/YR	HYDRAULIC RESIDENCE TIME YRS	TOTAL N POOL CONC MG/M3	TOTAL N RESIDENCE TIME YRS	TOTAL N TURNOVER RATIO -	TOTAL N RETENTION COEF -
.88	3.1988	1278.6	2.1264	.4703	.2888

CASE: 75% Crooked Lakes Stream Inputs

OBSERVED AND PREDICTED DIAGNOSTIC VARIABLES
RANKED AGAINST CE MODEL DEVELOPMENT DATA SET

SEGMENT: 1 Lower 381030

VARIABLE	VALUES OBSERVED	VALUES ESTIMATED	RANKS (%) OBSERVED	RANKS (%) ESTIMATED
TOTAL P MG/M3	40.00	45.11	42.1	47.3
TOTAL N MG/M3	1368.00	1175.62	68.7	59.9
C.NUTRIENT MG/M3	37.21	39.89	52.1	55.5
CHL-A MG/M3	13.87	19.05	69.4	82.1
SECCHI M	1.33	1.13	60.8	52.6
ORGANIC N MG/M3	1263.00	1057.09	97.3	94.2
TP-ORTHO-P MG/M3	31.00	32.71	51.4	53.6
ANTILOG PC-1	400.99	503.53	64.7	70.9
ANTILOG PC-2	11.25	12.04	85.6	88.3
(N - 150) / P	30.45	22.74	80.4	66.5
INORGANIC N / P	11.67	9.56	17.4	12.7
TURBIDITY 1/M	.41	.41	32.2	32.2
ZMIX * TURBIDITY	2.10	2.10	30.0	30.0
ZMIX / SECCHI	3.90	4.57	36.4	47.0
CHL-A * SECCHI	18.45	21.61	79.9	85.6
CHL-A / TOTAL P	.35	.42	81.5	88.6
FREQ(CHL-a>10) %	82.65	97.71	.0	.0
FREQ(CHL-a>20) %	8.53	37.73	.0	.0
FREQ(CHL-a>30) %	.33	4.81	.0	.0
FREQ(CHL-a>40) %	.01	.44	.0	.0
FREQ(CHL-a>50) %	.00	.04	.0	.0
FREQ(CHL-a>60) %	.00	.00	.0	.0
CARLSON TSI-P	57.34	59.08	.0	.0
CARLSON TSI-CHLA	56.40	59.51	.0	.0
CARLSON TSI-SEC	55.89	58.18	.0	.0

SEGMENT: 2 Upper 385553

VARIABLE	VALUES OBSERVED	VALUES ESTIMATED	RANKS (%) OBSERVED	RANKS (%) ESTIMATED
TOTAL P MG/M3	60.00	45.11	59.9	47.3
TOTAL N MG/M3	1180.00	1177.29	60.1	59.9
C.NUTRIENT MG/M3	49.18	39.91	65.6	55.5
CHL-A MG/M3	29.76	19.06	93.3	82.1
SECCHI M	.71	.88	29.3	39.5
ORGANIC N MG/M3	1054.00	1089.72	94.1	94.9
TP-ORTHO-P MG/M3	47.00	37.67	68.2	59.5
ANTILOG PC-1	906.22	573.78	84.1	74.2
ANTILOG PC-2	11.46	10.21	86.4	81.0
(N - 150) / P	17.17	22.77	50.6	66.6
INORGANIC N / P	9.69	11.77	13.0	17.6
TURBIDITY 1/M	.66	.66	53.4	53.4
ZMIX * TURBIDITY	1.48	1.48	16.5	16.5
ZMIX / SECCHI	3.16	2.56	24.0	14.2
CHL-A * SECCHI	21.25	16.82	85.0	76.0
CHL-A / TOTAL P	.50	.42	92.8	88.6
FREQ(CHL-a>10) %	99.98	97.72	.0	.0
FREQ(CHL-a>20) %	88.00	37.81	.0	.0
FREQ(CHL-a>30) %	42.98	4.83	.0	.0
FREQ(CHL-a>40) %	12.80	.44	.0	.0
FREQ(CHL-a>50) %	3.01	.04	.0	.0
FREQ(CHL-a>60) %	.64	.00	.0	.0
CARLSON TSI-P	63.19	59.08	.0	.0
CARLSON TSI-CHLA	63.89	59.52	.0	.0
CARLSON TSI-SEC	64.85	61.80	.0	.0

SEGMENT: 3 AREA-WTD MEAN

VARIABLE	VALUES OBSERVED	VALUES ESTIMATED	RANKS (%) OBSERVED	RANKS (%) ESTIMATED
TOTAL P MG/M3	49.51	45.11	51.5	47.3
TOTAL N MG/M3	1278.63	1176.41	64.8	59.9
C.NUTRIENT MG/M3	42.90	39.90	59.1	55.5
CHL-A MG/M3	21.42	19.05	85.8	82.1
SECCHI M	1.04	1.01	47.9	46.7
ORGANIC N MG/M3	1163.65	1072.60	96.1	94.5
TP-ORTHO-P MG/M3	38.61	35.07	60.5	56.5
ANTILOG PC-1	605.56	533.82	75.5	72.4
ANTILOG PC-2	12.29	11.19	89.1	85.4
(N - 150) / P	22.80	22.75	66.7	66.6
INORGANIC N / P	10.55	10.34	14.9	14.4
TURBIDITY 1/M	.52	.52	43.3	43.3
ZMIX * TURBIDITY	1.99	1.99	27.7	27.7
ZMIX / SECCHI	3.66	3.74	32.4	33.7
CHL-A * SECCHI	22.22	19.34	86.4	81.7
CHL-A / TOTAL P	.43	.42	89.4	88.6
FREQ(CHL-a>10) %	99.16	97.72	.0	.0
FREQ(CHL-a>20) %	53.16	37.77	.0	.0
FREQ(CHL-a>30) %	10.16	4.81	.0	.0
FREQ(CHL-a>40) %	1.28	.44	.0	.0
FREQ(CHL-a>50) %	.15	.04	.0	.0
FREQ(CHL-a>60) %	.02	.00	.0	.0
CARLSON TSI-P	60.42	59.08	.0	.0
CARLSON TSI-CHLA	60.66	59.51	.0	.0
CARLSON TSI-SEC	59.47	59.79	.0	.0

CASE: 90% Crooked Lakes Stream Inputs

HYDRAULIC AND DISPERSION PARAMETERS:

SEG	OUT	NET INFLOW HM3/YR	RESIDENCE TIME YRS	OVERFLOW RATE M/YR	MEAN VELOCITY KM/YR	----DISPERSION----- ESTIMATED KM2/YR	NUMERIC KM2/YR	EXCHANGE RATE HM3/YR
1	0	2.34	1.87178	1.8	2.1	1000.	4.	0.
2	1	.00	.00000	.0	1.0	1000.	0.	181.

CASE: 90% Crooked Lakes Stream Inputs

GROSS WATER BALANCE:

ID	T	LOCATION	DRAINAGE AREA KM2	---- FLOW (HM3/YR) ---- MEAN	VARIANCE	CV	RUNOFF M/YR
1	1	Inlet 385552	186.766	1.870	.000E+00	.000	.010
2	4	Outlet 385554	223.908	2.220	.000E+00	.000	.010
3	1	TRIBUTARIES	34.605	.604	.000E+00	.000	.017
		PRECIPITATION	2.537	1.471	.866E-01	.200	.580
		TRIBUTARY INFLOW	221.371	2.474	.000E+00	.000	.011
		***TOTAL INFLOW	223.908	3.945	.866E-01	.075	.018
		GAUGED OUTFLOW	223.908	2.220	.000E+00	.000	.010
		ADVECTIVE OUTFLOW	.000	.000	.354E+00	9.990	-114.349
		***TOTAL OUTFLOW	223.908	2.220	.354E+00	.268	.010
		***EVAPORATION	.000	1.725	.268E+00	.300	.000

GROSS MASS BALANCE BASED UPON OBSERVED CONCENTRATIONS

COMPONENT: CONSERV

ID	T	LOCATION	----- LOADING ---- KG/YR	%(I)	--- VARIANCE --- KG/YR**2	%(I)	CV	CONC MG/M3	EXPORT KG/KM2
1	1	Inlet 385552	.0	.0	.000E+00	.0	.000	.0	.0
2	4	Outlet 385554	.0	.0	.000E+00	.0	.000	.0	.0
3	1	TRIBUTARIES	.0	.0	.000E+00	.0	.000	.0	.0

OVERFLOW RATE M/YR	HYDRAULIC RESIDENCE TIME YRS	-------------- CONSERV -------------- POOL CONC MG/M3	RESIDENCE TIME YRS	TURNOVER RATIO -	RETENTION COEF -
.88	3.1988	.0	.0000	.0000	.0000

GROSS MASS BALANCE BASED UPON OBSERVED CONCENTRATIONS

COMPONENT: TOTAL P

ID	T	LOCATION	LOADING KG/YR	LOADING %(I)	VARIANCE KG/YR**2	VARIANCE %(I)	CV	CONC MG/M3	EXPORT KG/KM2
1	1	Inlet 385552	54.2	33.2	.106E+02	.7	.060	29.0	.3
2	4	Outlet 385554	75.2	46.0	.500E+02	3.4	.094	33.9	.3
3	1	TRIBUTARIES	33.1	20.3	.000E+00	.0	.000	54.9	1.0
		PRECIPITATION	76.1	46.6	.145E+04	99.3	.500	51.7	30.0
		TRIBUTARY INFLOW	87.3	53.4	.106E+02	.7	.037	35.3	.4
		***TOTAL INFLOW	163.4	100.0	.146E+04	100.0	.234	41.4	.7
		GAUGED OUTFLOW	88.8	54.3	.000E+00	.0	.000	40.0	.4
		ADVECTIVE OUTFLOW	.0	.0	.567E+03	38.9	9.999	40.0	-4574.0
		***TOTAL OUTFLOW	88.8	54.3	.567E+03	38.9	.268	40.0	.4
		***RETENTION	74.6	45.7	.203E+04	138.9	.603	.0	.0

OVERFLOW RATE M/YR	HYDRAULIC RESIDENCE TIME YRS	TOTAL P POOL CONC MG/M3	TOTAL P RESIDENCE TIME YRS	TOTAL P TURNOVER RATIO -	TOTAL P RETENTION COEF -
.88	3.1988	49.5	2.1516	.4648	.4565

GROSS MASS BALANCE BASED UPON OBSERVED CONCENTRATIONS

COMPONENT: TOTAL N

ID	T	LOCATION	LOADING KG/YR	LOADING %(I)	VARIANCE KG/YR**2	VARIANCE %(I)	CV	CONC MG/M3	EXPORT KG/KM2
1	1	Inlet 385552	1308.7	29.2	.829E+03	.1	.022	699.8	7.0
2	4	Outlet 385554	2605.5	58.0	.299E+04	.2	.021	1173.7	11.6
3	1	TRIBUTARIES	643.3	14.3	.000E+00	.0	.000	1065.0	18.6
		PRECIPITATION	2537.0	56.5	.161E+07	99.9	.500	1724.1	1000.0
		TRIBUTARY INFLOW	1951.9	43.5	.829E+03	.1	.015	789.0	8.8
		***TOTAL INFLOW	4488.9	100.0	.161E+07	100.0	.283	1137.7	20.0
		GAUGED OUTFLOW	3037.0	67.7	.000E+00	.0	.000	1368.0	13.6
		ADVECTIVE OUTFLOW	.4	.0	.663E+06	41.2	9.999	1368.0	********
		***TOTAL OUTFLOW	3037.4	67.7	.663E+06	41.2	.268	1368.0	13.6
		***RETENTION	1451.6	32.3	.227E+07	141.2	1.039	.0	.0

