Phosphorus TMDL for Lac Courte Oreilles

Sawyer County, Wisconsin

Draft

July 16, 2014

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1 Introduction

Lac Courte Oreilles (LCO) is a 5,039-acre drainage lake in Sawyer County, Wisconsin (Wisconsin Waterbody Identification Code 2390800). The lake has been classified as an Outstanding Resource Water (ORW) since 1993. Lac Courte Oreilles has a drainage area of approximately 68,990 acres (108 square miles) within the Upper Chippewa River Basin (Figure 1). The main tributaries to the lake are Grindstone, Osprey, and Whitefish Creeks.

Land use/land cover in the watershed is predominantly forested and open water/wetland; five cranberry bogs are located within the LCO direct drainage area that withdraw water from and discharge to the lake. With multiple sport fishes, LCO is a two-story fishery with a maximum depth of 90 feet and a mean depth of 34 feet. LCO is widely recognized for its exceptional recreational and economic benefits as it provides about $700,000 annually through fishing trips to the region, with pursuits in Musky Bay contributing roughly 12% of that total (Pratt, 2013). The lake is central to the region's economy with real estate valued at over $332 million, annual property taxes of $2.9 million, supporting of local infrastructure, plus associated expenditures from residents and vacationers estimated to be about $9.8 million to $14.8 million per year (Wilson, 2010; Appendix A). LCO is also central to the culture of the Lac Courte Oreilles Band of Lake Superior Chippewa. One-third of Lac Courte Oreilles lake is located within reservation boundaries, with the rest of the lake located within the ceded territory.

Three major bays (Musky, Stuckey, and Northeast) and three major basins (West, Central, and East) comprise the lake (Figure 1). Most of these are classified as oligotrophic; however, Musky Bay has been characterized by eutrophic conditions in recent years (Wilson, 2011). In 2012, Musky Bay was placed on the Wisconsin Department of Natural Resources (WDNR) 303(d) impaired waters list for impairment to water quality use restrictions due to elevated total phosphorus (TP; Table 1). Recreational use has been limited in Musky Bay due to the presence of algal mats, as well as excessive aquatic plant growth including the invasive species curly leaf pond weed. Elevated phosphorus in the other basins of the lake has resulted in increased oxygen demand and degraded conditions for the two-story fishery. In particular, phosphorus concentrations in Stuckey Bay are of concern for both fish and aquatic life uses and recreational use. West Basin is impacted by elevated phosphorus concentrations from both Stuckey Bay and Musky Bay.

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The goal of this Total Maximum Daily Load (TMDL) is to restore and protect the attainment of beneficial uses throughout the lake by reducing phosphorus loadings to Lac Courte Oreilles. The phosphorus loads specified in this TMDL are designed to: decrease the frequency and severity of algal blooms in Musky Bay; increase dissolved oxygen levels throughout the lake sufficient to protect the two-story cold water fishery; stop eutrophication from proceeding in the west end of the lake, and protect this outstanding natural resource from further degradation.

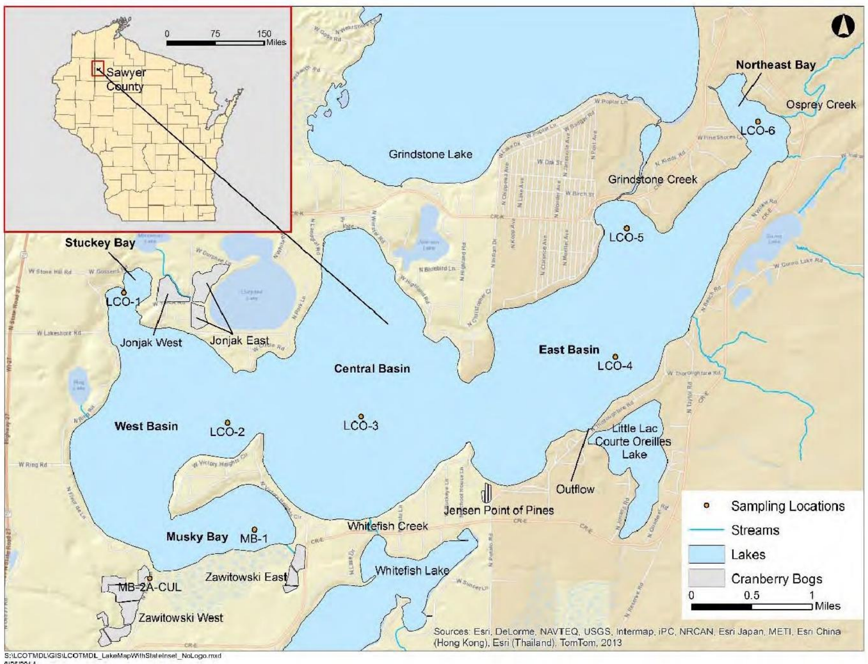

Figure 1. Location of Lac Courte Oreilles

Table 1. WDNR 2012 303(d) Impaired waters listing for Musky Bay in Lac Courte Oreilles

Local Waterbody Name	WBIC	Pollutant	Impairment Indicator
Musky Bay	2390800	Total Phosphorus	Water Quality Use Restrictions

2 Problem Statement

Water quality and the cold water fishery in LCO is threatened by ongoing excessive phosphorus loading. Sources of phosphorus to LCO include nearby forested and agricultural land uses, adjacent wetlands, shoreline development, inputs from adjacent cranberry bogs, atmospheric deposition, and phosphorus release from sediments in the lake. Water quality degradation has been most apparent in Musky Bay, which has seen shifts in vegetation composition and increased persistence of dense, floating algal mats (Fitzpatrick et al., 2003; Wilson, 2011). Consequently, WDNR included Musky Bay on its 2012 303(d) list of impaired waters. WDNR indicated that *"Total phosphorus concentrations exceed WisCALM listing thresholds for recreation use… Observed macrophyte density in Musky Bay is not representative of expected conditions and is in fact causing an impairment of the recreational use."* U.S. Environmental Protection Agency approved Wisconsin's 2012 303(d) list on June 25, 2014, concurring with WDNR's listing of Musky Bay and it's rationale for doing so.

Increased spatial distribution of floating algal mats and macrophytes has been observed in Musky Bay in recent years. Excessive algal growth results in depleted dissolved oxygen conditions from decomposition of dying algae, which also leads to degradation of substrate through deposition and accumulation of organic matter (Fitzpatrick, et al., 2003). Cumulatively, these conditions can be detrimental to suitable habitat conditions for fish spawning and refugia and have likely led to reduced fish populations in Musky Bay.

While water quality is fairly high in much of LCO, hypoxic conditions (< 2 mg/L) develop in the hypolimnion of some bays and basins during the summer stratification period, threatening cold water fish species, including cisco and whitefish, and limiting successful spawning of muskellunge particularly in Musky Bay, which, historically has been the preferred spawning site for muskellunge in LCO. . Continued loading of phosphorus to the major basins and bays of LCO at current rates will contribute to a trend of increasing summertime dissolved oxygen depletion in the hypolimnion through increased phytoplankton productivity and subsequent decay. Hypoxic conditions also lead to increased rates of internal loading of phosphorus from the sediments, which has been measured in laboratory experiments on intact sediment cores (James, 2013a; James, 2013b). These degraded conditions in LCO are likely to be amplified with ongoing climate change as watershed loads increase and surface waters warm resulting in further degradation of recreational uses and habitat suitable for cold water fisheries.