OVERFLOW RATE M/YR	HYDRAULIC RESIDENCE TIME YRS	TOTAL N POOL CONC MG/M3	TOTAL N RESIDENCE TIME YRS	TOTAL N TURNOVER RATIO -	TOTAL N RETENTION COEF -
.88	3.1988	1278.6	2.0231	.4943	.3234

CASE: 90% Crooked Lakes Stream Inputs

OBSERVED AND PREDICTED DIAGNOSTIC VARIABLES
RANKED AGAINST CE MODEL DEVELOPMENT DATA SET

SEGMENT: 1 Lower 381030

VARIABLE	VALUES OBSERVED	VALUES ESTIMATED	RANKS (%) OBSERVED	RANKS (%) ESTIMATED
TOTAL P MG/M3	40.00	47.75	42.1	49.9
TOTAL N MG/M3	1368.00	1235.77	68.7	62.8
C.NUTRIENT MG/M3	37.21	42.23	52.1	58.3
CHL-A MG/M3	13.87	20.45	69.4	84.4
SECCHI M	1.33	1.09	60.8	50.5
ORGANIC N MG/M3	1263.00	1111.57	97.3	95.3
TP-ORTHO-P MG/M3	31.00	34.79	51.4	56.2
ANTILOG PC-1	400.99	561.64	64.7	73.7
ANTILOG PC-2	11.25	12.27	85.6	89.0
(N - 150) / P	30.45	22.74	80.4	66.5
INORGANIC N / P	11.67	9.58	17.4	12.7
TURBIDITY 1/M	.41	.41	32.2	32.2
ZMIX * TURBIDITY	2.10	2.10	30.0	30.0
ZMIX / SECCHI	3.90	4.75	36.4	49.7
CHL-A * SECCHI	18.45	22.32	79.9	86.6
CHL-A / TOTAL P	.35	.43	81.5	89.1
FREQ(CHL-a>10) %	82.65	98.73	.0	.0
FREQ(CHL-a>20) %	8.53	47.00	.0	.0
FREQ(CHL-a>30) %	.33	7.68	.0	.0
FREQ(CHL-a>40) %	.01	.85	.0	.0
FREQ(CHL-a>50) %	.00	.09	.0	.0
FREQ(CHL-a>60) %	.00	.01	.0	.0
CARLSON TSI-P	57.34	59.90	.0	.0
CARLSON TSI-CHLA	56.40	60.21	.0	.0
CARLSON TSI-SEC	55.89	58.74	.0	.0

SEGMENT: 2 Upper 385553

VARIABLE	VALUES OBSERVED	VALUES ESTIMATED	RANKS (%) OBSERVED	RANKS (%) ESTIMATED
TOTAL P MG/M3	60.00	47.74	59.9	49.8
TOTAL N MG/M3	1180.00	1237.08	60.1	62.9
C.NUTRIENT MG/M3	49.18	42.24	65.6	58.3
CHL-A MG/M3	29.76	20.46	93.3	84.4
SECCHI M	.71	.86	29.3	38.0
ORGANIC N MG/M3	1054.00	1143.88	94.1	95.8
TP-ORTHO-P MG/M3	47.00	39.74	68.2	61.6
ANTILOG PC-1	906.22	636.66	84.1	76.7
ANTILOG PC-2	11.46	10.47	86.4	82.3
(N - 150) / P	17.17	22.77	50.6	66.6
INORGANIC N / P	9.69	11.64	13.0	17.3
TURBIDITY 1/M	.66	.66	53.4	53.4
ZMIX * TURBIDITY	1.48	1.48	16.5	16.5
ZMIX / SECCHI	3.16	2.64	24.0	15.4
CHL-A * SECCHI	21.25	17.52	85.0	77.7
CHL-A / TOTAL P	.50	.43	92.8	89.1
FREQ(CHL-a>10) %	99.98	98.73	.0	.0
FREQ(CHL-a>20) %	88.00	47.02	.0	.0
FREQ(CHL-a>30) %	42.98	7.69	.0	.0
FREQ(CHL-a>40) %	12.80	.85	.0	.0
FREQ(CHL-a>50) %	3.01	.09	.0	.0
FREQ(CHL-a>60) %	.64	.01	.0	.0
CARLSON TSI-P	63.19	59.90	.0	.0
CARLSON TSI-CHLA	63.89	60.21	.0	.0
CARLSON TSI-SEC	64.85	62.24	.0	.0

SEGMENT: 3 AREA-WTD MEAN

VARIABLE		VALUES OBSERVED	VALUES ESTIMATED	RANKS (%) OBSERVED	RANKS (%) ESTIMATED
TOTAL P	MG/M3	49.51	47.75	51.5	49.9
TOTAL N	MG/M3	1278.63	1236.39	64.8	62.9
C.NUTRIENT	MG/M3	42.90	42.23	59.1	58.3
CHL-A	MG/M3	21.42	20.46	85.8	84.4
SECCHI	M	1.04	.98	47.9	44.9
ORGANIC N	MG/M3	1163.65	1126.93	96.1	95.5
TP-ORTHO-P	MG/M3	38.61	37.14	60.5	58.9
ANTILOG PC-1		605.56	594.10	75.5	75.1
ANTILOG PC-2		12.29	11.43	89.1	86.3
(N - 150) / P		22.80	22.75	66.7	66.6
INORGANIC N / P		10.55	10.32	14.9	14.4
TURBIDITY	1/M	.52	.52	43.3	43.3
ZMIX * TURBIDITY		1.99	1.99	27.7	27.7
ZMIX / SECCHI		3.66	3.87	32.4	36.0
CHL-A * SECCHI		22.22	20.04	86.4	83.0
CHL-A / TOTAL P		.43	.43	89.4	89.1
FREQ(CHL-a>10)	%	99.16	98.73	.0	.0
FREQ(CHL-a>20)	%	53.16	47.01	.0	.0
FREQ(CHL-a>30)	%	10.16	7.69	.0	.0
FREQ(CHL-a>40)	%	1.28	.85	.0	.0
FREQ(CHL-a>50)	%	.15	.09	.0	.0
FREQ(CHL-a>60)	%	.02	.01	.0	.0
CARLSON TSI-P		60.42	59.90	.0	.0
CARLSON TSI-CHLA		60.66	60.21	.0	.0
CARLSON TSI-SEC		59.47	60.30	.0	.0

Appendix C
A Calibrated Trophic Response Model for Crooked Lake

A Calibrated Trophic Response Model (BATHTUB) for Crooked Lake
As a Tool to Evaluate Various Nutrient Reduction Alternatives
Based on Data Collected by the South McLean Soil Conservation District from
January 2010 through December 2012

Prepared by
Peter Wax
April, 2012

Introduction

The objective of monitoring Crooked Lake and Crooked Lake's hydraulic and nutrient load is to: (1) develop a water and nutrient budget for the reservoir; (2) identify the primary sources and causes of nutrients and sediments to the reservoir; and (3) examine and make recommendations for reservoir preservation measures that reduce documented nutrient and sediment loadings to the reservoir, and (4) develop a calibrated trophic response model for Crooked Lake.

A calibrated trophic response model enables managers to investigate various nutrient reduction alternatives relative to preserving and improving Crooked Lake's trophic status for future generations. The model allows water and land resource managers to relate changes in nutrient loadings to the lake's trophic response and to set realistic goals that are scientifically defensible, physically achievable, and socially acceptable.

Methods

For purposes of this project, the BATHTUB model was used to predict changes in trophic status based on changes in nutrient loading. The BATHTUB program, developed by the US Army Corps of Engineers Waterways Experiment Station (Walker 1996), applies an empirically derived eutrophication model to reservoirs. The model is developed in three phases. The first two phases involve the analysis and reduction of the tributary and in-lake water quality data. The third phase involves model calibration. In the data reduction phase, the in-lake and tributary monitoring data collected as part of the project are summarized, or reduced, into a format which can serve as inputs to the model. The following is a brief explanation of the computer software, methods, and procedures used to complete each of these phases.

Tributary Data

To facilitate the analysis and reduction of tributary inflow and outflow water quality and flow data the FLUX program was employed. The FLUX program, also developed by the US Corps of Engineers Waterways Experiment Station (Walker 1996), uses six calculation techniques to estimate the average mass discharge or loading that passes a given river or stream site. FLUX estimates loadings based on chemical grab sample concentrations and continuous daily flow record. Load is therefore defined as the mass of a pollutant during a given time period (e.g., hour, day, month, season, year). The FLUX program allows the user, through various iterations, to select the most appropriate load calculation technique and data stratification scheme, either by flow or date, which will give a load estimate with the smallest statistical error, as represented by the coefficient of variation. Output from the FLUX program is then provided as an input file to calibrate the BATHTUB eutrophication response model. For a complete description of the FLUX program the reader is referred to Walker (1996).

Lake Data

Crooked Lake's water quality data was reduced using the Microsoft Excel program. The data as reduced to provide the two year average concentration. Microsoft Excel is very robust and able to provide many computational functions, including the ability to display constitutes as a function of depth, location and/or date, and calculate summary statistics (e.g., mean, median and standard deviation. As is the case with FLUX, output from the Excel program is used as input to calibrate the BATHTUB model.

Bathtub Model Calibration

As stated previously, the BATHTUB eutrophication model was selected for this project as a means evaluating the effects of various nutrient reduction alternatives on the predicted trophic status of Crooked Lake. BATHTUB performs water and nutrient balance calculations in a steady state. Eutrophication related water quality variables (e.g., total phosphorus, total nitrogen, chlorophyll-*a*, secchi depth, organic nitrogen, orthophosphorous, and hypolimnetic oxygen depletion rate) are predicted using empirical relationships previously developed and tested for reservoir systems (Walker 1985).

Within the BATHTUB program the user can select from six schemes based on reservoir morphometry and the needs of the resource manager. Using BATHTUB the user can view the reservoir as a single spatially averaged reservoir or as single segmented reservoir. The user can also model parts of the reservoir, such as an embayment, or model a collection of reservoirs. For purposes of this project, Crooked Lake was modeled as a single, spatially averaged, reservoir.

Once input is provided to the model from FLUX and Excel the user can compare predicted conditions (i.e., model output) to actual conditions. Since BATHTUB uses a set of generalized rates and factors, predicted vs. actual conditions may differ by a factor of 2 or more using the initial, un-calibrated, model. These differences reflect a combination of measurement errors in the inflow and outflow data, as well as unique features of the reservoir being modeled.

In order to closely match an actual in-lake condition with the predicted condition, BATHTUB allows the user to modify a set of calibration factors (Table 1). For a complete description of the BATHTUB model the reader is referred to Walker (1996).

Table 1. Selected Model Parameters, Number and Name of Model, and Where Appropriate the Calibration Factor Used for Crooked Lake's Bathtub Model

Model Option	Model Selection	Calibration Factor
Conservative Substance	1 Computed	1.00
Phosphorus Balance	7 Settling Velocity	1.39
Phosphorus – Ortho P	7 Settling Velocity	0.80
Nitrogen Balance	7 Settling Velocity	1.31
Organic Nitrogen	7 Settling Velocity	1.70
Chlorophyll-a	1 P, N, Low Turbidity	0.95
Secchi Depth	1 vs. Chla & Turbidity	1.0
Phosphorus Calibration	1 Concentrations	NA
Nitrogen Calibration	1 Concentrations	NA
Availability Factors	0 Ignore	NA
Mass-Balance Tables	0 Use Observed Concentrations	NA

Results

The trophic response model, BATHTUB, has been calibrated to match Crooked Lake's trophic condition for the period between May 23, 2010 and November 24, 2011. Calibration was accomplished by combining tributary loading estimates for the project period (January 1, 2010 through December 31, 2011) with in-lake water quality estimates. Tributary flow and concentration data for the project period are reduced by the FLUX program and the corresponding in-lake water quality data were reduced utilizing Microsoft Excel and the output from these two programs are then provided as input to the BATHTUB model.

The BATHTUB model is calibrated through several iterations, first by selecting appropriate empirical relationships for model coefficients (e.g., nitrogen and phosphorus sedimentation, nitrogen and phosphorus decay, oxygen depletion, and algal/chlorophyll growth), and second by adjusting the models calibration factors for those coefficients (Table 1). The model is termed calibrated when the predicted estimates for the trophic response variables are similar to observed estimates made from project monitoring data.

The two most important nutrients controlling trophic response in Crooked Lake are nitrogen and phosphorus. After calibration the observed average annual concentration of total nitrogen and total phosphorus compare well with those of the BATHTUB model. Once calibrated, the model predicted the reservoirs annual total nitrogen concentration at 1276.4 µg L^{-1} and total phosphorus at 49.5 µg L^{-1}compared to observed values of 1278.6 µg L^{-1} and 49.5 µg L^{-1}, respectively (Table 2).

Other measures of trophic response predicted by the model are mean annual chlorophyll-a concentration and average secchi disk transparency. After calibration the model did just as good a job of predicting average chlorophyll-a concentration and secchi disk transparency within the reservoir as total phosphorus and total nitrogen (Table 2).

Once predictions of total phosphorus, chlorophyll-a, and secchi disk transparency are made, the model calculates Carlson's Trophic Status Index (TSI) (Carlson 1977) as a means of expressing trophic response (Table 2). Carlson's TSI is an index that can be used to measure the relative trophic state of a lake or reservoir. Simply stated, trophic state is how much production (i.e., algal and weed growth) occurs in the waterbody. The lower the nutrient concentrations are within the waterbody the lower the production and the lower the trophic state or level. In contrast, increased nutrient concentrations in a lake or reservoir increase the production of algae and weeds which make the lake or reservoir more eutrophic or of a higher trophic state. Oligotrophic is the term which describes the least productive lakes and hypereutrophic is the term used to describe lakes and reservoirs with excessive nutrients and primary production.

Table 2. Observed and Predicted Values for Selected Trophic Response Variables for the Calibrated BATHTUB Model

Variable	Observed	Predicted
Total Phosphorus as P (µg/L)	49.51	49.50
Total Dissolved Phosphorus as P (µg/L)	38.61	38.54
Total Nitrogen as N (µg/L)	1278.63	1276.38
Organic Nitrogen as N (µg/L)	1163.65	1163.57
Chlorophyll-a (µg/L)	21.42	21.40
Secchi Disk Transparency (meters)	1.04	0.96
Carlson’s TSI for Phosphorus	60.42	60.42
Carlson’s TSI for Chlorophyll-a	60.66	60.65
Carlson’s TSI for Secchi Disk	59.47	60.63

Figure 1 provides a graphic summary of the TSI range for each trophic level compared to values for each of the trophic response variables. The calibrated model provided predictions of trophic status which are similar to the observed TSI values for the project period (Table 2). Predicted and observed TSI values for phosphorus and chlorophyll-a suggest Crooked Lake is beginning life as hypereutrophic, while the TSI value of secchi disk depth indicated the reservoir is eutrophic.

Model Predictions

Once the model is calibrated to existing conditions, the model can be used to evaluate the effectiveness of any number of nutrient reduction or lake restoration alternatives. This evaluation is accomplished by comparing the predicted trophic state, as reflected by Carlson’s TSI, with currently observed TSI values. Modeled nutrient reduction alternatives are presented in three basic categories: (1) reducing externally derived nutrient loads; (2) reducing internally available nutrients; and (3) reducing both external and internal nutrient loads. For Crooked Lake only external nutrient loads were addressed. External nutrient loads were addressed because they are known to cause eutrophication and because they are controllable through the implementation of watershed Best Management Practices (BMPs).

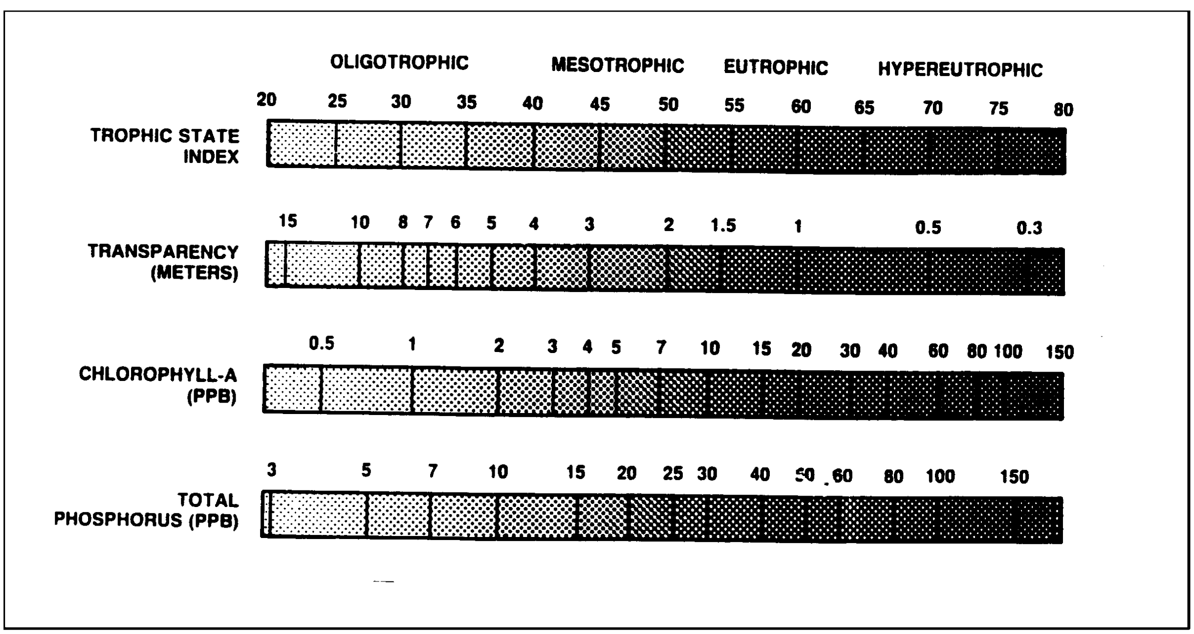

Figure 1. Graphic Depiction of Carlson's Trophic Status Index.

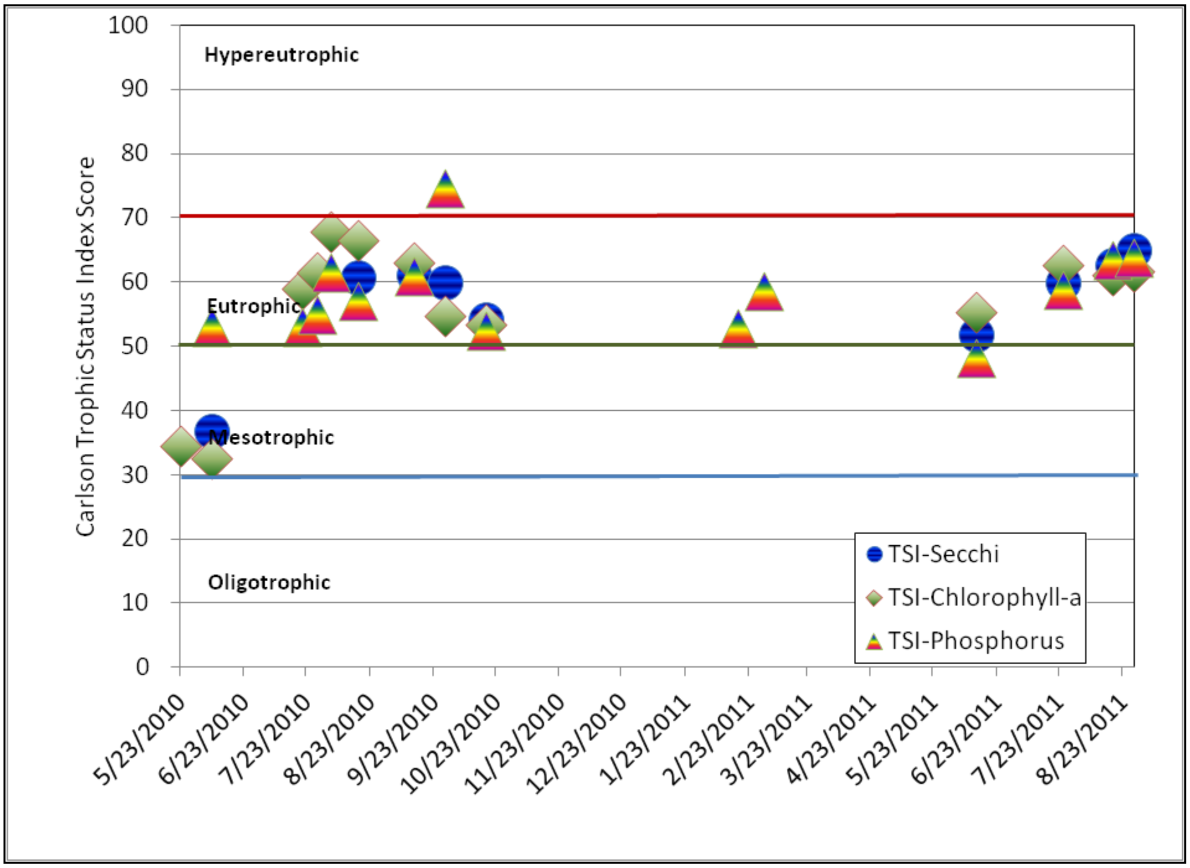

Figure 2. Temporal Distribution of Carlson's Trophic Status Index Scores for Crooked Lake (5/23/2010 though 9/24/2011)

Predicted changes in Crooked Lake's trophic response were evaluated by reducing externally derived nutrient loads by 10, 25, 50, and 75 percent. These reductions were simulated in the model by reducing all species of phosphorus and nitrogen concentrations in the contributing tributary and other external delivery sources by 10, 25, 50, and 75 percent. Since there is no reliable means of estimating how much hydraulic discharge would be reduced through the implementation of BMPs, flow was held constant.