Water Quality Targets

Lac Courte Oreilles is designated by WDNR as an Outstanding Resource Water (ORW). As such, it is protected by Wisconsin's antidegradation rule (WAC NR 207.03(3)), with the intent that water quality in the lake is not lowered; any new or expanded discharge would be required to discharge at background water quality levels. As a two-story cold water fishery, the current applicable statewide TP criterion in LCO is 15 µg/L (WAC NR 102.06). However, this criterion does not consider the ORW designation of this resource nor the site-specific recreational and aquatic life uses and characteristics. To address these concerns, the Courte Oreilles Lakes Association (COLA), in cooperation with the Lac Courte Oreilles Band of Lake Superior Chippewa Indians (Tribe), developed a site-specific criterion (SSC) or water quality target for LCO consisting of a lake-wide average of 10 µg/L TP (COLA, 2014; Appendix B). This target was set in order to restore and protect designated uses and comply with antidegradation for an ORW. More specifically, the lake-wide average target of 10 µg/L TP is based on the following considerations:

1. Following commonly accepted limnological practice and terminology, the three bays (Musky, Stuckey, and Northeast) and three basins (West, Central, and East) comprise one lake referred to as Lac Courte Oreilles and are identified by one lake identification number (ID # 2390800);
2. All of the bays and basins are inter-connected and share one water level (relative to sea level except for short-term variations caused by wind, seiche, storm inflows etc.);
3. Documented impairments in Musky Bay even while the bay was meeting its WDNR-applied 40 μg/L total phosphorus criterion (Pratt, 2013; Appendix C);
4. The direct connection of Musky Bay to LCO and, therefore, its influence on water quality in the rest of LCO;
5. Stratification status of Musky Bay as "deep" based on temperature profiles collected in the bay;
6. Evidence of significant increases in phosphorus loading to LCO since pre-settlement conditions based on the sediment diatom record;
7. Despite attainment of current total phosphorus criteria (15 μg/L) in LCO, a biologic impairment exists in the lake due to dissolved oxygen concentrations below 6 mg/L in the hypolimnion, indicating negative impacts to the cold water fishery in LCO;
8. Dissolved oxygen levels in the flocculent sediment at the bottom of Musky Bay are below concentrations necessary for muskellunge egg survival during spawning season; and,
9. The need to proactively protect against future degradation of fish populations due to climate change through watershed management practices.

Based on a review of available scientific literature, 10 μg/L was selected for LCO as appropriate for protection of water quality and the cold water fishery. A thorough review of phosphorus, dissolved oxygen, secchi depth, and chlorophyll *a* levels and health of various cold and warm-water fish species in Minnesota lakes can be found in Heiskary and Wilson (2005) and Heiskary and Wilson (2008). The important findings from these studies that support the proposed 10 μg/L total phosphorus criterion for LCO are:

- Dissolved oxygen depletion occurs when total phosphorus concentrations are greater than 10 μg/L, which is often used as an upper bound for oligotrophic conditions. A study of phosphorus and hypolimnetic oxygen demand lakes in British Columbia found that cold-water salmonid fisheries were protected with total phosphorus levels ranging from 5 to 15 μg/L (Nordin, 1986).
- Whitefish and cisco are most abundant in a trophic state index (TSI) range of 30 to 40, which corresponds to total phosphorus levels of 6 to 12 μg/L.
- Typical concentrations of total phosphorus in Minnesota designated lake trout lakes is 9 to 16 μg/L. For the lakes exhibiting adequate refuge for lake trout, the summer average total phosphorus commonly ranged from 8 to 10 μg/L;
- The upper bound for total phosphorus concentrations sustaining lake trout is likely 15 μg/L.

Ultimately, phosphorus loading to LCO must be reduced to restore the water quality and biologic conditions in this rare ORW. The threat of negative impacts from climate change heightens this need. Therefore, this TMDL is developed to protect LCO for a lake-wide average concentration of 10 μg/L. Achieving this target will reduce the frequency and extent of algal blooms and lead to improvements in hypolimnetic dissolved oxygen concentration that is necessary for success and proliferation of the cold water fisheries.

Monitoring Background

The Lac Courte Oreilles Conservation Department (LCOCD) has been overseeing water quality sampling in LCO since 1996. Sampling is conducted by LCOCD under a Quality Assurance Project Plan approved by U.S. EPA (LCOCD, 2011; Appendix D). More intensive monitoring began in 2002 with increased frequency of sampling for TP, chlorophyll *a* and secchi depth in each of the major bays and basins. Monitoring locations are presented in Figure 1. Measurements for *in situ* temperature and dissolved oxygen were also collected at varying depths for representative measurements in the epilimnion, metalimnion, and hypolimnion. In most years, sampling was generally conducted bi-monthly from May-October. TP and chlorophyll *a* samples were collected from the surface with hypolimnetic sampling for TP occurring in 2002 and 2013.

Water quality was evaluated for the period defining the summer growing season following the 2014 WisCALM methodology (WDNR, 2013). The summer growing season for TP is defined as June 1 – September 15; and the summer growing season for chlorophyll *a* and secchi depth is defined as July 15 – September 15. No significant temporal trend in seasonal mean TP or chlorophyll *a* concentration was found in the bays or basins (α = 0.05). Therefore, seasonal means for the period of 2002-2013 were calculated in the major bays and basins for TP, chlorophyll *a* and secchi depth. Additionally, an area-weighted lake-wide average was calculated for TP.

In general, TP (Figure 2) and chlorophyll *a* (Figure 3) concentrations were higher in Musky Bay than all other bays or basins. Consistent with this pattern, seasonal mean secchi depth was lowest in Musky Bay (Figure 4). The area-weighted lake-wide average TP of 12.5 µg/L for this period exceeds the TMDL target of 10 µg/L by 25%.

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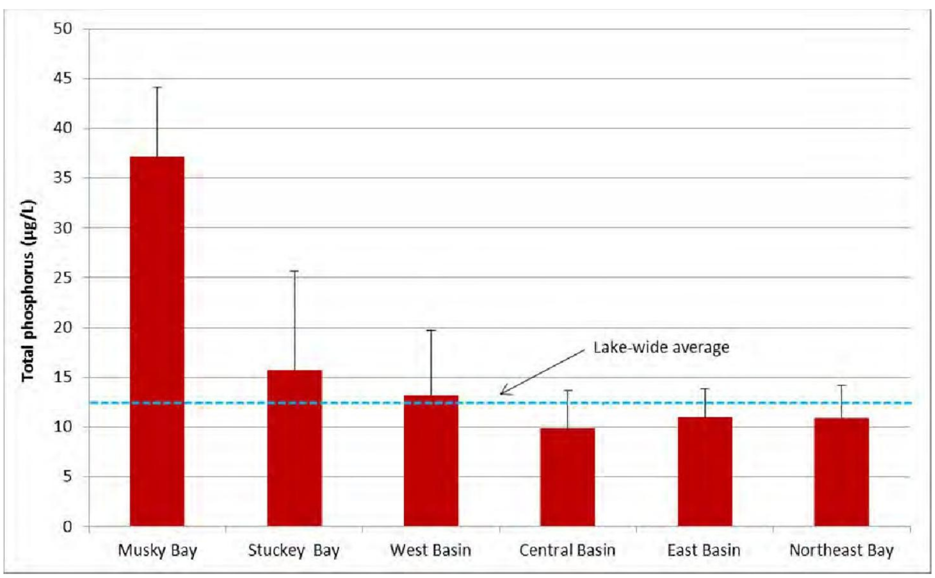