The model results indicate that even if it were possible to reduce external nutrient loading to Crooked Lake by up to 75 percent, the lake would experience minimal reduction of in-lake total phosphorus resulting in little or no decrease in chlorophyll-a concentrations and water clarity (Table 3, Figure 3). It is important to note that reducing total phosphorus concentrations in the contributing tributaries that are currently averaging 0.03 mg L-1 by 75% is not possible.

Table 3. Observed and Predicted Values for Selected Trophic Response Variables from a 10, 25, 50, and 75 Percent Reduction in External Phosphorus and Nitrogen Loading

Variable	Observed	-10%	-25%	-50%	-75%
Total Phosphorus as P (µg/L)	49.51	47.75	45.11	40.72	36.33
Total Nitrogen as N (µg/L)	1276.63	1236.39	1176.41	1076.44	976.48
Chlorophyll-a (µg/L)	21.42	20.46	19.05	16.77	14.54
Secchi Disk Transparency (meters)	1.04	0.98	1.01	1.08	1.15
Carlson's TSI for Phosphorus	60.42	59.90	59.08	57.60	55.96
Carlson's TSI for Chlorophyll-a	60.66	60.21	59.51	58.26	56.86
Carlson's TSI for Secchi Disk	59.47	60.30	59.79	58.91	58.00

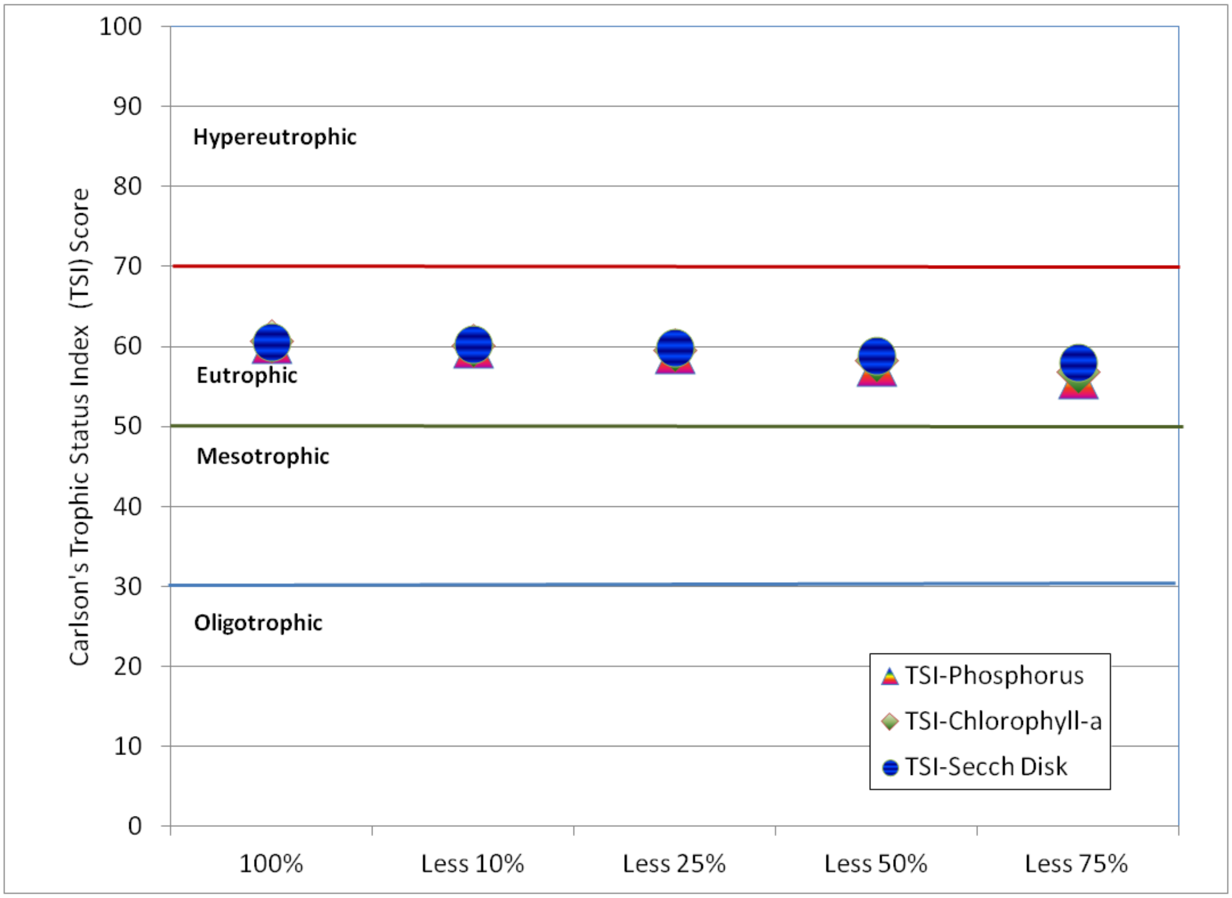

Figure 3. Predicted Change in Crooked Lake's Trophic Condition to Nutrient Load Reductions of 10, 25, 50, and 75 Percent

Appendix D
US EPA Region 8 TMDL Review Form and Decision Document

EPA REGION 8 TMDL REVIEW FORM AND DECISION DOCUMENT

TMDL Document Info:

Document Name:	**Nutrient and Dissolved Oxygen TMDLs for Crooked Lake in McLean County, North Dakota**
Submitted by:	**Mike Ell, North Dakota Department of Health**
Date Received:	**August 20, 2012**
Review Date:	**October 22, 2012**
Reviewer:	**Vern Berry, US Environmental Protection Agency**
Rough Draft / Public Notice / Final Draft?	**Public Notice**
Notes:	

Reviewers Final Recommendation(s) to EPA Administrator (used for final draft review only):

- ☐ Approve
- ☐ Partial Approval
- ☐ Disapprove
- ☐ Insufficient Information

Approval Notes to the Administrator:

This document provides a standard format for EPA Region 8 to provide comments to state TMDL programs on TMDL documents submitted to EPA for either formal or informal review. All TMDL documents are evaluated against the TMDL review elements identified in the following 8 sections:

1. Problem Description
   a.… TMDL Document Submittal
   b. Identification of the Waterbody, Impairments, and Study Boundaries
   c. Water Quality Standards
2. Water Quality Target
3. Pollutant Source Analysis
4. TMDL Technical Analysis
   a. Data Set Description
   b. Waste Load Allocations (WLA)
   c. Load Allocations (LA)
   d. Margin of Safety (MOS)
   e. Seasonality and variations in assimilative capacity
5. Public Participation
6. Monitoring Strategy
7. Restoration Strategy
8. Daily Loading Expression

Under Section 303(d) of the Clean Water Act, waterbodies that are not attaining one or more water quality standard (WQS) are considered “impaired.” When the cause of the impairment is determined to be a pollutant, a TMDL analysis is required to assess the appropriate maximum allowable pollutant loading rate. A TMDL document consists of a technical analysis conducted to: (1) assess the maximum pollutant loading rate that a waterbody is able to assimilate while maintaining water quality standards; and (2) allocate that assimilative capacity among the known sources of that pollutant**.** A well written TMDL document will describe a path forward that may be used by those who implement the TMDL recommendations to attain and maintain WQS.

Each of the following eight sections describes the factors that EPA Region 8 staff considers when reviewing TMDL documents. Also included in each section is a list of EPA's review elements relative to that section, a brief summary of the EPA reviewer's findings, and the reviewer's comments and/or suggestions. Use of the verb "must" in this review form denotes information that is required to be submitted because it relates to elements of the TMDL required by the CWA and by regulation. Use of the term "should" below denotes information that is generally necessary for EPA to determine if a submitted TMDL is approvable.

This review form is intended to ensure compliance with the Clean Water Act and that the reviewed documents are technically sound and the conclusions are technically defensible.

1. Problem Description

A TMDL document needs to provide a clear explanation of the problem it is intended to address. Included in that description should be a definitive portrayal of the physical boundaries to which the TMDL applies, as well as a clear description of the impairments that the TMDL intends to address and the associated pollutant(s) causing those impairments. While the existence of one or more impairment and stressor may be known, it is important that a comprehensive evaluation of the water quality be conducted prior to development of the TMDL to ensure that all water quality problems and associated stressors are identified. Typically, this step is conducted prior to the 303(d) listing of a waterbody through the monitoring and assessment program. The designated uses and water quality criteria for the waterbody should be examined against available data to provide an evaluation of the water quality relative to all applicable water quality standards. If, as part of this exercise, additional WQS problems are discovered and additional stressor pollutants are identified, consideration should be given to concurrently evaluating TMDLs for those additional pollutants. If it is determined that insufficient data is available to make such an evaluation, this should be noted in the TMDL document.

1.1 TMDL Document Submittal

When a TMDL document is submitted to EPA requesting review or approval, the submittal package should include a notification identifying the document being submitted and the purpose of the submission.

Review Elements:

☒ Each TMDL document submitted to EPA should include a notification of the document status (e.g., pre-public notice, public notice, final), and a request for EPA review.

☐ Each TMDL document submitted to EPA for final review and approval should be accompanied by a submittal letter that explicitly states that the submittal is a final TMDL submitted under Section 303(d) of the Clean Water Act for EPA review and approval. This clearly establishes the State's/Tribe's intent to submit, and EPA's duty to review, the TMDL under the statute**.** The submittal letter should contain such identifying information as the name and location of the waterbody and the pollutant(s) of concern, which matches similar identifying information in the TMDL document for which a review is being requested.

Recommendation:
☒ Approve ☐ Partial Approval ☐ Disapprove ☐ Insufficient Information ☐ N/A

Summary: *The notification of the availability of the public notice draft TMDL document was submitted to EPA via a letter received on August 20, 2012. The letter includes the details of the public notice, explains how to obtain a copy of the TMDL, and requests the submittal of comments to NDDoH by September 17, 2012.*

Comments: *No comments.*

1.2 Identification of the Waterbody, Impairments, and Study Boundaries

The TMDL document should provide an unambiguous description of the waterbody to which the TMDL is intended to apply and the impairments the TMDL is intended to address. The document should also clearly delineate the physical boundaries of the waterbody and the geographical extent of the watershed area studied. Any additional information needed to tie the TMDL document back to a current 303(d) listing should also be included.

Review Elements:

☒ The TMDL document should clearly identify the pollutant and waterbody segment(s) for which the TMDL is being established. If the TMDL document is submitted to fulfill a TMDL development requirement for a waterbody on the state's current EPA approved 303(d) list, the TMDL document submittal should clearly identify the waterbody and associated impairment(s) as they appear on the State's/Tribe's current EPA approved 303(d) list, including a full waterbody description, assessment unit/waterbody ID, and the priority ranking of the waterbody. This information is necessary to ensure that the administrative record and the national TMDL tracking database properly link the TMDL document to the 303(d) listed waterbody and impairment(s).