Figure 2. Seasonal mean total phosphorus (June 1-Sept 15) in major bays and basins of LCO (2002-2013). Errors bars indicate ±1 SD

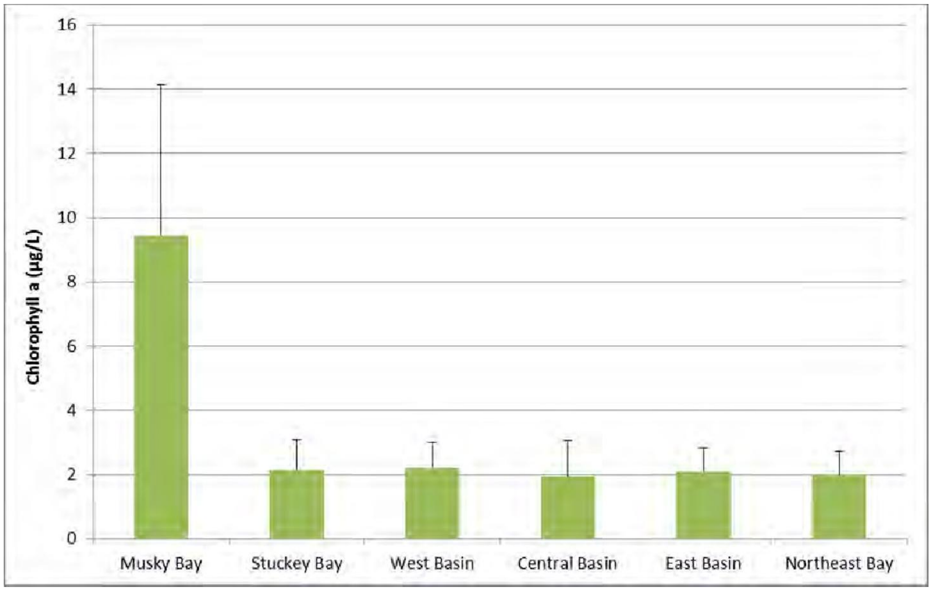

Figure 3. Seasonal mean chlorophyll *a* (July 15- Sept 15) in major basins and bays of LCO (2002-2013). Errors bars indicate ±1 SD

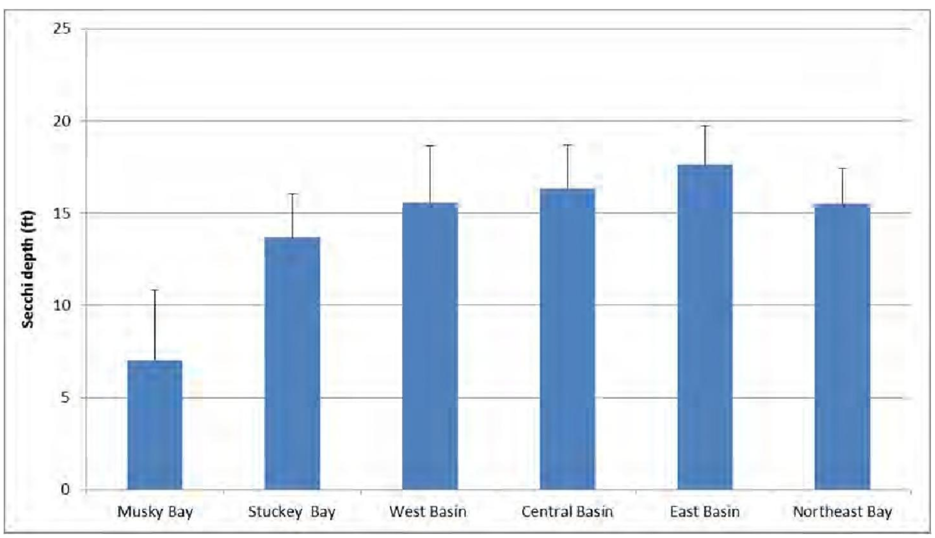

Figure 4. Seasonal mean secchi depth (July 15- Sept 15) in major basins and bays of LCO (2002-2013). Errors bars indicate ±1 SD

Using temperature profiles collected in 2013, the average hypolimnetic dissolved oxygen (DO) concentration was determined for measurements collected after the onset of stratification, and the frequency of average hypolimnetic DO concentrations below 6 mg/L was calculated for each monitoring station (Table 2). The data indicates significant extent and frequency of DO concentrations depressed below the 6 mg/L threshold for protection of a cold water fishery.

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Table 2. Summary of hypolimnetic dissolved oxygen in major basins and bays of LCO (June – October 2013)

Bay/Basin	Mean DO (mg/L)	Min DO (mg/L)	Max DO (mg/L)	Count of Daily Means	% Less than 6 mg/L
Musky Bay	3.24	0.85	9.87	11	82%
Stuckey Bay	8.44	6.11	11.24	9	0%
West Basin	2.23	0.04	8.43	19	84%
Central Basin	3.50	0.13	9.78	19	68%
East Basin	5.47	0.04	11.20	32 (two stations)	44%
Northeast Bay	7.99	5.95	11.22	14	7%

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3 Load Development

The development of estimates of phosphorus loads to LCO are described in this section. Loads were estimated for the following sources:

- Major tributary streams with sufficient monitoring data, including Grindstone Creek, Osprey Creek, and Whitefish Creek;
- Drainage areas outside of the major tributaries;
- Cranberry bogs; and
- Atmospheric deposition.

Subwatershed delineations for the major tributaries and the other direct drainage areas are presented in Figure 5. Loads resulting from the release of phosphorus from bottom sediments in LCO were included in the model development and calibration, and is discussed in Section 4 of this TMDL report.

Major Tributary Loads

Annual TP loads from the major tributaries to LCO were estimated using monitoring data and the FLUX32 tributary loading model (Walker, 1985). The FLUX32 model was applied for Grindstone Creek, Osprey Creek, and Whitefish Creek subwatersheds based on tributary TP and flow monitoring data from 2013 collected by LCOCD. FLUX32 calculates tributary loads using six options; the flow weighted average method (Method 2) was selected as most appropriate for the available datasets.
Results from the FLUX32 model are presented in Table 3.

Table 3. Estimated annual total phosphorus loads for major tributaries

Load Source	Bay or Basin Receiving Load	Total Flow (acre-ft)	Average TP Concentration (µg/L)	Annual TP Load (lb)
Tributaries				
Grindstone Creek	East Basin	15,543	20.5	921
Osprey Creek	Northeast Bay	1,393	55.5	194
Whitefish Creek	Central Basin	13,434	20.4	683

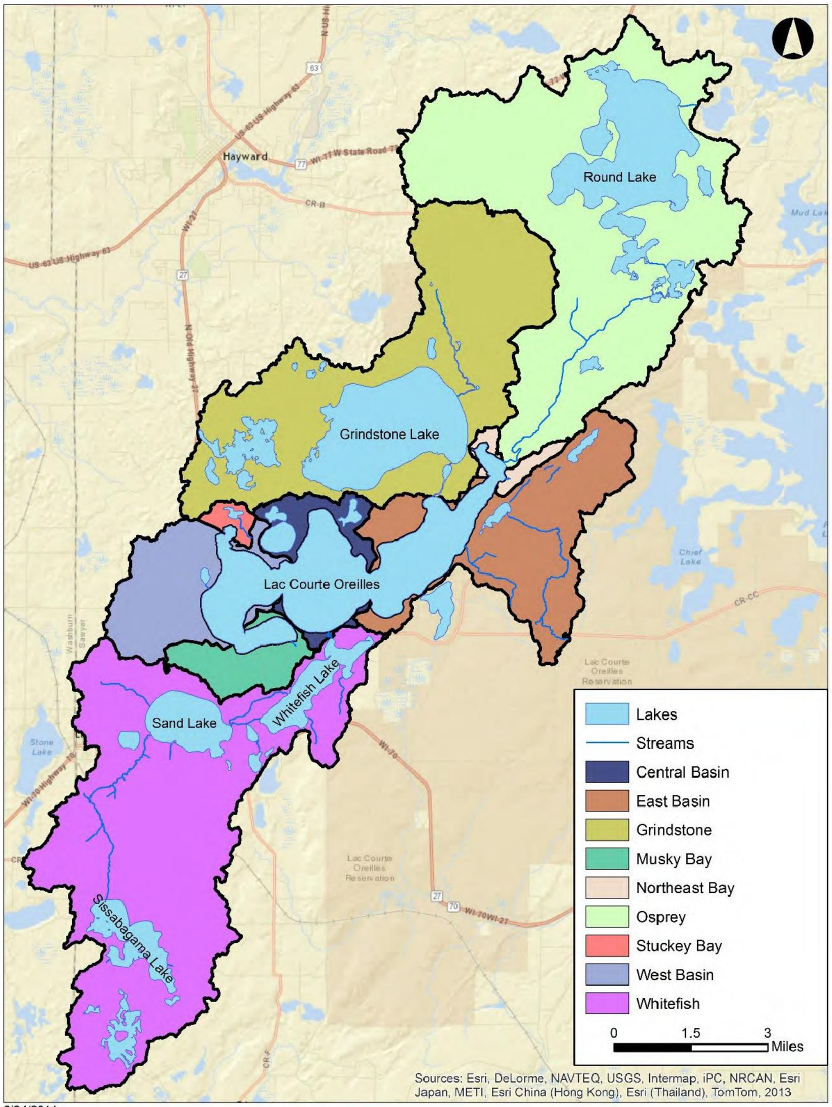

Figure 5. Subwatershed delineations

Other Direct Drainage Area Loads

Loading from areas draining to LCO outside of the three major tributaries was determined using NLCD 2006 land use percentages (agriculture, urban, grassland, forest, shrubland, open water) and baseline export coefficients specific to each land use. Figure 6 presents the land use designations in the watershed. Note that in practice, the pasture and cultivated cropland covers in the watershed are predominantly corn and soybean rotations with occasional hay and alfalfa. Table 4 presents the percentage of each land use type in the drainage areas. Baseline export coefficients were taken from the Lake St. Croix TMDL (WDNR and MPCA, 2012) and are presented in Table 5. Estimated annual phosphorus loads for each of the direct drainage areas is given in Table 6.

Table 4. Land use percentages for other direct drainage areas

Direct Drainage Area	Total Area (acres)	Percent Agriculture	Percent Urban	Percent Grassland	Percent Forest	Percent Shrubland	Percent Open Water
West Basin	3,100	13%	8%	41%	33%	0%	4%
Central Basin	1,336	1%	15%	6%	45%	0%	33%
East Basin	5,898	0%	9%	1%	75%	1%	13%
Musky Bay	1,350	3%	8%	23%	45%	0%	21%
Stuckey Bay	328	2%	11%	10%	59%	0%	17%
Northeast Bay	461	1%	9%	0%	75%	0%	15%

Table 5. Baseline phosphorus export coefficients

Land Use Category	Baseline Export Coefficient (lbs/ac/yr)
Agriculture	0.561
Urban	0.561
Grassland	0.197
Forest	0.088
Shrubland	0.088
Open Water	0.006

Table 6. Estimated annual flows and total phosphorus loads for direct drainage areas

Direct Drainage Area	Annual Flow (acre-ft)	Unit Area Load (lb/ac/yr)	Annual TP Load (lb)
West Basin	2,335	0.233	722
Central Basin	1,416	0.143	191
East Basin	440	0.121	716
Musky Bay	1,017	0.148	200
Stuckey Bay	348	0.148	48
Northeast Bay	34	0.121	55