☒ One or more maps should be included in the TMDL document showing the general location of the waterbody and, to the maximum extent practical, any other features necessary and/or relevant to the understanding of the TMDL analysis, including but not limited to: watershed boundaries, locations of major pollutant sources, major tributaries included in the analysis, location of sampling points, location of discharge gauges, land use patterns, and the location of nearby waterbodies used to provide surrogate information or reference conditions. Clear and concise descriptions of all key features and their relationship to the waterbody and water quality data should be provided for all key and/or relevant features not represented on the map

☒ If information is available, the waterbody segment to which the TMDL applies should be identified/geo-referenced using the National Hydrography Dataset (NHD). If the boundaries of the TMDL do not correspond to the Waterbody ID(s) (WBID), Entity ID information or reach code (RCH_Code) information should be provided. If NHD data is not available for the waterbody, an alternative geographical referencing system that unambiguously identifies the physical boundaries to which the TMDL applies may be substituted.

Recommendation:

☐ Approve ☒ Partial Approval ☐ Disapprove ☐ Insufficient Information

<u>Summary:</u>

Physical Setting and Listing History:

Crooked Lake is a 375 acre natural lake located approximately seven miles north of the town of Turtle Lake, North Dakota. The lake is located in McLean County and receives water from a watershed drainage area of approximately 65,600 acres. Crooked Lake is part of the Painted Woods-Square Butte sub-basin which is part of the larger Missouri River basin watershed.

North Dakota Administrative Code, 33-16-02.1, Appendix II, Standards of Quality of Waters of the State, assigns the following classification for Crooked Lake. The benecial water uses and parameter limitations designated for Class I streams shall apply to all classied lakes and reservoirs. For lakes not listed, the following default classication applies: Class 4.

Crooked Lake; ND-10130103-003-L_00; Class 3.

Impairment status*:*
The 2012 North Dakota Integrated Report identifies Crooked Lake as not supporting the following beneficial uses:

Assessment Unit	Designated Use / Support Status	Impairment Cause	TMDL Priority
Crooked Lake ND-10130101-003-L_00	*Fish and Other Aquatic Biota / Fully Supporting but Threatened*	*Nutrient / Eutrophication Biological Indicators*	*High*
	Fish and Other Aquatic Biota / Fully Supporting but Threatened	*Dissolved Oxygen*	*High*
	Recreation / Fully Supporting but Threatened	*Nutrient / Eutrophication Biological Indicators*	*High*

Comments: *The 2012 303(d) list shows Crooked Lake as 375 acres in size. This is not consistent with the acreage given in Section 1.0 and Table 1. The listing information used in the TMDL appears to be based on the 2010 303(d) list (see Table 2). We suggest revising the TMDL to be consistent with the 2012 303(d) listing information.*

Section 1.1 seems to indicate that this TMDL document only addresses the nutrient / eutrophication / biological indicators impairment, whereas the title of the document seems to indicate that it addresses the dissolved oxygen impairment too. We suggest that revising one or the other to be consistent.

Pages 1 and 6 include reference to "NDDoH 1993" which we assume is the Lake Water Quality Assessment Project report. However, Section 12.0, References does not include the details of the report being referenced.

1.3 Water Quality Standards

TMDL documents should provide a complete description of the water quality standards for the waterbodies addressed, including a listing of the designated uses and an indication of whether the uses are being met, not being met, or not assessed. If a designated use was not assessed as part of the TMDL analysis (or not otherwise recently assessed), the documents should provide a reason for the lack of assessment (e.g., sufficient data was not available at this time to assess whether or not this designated use was being met).

Water quality criteria (WQC) are established as a component of water quality standard at levels considered necessary to protect the designated uses assigned to that waterbody. WQC identify quantifiable targets and/or qualitative water quality goals which, if attained and maintained, are intended to ensure that the designated uses for the waterbody are protected. TMDLs result in maintaining and attaining water quality standards by determining the appropriate maximum pollutant loading rate to meet water quality criteria, either directly, or through a surrogate measurable target. The TMDL document should include a description of all applicable water quality criteria for the impaired designated uses and address whether or not the criteria are being attained, not attained, or not evaluated as part of the analysis. If the criteria were not evaluated as part of the analysis, a reason should be cited (e.g. insufficient data were available to determine if this water quality criterion is being attained).

Review Elements:

☒ The TMDL must include a description of the applicable State/Tribal water quality standard, including the designated use(s) of the waterbody, the applicable numeric or narrative water quality criterion, and the anti-degradation policy. (40 C.F.R. §130.7(c)(1)).

☒ The purpose of a TMDL analysis is to determine the assimilative capacity of the waterbody that corresponds to the existing water quality standards for that waterbody, and to allocate that assimilative capacity between the identified sources. Therefore, <u>all TMDL documents must be written to meet the existing water quality standards</u> for that waterbody (CWA §303(d)(1)(C)). *Note: In some circumstances, the load reductions determined to be necessary by the TMDL analysis may prove to be infeasible and may possibly indicate that the existing water quality standards and/or assessment methodologies may be erroneous. However, the TMDL must still be determined based on existing water quality standards. Adjustments to water quality standards and/or assessment methodologies may be evaluated separately, from the TMDL.*

☒ The TMDL document should describe the relationship between the pollutant of concern and the water quality standard the pollutant load is intended to meet. This information is necessary for EPA to evaluate whether or not attainment of the prescribed pollutant loadings will result in attainment of the water quality standard in question.

☒ If a standard includes multiple criteria for the pollutant of concern, the document should demonstrate that the TMDL value will result in attainment of all related criteria for the pollutant. For example, both acute and chronic values (if present in the WQS) should be addressed in the document, including consideration of magnitude, frequency and duration requirements.

Recommendation:
☒ Approve ☐ Partial Approval ☐ Disapprove ☐ Insufficient Information

<u>Summary</u>: *Crooked Lake is classified as a Class 3 warm water fishery. Class 3 fisheries are defined as waterbodies "capable of supporting natural reproduction and growth of warm water fishes (i.e. largemouth bass and bluegill) and associated aquatic biota. Some cool water species may also be* *present." All classified lakes in North Dakota are assigned aquatic life, recreation, irrigation, livestock watering, and wildlife beneficial uses. The North Dakota State Water Quality Standards state that lakes shall use the same numeric criteria as Class 1 streams, including the State standard for dissolved nitrate as N, of 1.0 mg/L, where up to 10 percent of samples may exceed the 1.0 mg/L, and State guideline nutrient goals for lakes and reservoirs.*

Table 5. Numeric Standards Applicable for North Dakota Lakes and Reservoirs.

State Water Quality Standard	Parameter	Guidelines	Limit
Numeric Standard for Class I and Classified Lakes	Nitrates (dissolved)	1.0 mg/L	Maximum allowed[1]
	Dissolved oxygen	5 mg/L	Daily mimimum[2]
Guidelines for Goals in a Lake Improvement or Maintenance Program	NO3 as N	0.25 mg/L	Goal
	PO4 as P	0.02 mg/L	Goal

[1] "Up to 10% of samples may exceed"
[2] "Up to 10% of representative samples collected during any three year period may be less than this value provided that lethal conditions are avoided."

The Crooked Lake impairments addressed by this TMDL document include nutrients / eutrophication / biological indicators and dissolved oxygen. The North Dakota Department of Health has set narrative water quality standards that apply to all surface waters of the state. The NDDoH narrative standards that apply to nutrients include:

> *"All waters of the state shall be free from substances attributable to municipal, industrial, or other discharges or agricultural practices in concentrations or combinations which are toxic or harmful to humans, animals, plants, or resident aquatic biota." (See NDAC 33-16-02-08.1.a.(4))*

> *"No discharge of pollutants, which alone or in combination with other substances, shall:*
> *1. Cause a public health hazard or injury to environmental resources;*
> *2. Impair existing or reasonable beneficial uses of the receiving waters; or*
> *3. Directly or indirectly cause concentrations of pollutants to exceed applicable standards of the receiving waters." (See NDAC 33-16-02-08.1.e.)*

In addition to the narrative standards, the NDDH has set a biological goal for all surface waters of the state:

> *"The biological condition of surface waters shall be similar to that of sites or waterbodies determined by the department to be regional reference sites." (See NDAC 33-16-02-08.2.a.)*

Other applicable water quality standards are included on pages 9 - 10 of the TMDL report.

Comments: *No comments.*

2. Water Quality Targets

TMDL analyses establish numeric targets that are used to determine whether water quality standards are being achieved. Quantified water quality targets or endpoints should be provided to evaluate each listed pollutant/water body combination addressed by the TMDL, and should represent achievement of applicable water quality standards and support of associated beneficial uses. For pollutants with numeric water quality standards, the numeric criteria are generally used as the water quality target. For pollutants with narrative standards, the narrative standard should be translated into a measurable value. At a minimum, one target is required for each pollutant/water body combination. It is generally desirable, however, to include several targets that represent achievement of the standard and support of beneficial uses (e.g., for a sediment impairment issue it may be appropriate to include a variety of targets representing water column sediment such as TSS, embeddedness, stream morphology, up-slope conditions and a measure of biota).

Review Elements:

☒ The TMDL should identify a numeric water quality target(s) for each waterbody pollutant combination. The TMDL target is a quantitative value used to measure whether or not the applicable water quality standard is attained. *Generally, the pollutant of concern and the numeric water quality target are, respectively, the chemical causing the impairment and the numeric criteria for that chemical (e.g., chromium) contained in the water quality standard. Occasionally, the pollutant of concern is different from the parameter that is the subject of the numeric water quality target (e.g., when the pollutant of concern is phosphorus and the numeric water quality target is expressed as a numerical dissolved oxygen criterion). In such cases, the TMDL should explain the linkage between the pollutant(s) of concern, and express the quantitative relationship between the TMDL target and pollutant of concern. In all cases, TMDL targets must represent the attainment of current water quality standards.*

☒ When a numeric TMDL target is established to ensure the attainment of a narrative water quality criterion, the numeric target, the methodology used to determine the numeric target, and the link between the pollutant of concern and the narrative water quality criterion should all be described in the TMDL document. Any additional information supporting the numeric target and linkage should also be included in the document.