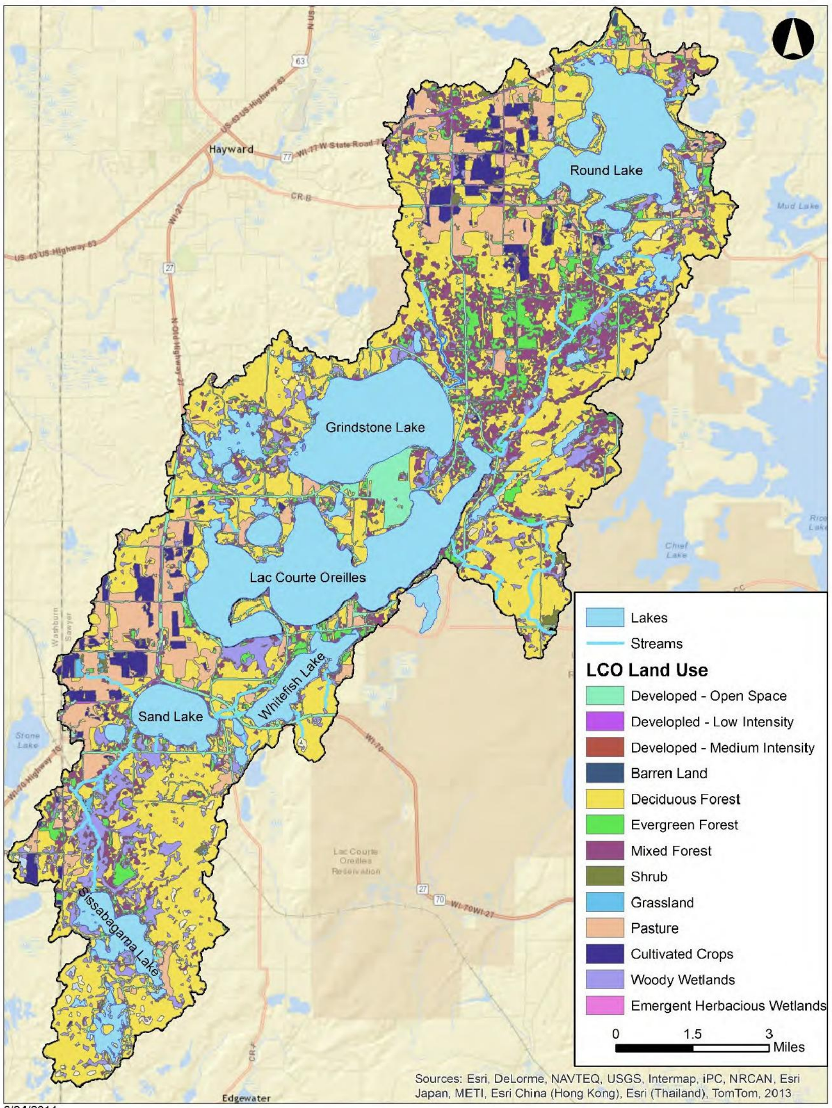

Figure 6. Watershed land use designations

Cranberry Bog Loads

TP loading from cranberry bogs was calculated using data from samples collected at station MB-2A-CUL (Figure 1). This station represents cranberry bog discharges into western Musky Bay. Concentrations from this sampling location were assumed to be representative of discharges from all five cranberry bogs that discharge to LCO. Samples were collected at least once monthly from March – October 2013, with additional sampling during the spring runoff period and storm events.

TP loads were estimated for several types of operational discharge events (spring overwinter crop protection and sprinkling or flooding; fall frost protection sprinkling or flooding; and fall harvest discharge) as well as precipitation driven runoff events. Water volumes for each operational discharge were calculated using the bog area (as calculated in GIS from aerial photographs) and an assumed water depth. For both spring and fall operational discharges, three events at 1-foot water depth were assumed to occur. The harvest discharge occurred once in the late fall and the water depth was assumed to be three feet. An average TP concentration was calculated from the sampling data for each type of event using field notes that indicated when the bog was discharging. Average spring and fall operational discharge concentrations were calculated to be 200 and 100 µg/L, respectively.

To represent TP loads resulting from precipitation driven discharges from the bogs, the Natural Resources Conservation Service (NRCS) Curve Number (CN) method (USDA, 1986) was used. A CN of 77.75 was applied corresponding to the average CN for hydrologic soil groups for the land use "Agriculture, non-row crops," consistent with the approach by WDNR (2014) for cranberry bogs using curve numbers from MacEnroe and Gonzalez (2003). The annual runoff volume was calculated using the bog area, total annual precipitation, and the CN of 77.75. Total annual precipitation for 2013 was 40.71 inches from the Couderay 7 W weather station (USC00471847) located six miles from LCO (NOAA, 2014). An average TP concentration in the precipitation runoff was calculated using field notes that indicated dates of storm water discharge from the bog. The average TP discharge concentration during runoff events was calculated to be 158 µg/L.

Table 7. Estimated annual total phosphorus loads for direct drainage areas

Parameter	Musky Bay West Bog	Musky Bay East Bog	Jonjak West Bog	Jonjak East Bog	Point of Pines Bog	Totals
Bog Area (ac)	73	23	22	45	6	169
Total Spring Load (lbs)	119	37	36	73	9	275
Total Fall Load (lbs)	60	19	18	37	5	138
Total Fall Harvest Load (lbs)	60	19	18	37	5	138
Total Runoff Load (lbs)	18	6	5	11	1	41
Annual Total Phosphorus Load (lbs)	257	80	77	158	20	592

Atmospheric Loads

Loads from atmospheric phosphorus deposition directly into LCO were specified using data reported by Robertson, et al. (2009) for nearby Whitefish Lake of 17.047 mg/m^2-yr. This results in a TP loading to LCO via atmospheric deposition of 765lbs/yr.

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4 Water Quality Model Development

Water quality models are used to define the relationship between pollutant loading and the resulting water quality. This TMDL is based upon the BATHTUB model. The development of the BATHTUB model is described in the following sections, including information on:

- Model selection
- Model inputs
- Model calibration

Model Selection

The BATHTUB water quality model (Walker, 1985) was used to define the relationship between external phosphorus loads and the resulting total phosphorus concentration, chlorophyll *a* concentration, and secchi depth. The BATHTUB model was selected because it provides an optimal balance between data requirements and technical rigor. BATHTUB has been used in other Wisconsin lake modeling projects, as well as numerous lake and reservoir TMDLs across the country. It has been cited as an effective tool for lake and reservoir water quality assessment and management (Ernst et al., 1994).

Model Inputs

This section gives an overview of the model inputs required for BATHTUB application and how they were derived. The following categories of inputs are required for BATHTUB:

- Model options
- Global variables
- Segmentation
- Dispersion coefficients
- Phosphorus loads

Model Options

BATHTUB provides a multitude of model options to estimate nutrient concentrations in a lake or reservoir. Model options were applied as shown in Table 88 for LCO, with the rationale for these options discussed as follows. No conservative substance was being simulated for the lake, so this option was not needed. The Canfield and Bachman model was used to simulate phosphorus. Nitrogen was not simulated since phosphorus is the nutrient of concern. Chlorophyll a was simulated using the Jones and Bachman model. Transparency was simulated using the Total P model. Longitudinal dispersion was specified using the Input Exchange option, with dispersion inputs based upon the results of an EFDC hydrodynamic model developed specifically for LCO (discussed below). Phosphorus calibrations were based on decay rates. No nitrogen calibration was required. Finally, the use of availability factors was not required, and observed concentrations were used to generate mass balance tables for the lakes.

Table 8. BATHTUB Model Options for Lac Courte Oreilles

Model	Model Option
Conservative substance	Not computed
Total phosphorus	Canfield and Bachman
Total nitrogen	Not computed
Chlorophyll-a	Jones and Bachman
Transparency	Total P
Longitudinal dispersion	Input Exchange
Phosphorus calibration	Decay Rates
Nitrogen calibration	None
Availability factors	Ignored
Mass-balance tables	Use observed concentrations

Global Variables

The global variables required by BATHTUB consist of:

- The averaging period for the analysis
- Precipitation, evaporation, and change in lake levels
- Atmospheric phosphorus loads

BATHTUB is a steady state model, whose predictions represent concentrations averaged over a period of time. A key decision in the application of BATHTUB is the selection of the length of time over which inputs and outputs should be modeled. The length of the appropriate averaging period for BATHTUB application depends upon what is called the nutrient residence time, i.e. the average length of time that phosphorus spends in the water column before settling or flushing out of the lake. Guidance for the BATHTUB model recommends that the averaging period used for the analysis be at least twice as large as nutrient residence time for the lake of interest. Initial simulations for LCO showed a phosphorus residence time on the order of one year, so a two year averaging period was used.

Precipitation inputs were taken from the Couderay 7 W weather station (USC00471847). This resulted in a typical annual precipitation input of 32 inches for the lake. Evaporation was set to equal precipitation.

Finally, atmospheric phosphorus loads were specified using data reported by Robertson, et al. (2009) for nearby Whitefish Lake of 17.047 mg/m^2-yr.)

Segmentation

BATHTUB provides the capability to divide the lake under study into a number of individual segments, allowing prediction of the change in phosphorus concentrations over the length of each basin or bay. The segmentation scheme selected for Lac Courte Oreilles was designed to provide one segment for each of the three primary lake basins (East, Central, and West), and distinct segments for each of the major embayments (Musky, Stuckey, and NE Bays).

BATHTUB requires that a range of inputs be specified for each segment. These include segment surface area, length, total water depth, and depth of thermocline and mixed layer. Segment-specific values for segment depths were calculated from segment volumes divided by surface areas. Segment lengths and surface areas were calculated using GIS.

Dispersion Coefficients

BATHTUB describes the degree of mixing that occurs between model segments through the use of dispersion coefficients. BATHTUB provides the capability of estimating these dispersion coefficients using empirical equations from the scientific literature. BATHTUB also allows the user to manually specify these dispersion coefficients in situations where the model user has better site-specific information to define this mixing. The latter approach was taken for LCO, because the rate of mixing controls:

1. The extent to which concentrations in the bays are caused solely by loads directly to the bays, versus concentrations in the main basins; and
2. The extent to which concentrations in the bays are expected to differ from concentrations in the main lake basins for a given loading scenario.

A fine-scale hydrodynamic model was developed for LCO to directly predict the amount of mixing between segments. The hydrodynamic model was based upon the Environmental Fluid Dynamics Code (EFDC), an EPA-supported modeling framework. Application of the EFDC model consisted of the following steps:

- Development of a model grid
- Comparison of model predictions to surface temperature data
- Application of the model to define mixing between bays and basins
- Translation of EFDC outputs into dispersion coefficients for use with BATHTUB

Development of the model grid consisted of digitizing the bathymetric map of LCO, then developing a curvilinear segmentation scheme that captured the variation of the bathymetry. The resulting grid has 2,125 cells horizontally; when applied in three-dimensional mode there are a total of 21,250 cells.

Once the model grid was established, EFDC was applied using observed 2012 climatic data (from Sawyer County Airport and the Rice Lake solar radiation site) as model inputs. Surface temperatures predicted by EFDC were successfully compared to observed data from multiple lake stations to demonstrate the reliability of model predictions.

The next step of EFDC application consisted of a dye tracer simulation to define mixing between bays and basins. The model was vertically condensed into two dimensions for computational purposes, and a slug of conservative dye was entered into the model at Musky Bay on June 1. EFDC predicted the rate at which this dye spread throughout the rest of the lake over the remainder of the year. Finite difference equations were developed to allow for the estimation of the dispersion taking place at each of the BATHTUB model segment interfaces.

The final step consisted of translating the EFDC outputs into dispersion coefficients for use with BATHTUB. The mixing coefficients determined above were in units of cubic meters per day, while BATHTUB requires dispersion coefficients be specified in units of cubic hectometers/year. A unit conversion factor of 0.000365 was applied to convert the EFDC estimates into values used in BATHTUB.

Phosphorus Loads

BATHTUB requires flow and nutrient concentrations for each tributary under consideration. Three tributaries were described: Grindstone Creek (discharging to East Basin), Whitefish Creek (discharging to Central Basin) and Osprey Creek (discharging to NE Bay.) Flows and TP concentrations for each tributary were estimated using data collected by the LCOCD as described in Section 3.

In addition to the above tributary loads, direct drainage and cranberry bog inputs were specified for each lake segment based on the load estimation described in Section 3.

Model Calibration

BATHTUB model calibration consists of:

1. Applying the model with all inputs specified as above
2. Comparing model results to observed phosphorus data
3. Adjusting model coefficients to provide the best comparison between model predictions and observed phosphorus data.
4. Comparing model results to observed chlorophyll *a* data
5. Adjusting model coefficients to provide the best comparison between model predictions and observed chlorophyll *a* data.
6. Comparing model results to observed secchi depth data
7. Adjusting model coefficients to provide the best comparison between model predictions and observed secchi depth data.

The BATHTUB model was initially applied with the model inputs as specified above. Observed data from Lac Courte Oreilles for the years 2002 and 2013 were used for calibration purposes, consistent with the assumption of a multiple-year averaging period for BATHTUB.

BATHTUB was first calibrated to match the observed average total phosphorus concentrations in each of the model segments. The calibration strategy consisted of using a single lake-wide calibration coefficient, rather than making calibration adjustments on a segment by segment basis. Model results in all six segments initially over-predicted the observed phosphorus data. Selection of a calibration coefficient of 1.55 resulted in an acceptable fit to the observed total phosphorus data in every modeled segment except Musky Bay, where the model under-predicted the observed phosphorus concentration. Phosphorus loss rates in BATHTUB rates reflect a typical "net settling rate" (i.e. settling minus sediment release) observed over a range of water bodies. Under-prediction of observed phosphorus concentrations can occur in cases of elevated phosphorus release from lake sediments. The mismatch between model and data for Musky Bay was corrected during the calibration process via the addition of an internal phosphorus load of 0.1 mg-P/m^2-day to the Musky Bay segment. The additional sediment phosphorus flux is consistent with the phosphorus flux measurement conducted by James (2013a; Appendix E), who measured sediment phosphorus fluxes in Musky Bay of 0.06 – 0.31 mg-P/m^2-day during oxic conditions, and sediment phosphorus fluxes of 0.46 – 2.96 mg-P/m^2-day during anoxic conditions. Because the BATHTUB input for sediment phosphorus flux represent the incremental increase in flux over "typical" lakes, observed sediment flux data provide an upper bound for the BATHTUB input. The BATHTUB input of 0.1 mg-P/m^2-day, which is equivalent to 90 lbs TP per year, is much lower than the majority of the observed range, supporting its appropriateness. The resulting predicted total phosphorus concentration is shown in Figure 77.

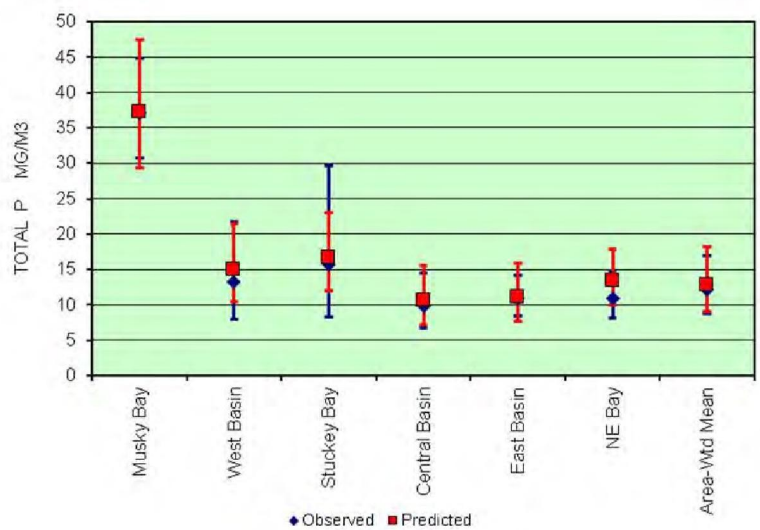

Figure 7. BATHTUB Model Calibration to Observed Total Phosphorus Data

BATHTUB was next calibrated to match the observed average chlorophyll *a* concentrations in each of the model segments. The calibration strategy consisted of using a single lake-wide calibration coefficient, rather than making calibration adjustments on a segment by segment basis. Model results in all six segments initially over-predicted the observed chlorophyll *a* data. Selection of a calibration coefficient of 1.6 resulted in an acceptable fit to the observed total chlorophyll *a* data in every modeled segment, as shown in Figure 8.