Recommendation:
☒ Approve ☐ Partial Approval ☐ Disapprove ☐ Insufficient Information

Summary: *The main water quality target for this TMDL is based on interpretation of narrative provisions found in the State's water quality standards. In North Dakota, algal blooms can limit contact and immersion recreation beneficial uses. Also algal blooms can deplete oxygen levels which can affect aquatic life uses. TSI measurements can be used to estimate how much algal production may occur in lakes. Therefore, TSI is used as a measure of the narrative standard in order to determine whether beneficial uses are being met.*

The chlorophyll-a trophic status indicator is used by the NDDoH as the primary means to assess whether a lake or reservoir is meeting the narrative standards. Trophic status is a measure of the productivity of a lake or reservoir and is directly related to the level of nutrients (i.e., phosphorus and nitrogen) entering the lake or reservoir from its watershed and/or from the internal recycling of nutrients. The NDDoH has established an in-lake growing season average chlorophyll-a concentration goal of 20 µg/L for most lake and reservoir nutrient TMDLs, including this TMDL for Crooked Lake. This chlorophyll-a goal corresponds to a chlorophyll-a TSI of 60 which is in the eutrophic range and, as *such, will be a trophic state sufficient to maintain both aquatic life and recreation uses of most lakes and reservoirs in the state, including Crooked Lake.*

Due to the relationship between trophic status indicators and the aquatic community (as reflected by the fishery) or between trophic status indicators and the frequency of algal blooms, trophic status is an effective indicator of aquatic life and recreation use support in lakes and reservoirs. While the three trophic state indicators, chlorophyll-a, Secchi disk transparency, and total phosphorus, used in Carlson's TSI each independently estimate algal biomass and should produce the same index value for a given combination of variable values, often they do not. Transparency and phosphorus may co-vary with trophic state, many times the changes in observed in a lake's transparency are not caused by changes in algal biomass, but may be due to particulate sediment. Total phosphorus may or may not be strongly related to algal biomass due to light limitation and/or nitrogen and carbon limitation. Therefore, neither transparency nor phosphorus is an independent estimator of trophic state. For these reasons, the NDDoH gives priority to chlorophyll-a as the primary trophic state indicator because this variable is the most accurate of the three at predicting algal biomass.

The same conclusion was also reached by a multi-state project team consisting of lake managers and water quality specialists from North Dakota, South Dakota, Montana, Wyoming and EPA Region 8. This group concluded that for lakes and reservoirs in the plains region of EPA Region 8, an average growing season chlorophyll-a concentration of 20 µg/L or less should be the basis for nutrient criteria development for lakes and reservoirs in the plains region (including North Dakota) and that this chlorophyll-a target would be protective of all of a lake or reservoir's beneficial uses, including recreation and aquatic life. A report, prepared by Houston Engineering, concluded that most lakes and reservoirs in the plains region typically have high total phosphorus concentrations, but maintain relatively low productivity, and that due to this condition, chlorophyll-a is a better measure of a lake or reservoirs trophic status than is total phosphorus.

Water quality data collected in the lake in 2010 and 2011 (see Table 4) showed an average chlorophyll-a concentration of 21.42 µg/l, an average total phosphorus concentration of 49.51 µg/l, an average Secchi Depth of 1.04 meters, and an average total nitrogen concentration of 1,277 µg/l. Based on these data, Crooked Lake is generally assessed as a eutrophic lake.

The North Dakota State Water Quality Standard for dissolved oxygen is 5 mg/L as a daily minimum, and where up to 10% of representative samples collected during any three year period may be less than this value provided that lethal conditions are avoided. This is the dissolved oxygen TMDL target for Crooked Lake.

Comments: *No comments.*

3. Pollutant Source Analysis

A TMDL analysis is conducted when a pollutant load is known or suspected to be exceeding the loading capacity of the waterbody. Logically then, a TMDL analysis should consider all sources of the pollutant of concern in some manner. The detail provided in the source assessment step drives the rigor of the pollutant load allocation. In other words, it is only possible to specifically allocate quantifiable loads or load reductions to each identified source (or source category) when the relative load contribution from each source has been estimated. Therefore, the pollutant load from each identified source (or source category) should be specified and quantified. This may be accomplished using site-specific monitoring data, modeling, or application of other assessment techniques. If insufficient time or resources are available to accomplish this step, a phased/adaptive management approach may be appropriate. The approach should be clearly defined in the document.

Review Elements:

☒ The TMDL should include an identification of the point and nonpoint sources of the pollutant of concern, including the geographical location of the source(s) and the quantity of the loading, e.g., lbs/per day. This information is necessary for EPA to evaluate the WLA, LA and MOS components of the TMDL.

☒ The level of detail provided in the source assessment should be commensurate with the nature of the watershed and the nature of the pollutant being studied. Where it is possible to separate natural background from nonpoint sources, the TMDL should include a description of both the natural background loads and the nonpoint source loads.

☒ Natural background loads should not be assumed to be the difference between the sum of known and quantified anthropogenic sources and the existing *in situ* loads (e.g. measured in stream) unless it can be demonstrated that the anthropogenic sources of the pollutant of concern have been identified, characterized, and quantified.

☒ The sampling data relied upon to discover, characterize, and quantify the pollutant sources should be included in the document (e.g. a data appendix) along with a description of how the data were analyzed to characterize and quantify the pollutant sources. A discussion of the known deficiencies and/or gaps in the data set and their potential implications should also be included.

Recommendation:
☐ Approve ☒ Partial Approval ☐ Disapprove ☐ Insufficient Information

<u>Summary</u>*: The TMDL document includes the landuse breakdown for the watershed based on the 2010 National Agricultural Statistics Service (NASS) data. In 2010, the dominant land use in the watershed that drains to Crooked Lake was agriculture. Approximately 19 percent of the landuse in the watershed was cropland, 57 percent was grassland/pastureland, and the remaining 24 percent was water, wetlands, forest, developed space, barren or fallow/idle cropland. The majority of the crops grown consisted of spring wheat, flax, canola, sunflowers, peas and durum wheat.*

TMDL identifies the major sources of phosphorus as coming from nonpoint source agricultural landuses within the watershed. There are no known point sources upstream of Crooked Lake. A nutrient loading analysis was performed using the Annualized Agricultural Nonpoint Source (AnnAGNPS) model which looked at various agricultural land uses and land management practices in the watershed (see Section 5.3 AnnAGNPS Watershed Model in the TMDL document). A five year simulation period was run on the Crooked Lake watershed at its present condition to provide a best estimation of the current land use practices applied to the soils and slopes of the watershed to obtain nutrient loads from the individual *cells as well as the watershed as a whole. Major land use in the Crooked Lake watershed was identified as wheat, winter wheat, barley, corn, soybeans, dry beans, sunflowers, pasture, rangeland, and residential/urban. Crop rotations were determined from three years of land survey data from the National Agricultural Statistical Service. The compiled data was used to assess the watershed to identify "critical cells" located in the watershed for potential best management practice implementation (see Figure 11 in the TMDL document). Critical cells were determined to be cells in the watershed providing an estimated annual phosphorus yield of 0.041 lbs/acre/year or greater.*

The model indicated that excessive nutrient loading is occurring and is primarily responsible for the low dissolved oxygen levels in Crooked Lake. Therefore, the nutrient loading sources to Crooked Lake are the same sources contributing to the dissolved oxygen impairment in the lake.

Comments: *The description of the AnnAGNPS modeling (Section 5.3, page 19) mentions landuse and crop types that are not consistent with the description of the Crooked Lake watershed in Section 1.2 . The end of Section 5.3 includes a reference to Figure 8 (critical cells) which appears to be incorrect. We believe the reference should be to Figure 11.*

4. TMDL Technical Analysis

TMDL determinations should be supported by an analysis of the available data, discussion of the known deficiencies and/or gaps in the data set, and an appropriate level of technical analysis**.** This applies to **all** of the components of a TMDL document. It is vitally important that the technical basis for **all** conclusions be articulated in a manner that is easily understandable and readily apparent to the reader.

A TMDL analysis determines the maximum pollutant loading rate that may be allowed to a waterbody without violating water quality standards. The TMDL analysis should demonstrate an understanding of the relationship between the rate of pollutant loading into the waterbody and the resultant water quality impacts. This stressor → response relationship between the pollutant and impairment and between the selected targets, sources, TMDLs, and load allocations needs to be clearly articulated and supported by an appropriate level of technical analysis. Every effort should be made to be as detailed as possible, and to base all conclusions on the best available scientific principles.

The pollutant loading allocation is at the heart of the TMDL analysis. TMDLs apportion responsibility for taking actions by allocating the available assimilative capacity among the various point, nonpoint, and natural pollutant sources. Allocations may be expressed in a variety of ways, such as by individual discharger, by tributary watershed, by source or land use category, by land parcel, or other appropriate scale or division of responsibility.

The pollutant loading allocation that will result in achievement of the water quality target is expressed in the form of the standard TMDL equation:

$$TMDL = \sum WLAs + \sum LAs + MOS$$

Where:

TMDL	=	Total Maximum Daily Load (also called the Loading Capacity)
LAs	=	Load Allocations
WLAs	=	Wasteload Allocations
MOS	=	Margin Of Safety

Review Elements:

- ☒ A TMDL must identify the loading capacity of a waterbody for the applicable pollutant, taking into consideration temporal variations in that capacity. EPA regulations define loading capacity as the greatest amount of a pollutant that a water can receive without violating water quality standards (40 C.F.R. §130.2(f)).
- ☒ The total loading capacity of the waterbody should be clearly demonstrated to equate back to the pollutant load allocations through a balanced TMDL equation. In instances where numerous LA, WLA and seasonal TMDL capacities make expression in the form of an equation cumbersome, a table may be substituted as long as it is clear that the total TMDL capacity equates to the sum of the allocations.
- ☒ The TMDL document should describe the methodology and technical analysis used to establish and quantify the cause-and-effect relationship between the numeric target and the identified pollutant sources. In many instances, this method will be a water quality model.
- ☒ It is necessary for EPA staff to be aware of any assumptions used in the technical analysis to understand and evaluate the methodology used to derive the TMDL value and associated loading allocations. Therefore, the TMDL document should contain a description of any important assumptions (including the basis for those assumptions) made in developing the TMDL, including but not limited to:

(1) the spatial extent of the watershed in which the impaired waterbody is located and the spatial extent of the TMDL technical analysis;
(2) the distribution of land use in the watershed (e.g., urban, forested, agriculture);
(3) a presentation of relevant information affecting the characterization of the pollutant of concern and its allocation to sources such as population characteristics, wildlife resources, industrial activities etc…;
(4) present and future growth trends, if taken into consideration in determining the TMDL and preparing the TMDL document (e.g., the TMDL could include the design capacity of an existing or planned wastewater treatment facility);
(5) an explanation and analytical basis for expressing the TMDL through surrogate measures, if applicable. Surrogate measures are parameters such as percent fines and turbidity for sediment impairments; chlorophyll *a* and phosphorus loadings for excess algae; length of riparian buffer; or number of acres of best management practices.

- ☒ The TMDL document should contain documentation supporting the TMDL analysis, including an inventory of the data set used, a description of the methodology used to analyze the data, a discussion of strengths and weaknesses in the analytical process, and the results from any water quality modeling used. This information is necessary for EPA to review the loading capacity determination, and the associated load, wasteload, and margin of safety allocations.
- ☒ TMDLs must take critical conditions (e.g., steam flow, loading, and water quality parameters, seasonality, etc…) into account as part of the analysis of loading capacity (40 C.F.R. §130.7(c)(1)). TMDLs should define applicable critical conditions and describe the approach used to determine both point and nonpoint source loadings under such critical conditions. In particular, the document should discuss the approach used to compute and allocate nonpoint source loadings, e.g., meteorological conditions and land use distribution.
- ☐ Where both nonpoint sources and NPDES permitted point sources are included in the TMDL loading allocation, and attainment of the TMDL target depends on reductions in the nonpoint source loads, the TMDL document must include a demonstration that nonpoint source loading reductions needed to implement the load allocations are actually practicable [40 CFR 130.2(i) and 122.44(d)].