The final aspect of BATHTUB calibration corresponded secchi depth transparency. The calibration strategy again consisted of using a single lake-wide calibration coefficient, rather than making calibration adjustments on a segment by segment basis. Model results in all six segments initially under-predicted the observed secchi depth data. Selection of a calibration coefficient of 1.8 resulted in an acceptable fit to the observed secchi depth data in every modeled segment, as shown in Figure 9.

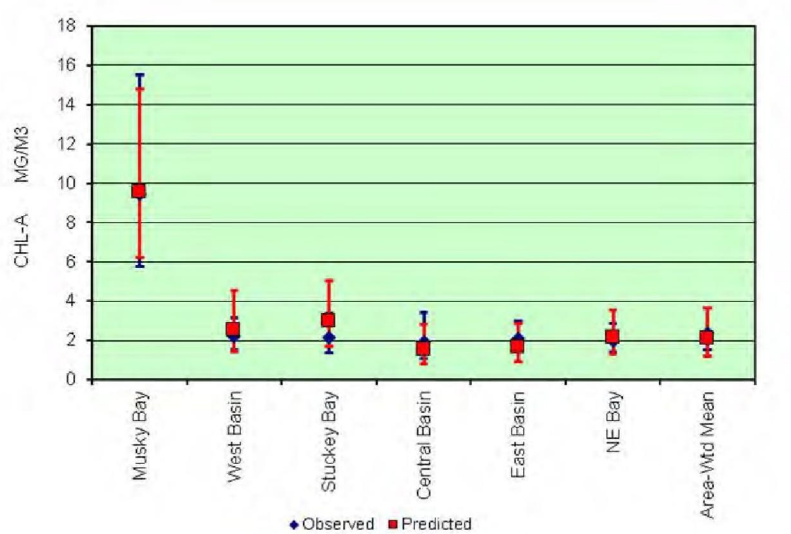

Figure 8. BATHTUB Model Calibration to Observed Chlorophyll *a* Data

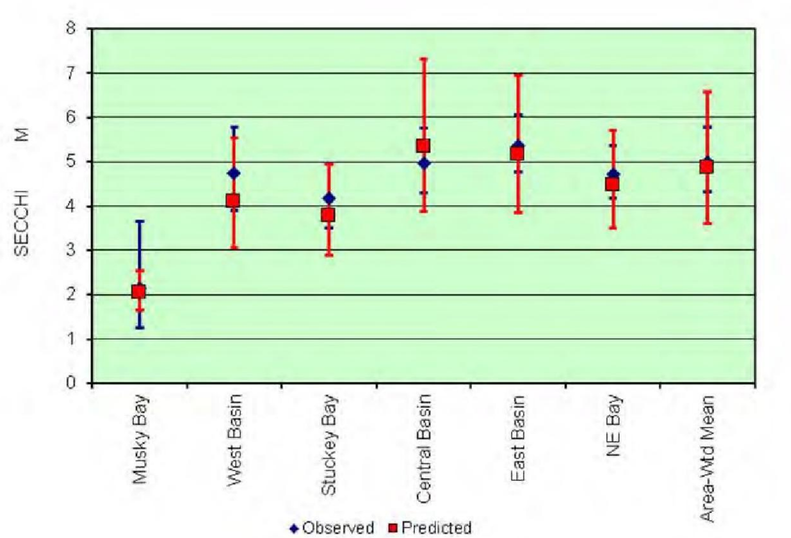

Figure 9. BATHTUB Model Calibration to Observed Secchi Depth Data

5 TMDL Development

Linkage Analysis

Establishing a link between watershed characteristics and resulting water quality is a crucial step in TMDL development. The primary concern for LCO is the amount of phosphorus entering the lake through direct runoff, tributaries, and cranberry bog discharges, as well as excess phosphorus releases from bottom sediments in Musky Bay. Phosphorus enters the lake in both dissolved and sediment-bound form from these sources. Excess phosphorus loading causes eutrophication of lakes, characteristics of which are increased macrophyte and algal growth and hypolimnetic oxygen depletion.

Water Quality Goals

The goal of this TMDL is to reduce external phosphorus loadings to LCO in order to support LCO's designated fish and aquatic life use of a two-story cold water fishery and to support recreational use of the lake. The water quality goal that has been established to support designated uses and to comply with antidegradation in this ORW is a lake-wide summer average epilimnetic TP concentration of 10 µg/L, which is the proposed site-specific phosphorus criterion for the lake. Reductions in chlorophyll *a* concentrations, improvements in water clarity (as measured by secchi depth), and reductions in hypolimnetic oxygen demand rates are expected as benefits of achieving this water quality target.

The water quality goal was set based on the proposed phosphorus site-specific criterion for LCO, review of literature on water quality requirements for cold water fisheries health, and stakeholder input.

The BATHTUB model was used to determine the phosphorus load reductions necessary to achieve the goal. Results of the BATHTUB model application indicates that, under existing phosphorus loading conditions of 5,178 lbs/yr, the lake-wide average epilimnetic TP concentration is 12.8 µg/L, 28% higher than the goal of 10 µg/L. BATHTUB model results for load reduction scenarios show that reducing the phosphorus load by 1,297 lbs/yr, or 25%, to 3,881 lbs/yr results in attainment of the lake-wide average TP concentration of 10 µg/L. Attaining this lake-wide average TP goal results in water quality improvements at varying levels throughout the lake. The improvement in TP concentrations, chlorophyll a concentrations, secchi depth, and hypolimnetic oxygen demand are presented in Table 9.

Table 9. Predicted water quality benefits of meeting lake-wide average phosphorus goal

	Lake-wide Average	Musky Bay	Stuckey Bay	West Basin	Central Basin	East Basin	Northeast Bay
Total Phosphorus (µg/L)							
Baseline	12.8	37.3	16.7	14.9	10.6	11.0	13.4
Goal Attainment	10.0	15.1	11.0	10.7	8.9	9.7	12.1
% Improvement	22%	60%	34%	28%	16%	12%	10%
Chlorophyll *a* (µg/L)							
Baseline	2.1	9.6	3.0	2.5	1.5	1.6	2.1
Goal Attainment	1.4	2.6	1.6	1.5	1.2	1.3	1.9
% Improvement	33%	73%	47%	40%	20%	19%	10%
Secchi Depth (m)							
Baseline	4.9	2.0	3.8	4.1	5.3	5.2	4.5
Goal Attainment	5.6	4.1	5.2	5.3	6.1	5.7	4.8
% Improvement	14%	105%	37%	29%	15%	10%	7%
Hypolimnetic Oxygen Demand (mg/L/day)							
Baseline	0.132	0.282	0.103	0.148	0.114	0.123	0.070
Goal Attainment	0.116	0.183	0.084	0.126	0.104	0.116	0.067
% Improvement	12%	35%	18%	15%	8%	6%	5%

Loading Capacity

The loading capacity defines the maximum loading allowable for a waterbody to achieve the water quality goals. As stated previously, the loading capacity to achieve the water quality goal of a lake-wide average TP concentration of 10 µg/L was 3,881 lbs/yr TP. The total loading capacity for the TMDL is defined as the sum of the wasteload allocation (WLA) for point sources, the load allocation (LA) for nonpoint sources[1], and a margin of safety (MOS) and is generally described with the following equation:

$$\text{TMDL Load Capacity} = \text{WLA} + \text{LA} + \text{MOS}$$

Required reductions of individual sources are shown in Table 10. The allocation of the allowable phosphorus load to each source, and the required reductions, are discussed below.