Recommendation:
☐ Approve ☒ Partial Approval ☐ Disapprove ☐ Insufficient Information

Summary: *The technical analysis should describe the cause and effect relationship between the identified pollutant sources, the numeric targets, and achievement of water quality standards. It should also include a description of the analytical processes used, results from water quality modeling, assumptions and other pertinent information. The technical analysis for the Crooked Lake watershed TMDL describes how the nutrient loads were derived in order to meet the applicable water quality standards for the 303(d) impaired waterbody.*

In order to determine the cause and effect relationship between the water quality target and the identified sources, various models and loading analysis were utilized. The FLUX model was used to facilitate the analysis and reduction of the tributary inflow and the lake outflow water quality data for nutrients and sediment, as well as flow data into and out of Crooked Lake. Output from the FLUX program was then used as an input file to calibrate the BATHTUB eutrophication response model. The BATHTUB model was used to evaluate and predict the effects of various nutrient reduction scenarios, and the subsequent eutrophication response in Crooked Lake.

The BATHTUB model was selected to simulate the eutrophication response within Crooked Lake. The BATHTUB model performs steady-state water and nutrient balance calculations in a spatially segmented hydraulic network. The model accounts for advective and diffusive transport and nutrient sedimentation. Eutrophication related water quality conditions are predicted using empirical relationships previously developed and tested for lakes and reservoirs.

The phosphorus loading capacity of Crooked Lake was computed using the BATHTUB model. The loading capacity for the lake was defined as the growing season TP load resulting in a seasonal mean Chl-a concentration value of 20.0 μg/L. The total existing phosphorus load to the lake was estimated to be 169.4 kg/yr and the model indicated that a 25 percent reduction is needed to reach an in-lake Chl-a concentration of 20.0 ug/L. Therefore, the phosphorus loading capacity from the watershed into the lake was determined to be 127.05 kg/yr.

High levels of nutrients can lead to eutrophication, which is defined as the undesirable growth of algae and other aquatic plants. In turn, eutrophication can lead to increased biological oxygen demand and oxygen depletion due to the respiration of microbes that decompose the dead algae and other organic material. The model indicated that excessive nutrient loading is occurring and is primarily responsible for the low dissolved oxygen levels in Crooked Lake. As a result of the direct influence of eutrophication on increased biological oxygen demand and microbial respiration, it is anticipated that meeting the chlorophyll-a concentration target for Crooked Lake will address the dissolved oxygen impairment. A reduction in chlorophyll-a concentration due to the resulting lower algal biomass levels in the water column, would reduce the biological oxygen demand exerted by the decomposition of these primary producers. The reduction in biological oxygen demand is therefore assumed to result in attainment of the dissolved oxygen standard.

Comments: *Section 5.4 and Section 6.2 contain references to the CNET model. We believe that the CNET model was not used in the development of this TMDL and that the references to its use should be deleted. Also, the Nurnberg calculations in the last paragraph of Section 5.4 use the lake acreage of 627, whereas we believe that 375 is the correct size of the lake based on the approved 303(d) lists.*

4.1 Data Set Description

TMDL documents should include a thorough description and summary of all available water quality data that are relevant to the water quality assessment and TMDL analysis. An inventory of the data used for the TMDL analysis should be provided to document, for the record, the data used in decision making. This also provides the reader with the opportunity to independently review the data. The TMDL analysis should make use of all readily available data for the waterbody under analysis unless the TMDL writer determines that the data are not relevant or appropriate. For relevant data that were known but rejected, an explanation of why the data were not utilized should be provided (e.g., samples exceeded holding times, data collected prior to a specific date were not considered timely, etc…).

Review Elements:

☒ TMDL documents should include a thorough description and summary of all available water quality data that are relevant to the water quality assessment and TMDL analysis such that the water quality impairments are clearly defined and linked to the impaired beneficial uses and appropriate water quality criteria.

☐ The TMDL document submitted should be accompanied by the data set utilized during the TMDL analysis. If possible, it is preferred that the data set be provided in an electronic format and referenced in the document. If electronic submission of the data is not possible, the data set may be included as an appendix to the document.

Recommendation:
☒ Approve ☐ Partial Approval ☐ Disapprove ☐ Insufficient Information

Summary: *The Crooked Lake TMDL data description and summary are included in the Available Water Quality Data section (Section 1.4). Recent water quality monitoring was conducted from May 2010 – September 2011. Sampling was conducted at one tributary inlet site, at the outlet from Crooked Lake and at two lake sites located on the north end of the lake (north basin) and in deepest area of the lake (south basin). Table 4 summarizes the water quality data collected in the lake. Dissolved oxygen profiles for the both in-lake sites are provided in Figures 7 and 8 of the TMDL document.*

Comments: *No comments.*

4.2 Waste Load Allocations (WLA):

Waste Load Allocations represent point source pollutant loads to the waterbody. Point source loads are typically better understood and more easily monitored and quantified than nonpoint source loads. Whenever practical, each point source should be given a separate waste load allocation. All NPDES permitted dischargers that discharge the pollutant under analysis directly to the waterbody should be identified and given separate waste load allocations. The finalized WLAs are required to be incorporated into future NPDES permit renewals.

Review Elements:

☒ EPA regulations require that a TMDL include WLAs, which identify the portion of the loading capacity allocated to individual existing and future point source(s) (40 C.F.R. §130.2(h), 40 C.F.R. §130.2(i)). In some cases, WLAs may cover more than one discharger, e.g., if the source is contained within a general permit. If no allocations are to be made to point sources, then the TMDL should include a value of zero for the WLA.

☐ All NPDES permitted dischargers given WLA as part of the TMDL should be identified in the TMDL, including the specific NPDES permit numbers, their geographical locations, and their associated waste load allocations.

Recommendation:
☒ Approve ☐ Partial Approval ☐ Disapprove ☐ Insufficient Information

Summary: *There are no permitted point sources in the Crooked Lake watershed. Therefore the WLA for this TMDL is zero (see Table 10 in the TMDL document).*

Comments: *No comments.*

4.3 Load Allocations (LA):

Load allocations include the nonpoint source, natural, and background loads. These types of loads are typically more difficult to quantify than point source loads, and may include a significant degree of uncertainty. Often it is necessary to group these loads into larger categories and estimate the loading rates based on limited monitoring data and/or modeling results. The background load represents a composite of all upstream pollutant loads into the waterbody. In addition to the upstream nonpoint and upstream natural load, the background load often includes upstream point source loads that are not given specific waste load allocations in this particular TMDL analysis. In instances where nonpoint source loading rates are particularly difficult to quantify, a performance-based allocation approach, in which a detailed monitoring plan and adaptive management strategy are employed for the application of BMPs, may be appropriate.

Review Elements:

☒ EPA regulations require that TMDL expressions include LAs which identify the portion of the loading capacity attributed to nonpoint sources and to natural background. Load allocations may range from reasonably accurate estimates to gross allotments (40 C.F.R. §130.2(g)). Load allocations may be included for both existing and future nonpoint source loads. Where possible, load allocations should be described separately for natural background and nonpoint sources.

☒ Load allocations assigned to natural background loads should not be assumed to be the difference between the sum of known and quantified anthropogenic sources and the existing *in situ* loads (e.g., measured in stream) unless it can be demonstrated that the anthropogenic sources of the pollutant of concern have been identified and given proper load or waste load allocations.

Recommendation:
☒ Approve ☐ Partial Approval ☐ Disapprove ☐ Insufficient Information

Summary: *The Technical Analysis section of the TMDL describes how the phosphorus loading capacity for the lake was derived and allocated to sources in the watershed. There are no point sources in the watershed upstream of Crooked Lake; therefore most of the loading capacity was allocated to nonpoint sources in the watershed. Ten percent of the loading capacity was allocated as an explicit margin of safety. See Table 10 in the TMDL document for the specific allocation values.*

Comments: *No comments.*

4.4 Margin of Safety (MOS):

Natural systems are inherently complex. Any mathematical relationship used to quantify the stressor → response relationship between pollutant loading rates and the resultant water quality impacts, no matter how rigorous, will include some level of uncertainty and error. To compensate for this uncertainty and ensure water quality standards will be attained, a margin of safety is required as a component of each TMDL. The MOS may take the form of a explicit load allocation (e.g., 10 lbs/day), or may be implicitly built into the TMDL analysis through the use of conservative assumptions and values for the various factors that determine the TMDL pollutant load → water quality effect relationship. Whether explicit or implicit, the MOS should be supported by an appropriate level of discussion that addresses the level of uncertainty in the various components of the TMDL technical analysis, the assumptions used in that analysis, and the relative effect of those assumptions on the final TMDL. The discussion should demonstrate that the MOS used is sufficient to ensure that the water quality standards would be attained if the TMDL pollutant loading rates are met. In cases where there is substantial uncertainty regarding the linkage between the proposed allocations and achievement of water quality standards, it may be necessary to employ a phased or adaptive management approach (e.g., establish a monitoring plan to determine if the proposed allocations are, in fact, leading to the desired water quality improvements).

Review Elements:

☒ TMDLs must include a margin of safety (MOS) to account for any lack of knowledge concerning the relationship between load and wasteload allocations and water quality (CWA §303(d) (1) (C), 40 C.F.R. §130.7(c)(1)). EPA's 1991 TMDL Guidance explains that the MOS may be implicit (i.e., incorporated into the TMDL through conservative assumptions in the analysis) or explicit (i.e., expressed in the TMDL as loadings set aside for the MOS).

☐ <u>If the MOS is implicit</u>, the conservative assumptions in the analysis that account for the MOS should be identified and described. The document should discuss why the assumptions are considered conservative and the effect of the assumption on the final TMDL value determined.

☒ <u>If the MOS is explicit</u>, the loading set aside for the MOS should be identified. The document should discuss how the explicit MOS chosen is related to the uncertainty and/or potential error in the linkage analysis between the WQS, the TMDL target, and the TMDL loading rate.

☐ <u>If</u>, rather than an explicit or implicit MOS, the <u>TMDL relies upon a phased approach</u> to deal with large and/or unquantifiable uncertainties in the linkage analysis, the document should include a description of the planned phases for the TMDL as well as a monitoring plan and adaptive management strategy.

Recommendation:
☒ Approve ☐ Partial Approval ☐ Disapprove ☐ Insufficient Information

<u>Summary:</u> *The Crooked Lake TMDL includes an explicit MOS derived by calculating 10 percent of the loading capacity.*

<u>Comments</u>*: No comments.*

4.5 Seasonality and variations in assimilative capacity:

The TMDL relationship is a factor of both the loading rate of the pollutant to the waterbody and the amount of pollutant the waterbody can assimilate and still attain water quality standards. Water quality standards often vary based on seasonal considerations. Therefore, it is appropriate that the TMDL analysis consider seasonal variations, such as critical flow periods (high flow, low flow), when establishing TMDLs, targets, and allocations.

Review Elements:

☒ The statute and regulations require that a TMDL be established with consideration of seasonal variations. The TMDL must describe the method chosen for including seasonal variability as a factor. (CWA §303(d)(1)(C), 40 C.F.R. §130.7(c)(1)).

Recommendation:
☒ Approve ☐ Partial Approval ☐ Disapprove ☐ Insufficient Information

<u>Summary</u>*: Section 303(d)(1)(C) of the Clean Water Act and the EPA's regulations require that a TMDL be established with seasonal variations. The Crooked Lake TMDL addresses seasonality because the BATHTUB and AnnAGNPS models incorporate seasonal differences in their prediction of annual total phosphorus loads.*

<u>Comments</u>*: No comments.*

5. Public Participation

EPA regulations require that the establishment of TMDLs be conducted in a process open to the public, and that the public be afforded an opportunity to participate. To meaningfully participate in the TMDL process it is necessary that stakeholders, including members of the general public, be able to understand the problem and the proposed solution. TMDL documents should include language that explains the issues to the general public in understandable terms, as well as provides additional detailed technical information for the scientific community. Notifications or solicitations for comments regarding the TMDL should be made available to the general public, widely circulated, and clearly identify the product as a TMDL and the fact that it will be submitted to EPA for review. When the final TMDL is submitted to EPA for approval, a copy of the comments received by the state and the state responses to those comments should be included with the document.

Review Elements:

☒ The TMDL must include a description of the public participation process used during the development of the TMDL (40 C.F.R. §130.7(c)(1)(ii)).

☐ TMDLs submitted to EPA for review and approval should include a summary of significant comments and the State's/Tribe's responses to those comments.

Recommendation:
☒ Approve ☐ Partial Approval ☐ Disapprove ☐ Insufficient Information

Summary: *The TMDL document includes a summary of the public participation process that has occurred. It describes the opportunities the public had to be involved in the TMDL development process. Letters notifying stakeholders of the availability of the draft TMDL document were mailed to stakeholders in the watershed during public comment. Also, the draft TMDL document was posted on NDoDH's Water Quality Division website, and a public notice for comment was published in local newspapers.*

Comments: *No comments.*

6. Monitoring Strategy

TMDLs may have significant uncertainty associated with the selection of appropriate numeric targets and estimates of source loadings and assimilative capacity. In these cases, a phased TMDL approach may be necessary. For Phased TMDLs, it is EPA's expectation that a monitoring plan will be included as a component of the TMDL document to articulate the means by which the TMDL will be evaluated in the field, and to provide for future supplemental data that will address any uncertainties that may exist when the document is prepared.

Review Elements:

☐ When a TMDL involves both NPDES permitted point source(s) and nonpoint source(s) allocations, and attainment of the TMDL target depends on reductions in the nonpoint source loads, the TMDL document should include a monitoring plan that describes the additional data to be collected to determine if the load reductions provided for in the TMDL are occurring.

☐ Under certain circumstances, a phased TMDL approach may be utilized when limited existing data are relied upon to develop a TMDL, and the State believes that the use of additional data or data based on better analytical techniques would likely increase the accuracy of the TMDL load calculation and merit development of a second phase TMDL. EPA recommends that a phased TMDL document or its implementation plan include a monitoring plan and a scheduled timeframe for revision of the TMDL. These elements would not be an intrinsic part of the TMDL and would not be approved by EPA, but may be necessary to support a rationale for approving the TMDL. http://www.epa.gov/owow/tmdl/tmdl_clarification_letter.pdf

Recommendation:
☒ Approve ☐ Partial Approval ☐ Disapprove ☐ Insufficient Information

Summary: *To insure that the BMPs implemented as a part of any watershed restoration plan will reduce phosphorus levels, water quality monitoring will be conducted in accordance with an approved Quality Assurance Project Plan. Specifically, monitoring will be conducted for all variables that are currently causing impairments to the beneficial uses of the waterbody. Once a watershed restoration* *plan (e.g. 319 PIP) is implemented, monitoring will be conducted in the lake/reservoir beginning two years after implementation and extending five years after the implementation project is complete.*

Comments: *No comments.*

7. Restoration Strategy

The overall purpose of the TMDL analysis is to determine what actions are necessary to ensure that the pollutant load in a waterbody does not result in water quality impairment. Adding additional detail regarding the proposed approach for the restoration of water quality is not currently a regulatory requirement, but is considered a value added component of a TMDL document. During the TMDL analytical process, information is often gained that may serve to point restoration efforts in the right direction and help ensure that resources are spent in the most efficient manner possible. For example, watershed models used to analyze the linkage between the pollutant loading rates and resultant water quality impacts might also be used to conduct "what if" scenarios to help direct BMP installations to locations that provide the greatest pollutant reductions. Once a TMDL has been written and approved, it is often the responsibility of other water quality programs to see that it is implemented. The level of quality and detail provided in the restoration strategy will greatly influence the future success in achieving the needed pollutant load reductions.

Review Elements:

☐ EPA is not required to and does not approve TMDL implementation plans. However, in cases where a WLA is dependent upon the achievement of a LA, "reasonable assurance" is required to demonstrate the necessary LA called for in the document is practicable. A discussion of the BMPs (or other load reduction measures) that are to be relied upon to achieve the LA(s), and programs and funding sources that will be relied upon to implement the load reductions called for in the document, may be included in the implementation/restoration section of the TMDL document to support a demonstration of "reasonable assurance".

Recommendation:
☒ Approve ☐ Partial Approval ☐ Disapprove ☐ Insufficient Information

Summary: *Implementation of this TMDL is dependent upon the availability of Section 319 NPS funds or other watershed restoration programs (e.g. USDA EQIP), as well as securing a local project sponsor and the required matching funds. Provided these three requirements are in place, a project implementation plan (PIP) will be developed in accordance with the TMDL and submitted to the North Dakota Nonpoint Source Pollution Task Force and US EPA for approval. The implementation of the BMPs contained in the NPS PIP is voluntary. Therefore, success of any TMDL implementation project is ultimately dependent on the ability of the local project sponsor to find cooperating producers.*

Comments: *No comments.*

8. Daily Loading Expression

The goal of a TMDL analysis is to determine what actions are necessary to attain and maintain WQS. The appropriate averaging period that corresponds to this goal will vary depending on the pollutant and the nature of the waterbody under analysis. When selecting an appropriate averaging period for a TMDL analysis, primary concern should be given to the nature of the pollutant in question and the achievement of the underlying WQS. However, recent federal appeals court decisions have pointed out that the title TMDL implies a "daily" loading rate. While the most appropriate averaging period to be used for developing a TMDL analysis may vary according to the pollutant, a daily loading rate can provide a more practical indication of whether or not the overall needed load reductions are being achieved. When limited monitoring resources are available, a daily loading target that takes into account the natural variability of the system can serve as a useful indicator for whether or not the overall load reductions are likely to be met. Therefore, a daily expression of the required pollutant loading rate is a required element in all TMDLs, in addition to any other load averaging periods that may have been used to conduct the TMDL analysis. The level of effort spent to develop the daily load indicator should be based on the overall utility it can provide as an indicator for the total load reductions needed.

Review Elements:

☒ The document should include an expression of the TMDL in terms of a daily load. However, the TMDL may also be expressed in temporal terms other than daily (e.g., an annual or monthly load). If the document expresses the TMDL in additional "non-daily" terms the document should explain why it is appropriate or advantageous to express the TMDL in the additional unit of measurement chosen.

Recommendation:
☒ Approve ☐ Partial Approval ☐ Disapprove ☐ Insufficient Information

Summary: *The Crooked Lake nutrient TMDL includes a daily phosphorus load expressed as 0.35 kg per day. The NDDoH believes that describing the phosphorus load as an annual load is more realistic and protective of the waterbody. Most phosphorus based eutrophication models use annual phosphorus loads, because seasonality and unpredictable precipitation patterns make a daily load unrealistic. EPA recognizes that, under the specific circumstances, the state may deem the annual load the most appropriate timeframe (i.e., the water quality target is based on an interpretation of narrative water quality standards which naturally does not include an averaging period). EPA notes that the Crooked Lake TMDL calculations for phosphorus include an approximated daily load derived through simple division of the annual load by the number of days in a year. This should be considered an "average" daily load that typically will not match the actual phosphorus load reaching the lake on a given day.*

Comments: *No comments.*

Appendix E
NDDoH's Response to Comments Received from US EPA Region 8

US EPA Region 8 Comments: The 2012 303(d) list shows Crooked Lake as 375 acres in size. This is not consistent with the acreage given in Section 1.0 and Table 1. The listing information used in the TMDL appears to be based on the 2010 303(d) list (see Table 2). We suggest revising the TMDL to be consistent with the 2012 303(d) listing information.

Section 1.1 seems to indicate that this TMDL document only addresses the nutrient / eutrophication / biological indicators impairment, whereas the title of the document seems to indicate that it addresses the dissolved oxygen impairment too. We suggest that revising one or the other to be consistent.

Pages 1 and 6 include reference to "NDDoH 1993" which we assume is the Lake Water Quality Assessment Project report. However, Section 12.0, References does not include the details of the report being referenced.

NDDoH Response to Comments: Section 1.1 and the accompanying Table 2 have been revised to reflect the most recent 2012 Section 303(d) listing information, including the lake's size as 375-acres. In addition, "low dissolved oxygen" has been added as an impairment cause in Table 2 and additional language has been added to the narrative in Section 1.1 stating that TMDL also addressed the low dissolved oxygen impairment.

References to the 2010 TMDL list have been changed to the most recent 2012 Integrated Report which includes the TMDL list. A reference to the 1993 Lake Water Quality Assessment Report has also been added to Section 12.0, References.

US EPA Region 8 Comments: The description of the AnnAGNPS modeling (Section 5.3, page 19) mentions landuse and crop types that are not consistent with the description of the Crooked Lake watershed in Section 1.2 . The end of Section 5.3 includes a reference to Figure 8 (critical cells) which appears to be incorrect. We believe the reference should be to Figure 11.

NDDoH Response to Comments: The land use and crop type description included in Section 5.3 has been changed to be consistent with the NASS information provided in Section 1.2. The reference to Figure 8 at the end of Section 5.3 has been changed to Figure 11.

US EPA Region 8 Comments: Section 5.4 and Section 6.2 contain references to the CNET model. We believe that the CNET model was not used in the development of this TMDL and that the references to its use should be deleted. Also, the Nurnberg calculations in the last paragraph of Section 5.4 use the lake acreage of 627, whereas we believe that 375 is the correct size of the lake based on the approved 303(d) lists.

NDDoH Response to Comments: Reference to the CNET model in Sections 5.4 and 6.2 were changed to the BATHTUB model which was used in the development of the TMDL.

The value for lake surface area was changed to 375 acres (1.52 km^2) which resulted in the ratio of mean depth to the surface area ($z/A_o^{0.5}$) equal to 2.27 for Crooked Lake. This value is also within the range of lakes used by Nürnberg.