[1] COLA is not aware of any determination by WDNR, U.S. EPA, or any other entity that cranberry discharges are nonpoint discharges.

Table 10. Source reductions required to meet lake-wide average phosphorus goal

Loading Source	Baseline Load (lbs)	Reduction Needed to Meet Target (%)	Reduction Needed to Meet Target (lb)	Reduction to Address Margin of Safety (lb)	Allowable Load to Meet TMDL (%)	Reduction Needed to Meet TMDL (%)
Grindstone Creek	921	10	92	0	829	10
Osprey Creek	194	0	0	0	194	0
Whitefish Creek	683	20	137	0	547	20
Direct Drainage Areas	1,933	20	387	130	1,417	27
Cranberry Bogs	592	100	592	0	0	100
Atmospheric Deposition	765	0	0	0	765	0
Musky Bay Excess Internal Load	90	100	90	0	0	100
Total	**5,178**	**25**	**1,297**	**130**	**3,751**	**28**

Wasteload Allocation

There are five cranberry bogs that discharge to LCO with a total annual phosphorus load of 592 lbs. The wasteload allocation for these discharges is set to zero. A total reduction of 100% of the TP load from each cranberry discharge is required to meet this TMDL.

Table 11. Wasteload Allocations to meet TMDL

Point source	Bay or Basin Receiving Discharge	Current Load (lb/yr)	Wasteload Allocation (lb/yr)	% Reduction Needed
Musky Bay West	Musky Bay	257	0	100%
Musky Bay East	Musky Bay	80	0	100%
Jonjak West	Stuckey Bay	77	0	100%
Jonjak East	West Basin	158	0	100%
Point of Pines	East Basin	20	0	100%

If any additional point source discharges are proposed in this watershed, an effluent limit of zero phosphorus would need to be included in the Wisconsin Pollution Discharge Elimination System (WPDES) permit. A zero phosphorus discharge would be necessary because of LCO's status as an ORW.

Load Allocation

The load allocation for LCO was developed based on BATHTUB model simulations and local knowledge and expertise of feasible reductions that may be made. The nonpoint sources to LCO and their associated load allocations are given in Table 12.

Table 12. Load Allocations to meet TMDL

Loading source	Current Load (lb/yr)	Load Allocation (lb/yr)	% Reduction Needed
Direct drainage (all bays/basins)	1,933	1,546	20%
Grindstone Creek	921	829	10%
Osprey Creek	194	194	0%
Whitefish Creek	683	547	20%
Atmospheric load	765	765	0%
Musky Bay Excess Internal Load	90	0	100%

The load allocations assume that the excess sediment phosphorus flux in Musky Bay, which is specified in the BATHTUB model as 0.01 mg/sq.m./day or 90 lbs per year, is eliminated through in-lake treatment. This internal loading rate in Musky Bay is the sediment flux in excess of "normal" flux rates, as described in Model Calibration. The load allocation for direct drainage areas will be further reduced to include a margin of safety, as described below.

Margin of Safety

The MOS, which is a required component of the TMDL, accounts for uncertainty in the relationship between water quality and pollutant loads. The MOS can be either explicitly defined during allocation of loads or implicitly accounted for through conservative assumptions made during load development and water quality model application. This TMDL includes a MOS that is 10% of the loading reduction required to reach the water quality target, or 130 pounds. The MOS was added to the load reductions necessary for direct drainage areas, resulting in an allowable load to meet the TMDL of 1,417 lbs/yr, or a 517 lbs/yr (27%) reduction from baseline loads (Table 13). Reductions from atmospheric loading and Osprey Creek are not likely, and additional reductions from Grindstone Creek and Whitefish Creek are likely not feasible. Therefore, the MOS was only applied to the direct drainage sources.

Table 13. Source reductions required to meet lake-wide average phosphorus goal

Loading Source	Baseline Load	Reduction Needed to Meet Target		Reduction to Address Margin of Safety	Allowable Load to Meet TMDL	Reduction Needed to Meet TMDL
	(lbs)	(%)	(lb)	(lb)	(%)	(%)
Direct Drainage Areas	1,933	20	387	130	1,417	27

Seasonal Variation

The TMDL includes consideration of seasonal variation. The BATHTUB model used for the phosphorus TMDL is designed to evaluate seasonal to annual loads. The seasonal loading analysis that was used is appropriate due to the long response time between phosphorus loading and biotic response. LCO has a phosphorus residence time on the order of one year. Also, BATHTUB is a steady state model, whose predictions represent concentrations averaged over a period of time. This is consistent with the WisCALM methodology for assessing lakes for eutrophication, using a seasonal averaging period from June to September.

Reasonable Assurance

The Clean Water Act requires that states provide a "reasonable assurance" that the TMDL will be implemented. Reasonable assurance for implementation of activities to meet this TMDL will be provided through continued cooperation between WDNR, COLA, LCOCD, and Sawyer County. Participation of cranberry bog owners and other agricultural owners will also be critical to achieving the water quality goals. Due to its status as an ORW, implementation activities to attain this TMDL should be given priority for local, state, or federal funding.

Reasonable assurance for this TMDL will be provided through a variety of voluntary and/or regulatory means. The TMDL will be implemented through enforcement of current regulations, financial incentives and various local, state and federal pollution control programs. Some of these programs are:

- Wisconsin Administrative Code NR151 identifies performance standards and prohibitions to control polluted nonpoint source runoff. The rule also sets urban performance standards
- The WDNR and Sawyer County Land Conservation Department (LCD) will implement agricultural and non-agricultural performance standards and manure management prohibitions to address sediment and nutrient loadings in the LCO watershed. Many landowners voluntarily install BMPs to help improve water quality and comply with the performance standards. Cost sharing may be available for many of these BMPs. In some cases, farmers will not be required to comply with the agricultural performance standards and prohibitions unless they are offered at least 70% in cost sharing funds. If cost-share money is offered but not accepted, those in violation of the standards will be required to implement BMPs to comply with the rule.
- Targeted Runoff Management (TRM) Grants – The Sawyer County LCD may apply for TRM grants through the WDNR. These grants are competitive financial awards to support small-scale, short term projects (up to 24 months) to reduce runoff pollution. Both urban and agricultural projects can be funded through TRM grants which require a local contribution to the project. The state cost share maximum is $150,000 per grant. Projects that correct violations of the performance standards and prohibitions and reduce runoff pollution to impaired waters are a high priority for this grant program.
- The Sawyer County Shoreland Zoning Ordinance requires an intact shoreline vegetation protection area or 35-foot deep strip of land along the shoreline. If a buffer is not present on a property, it is required prior to obtaining future building permits. Cost-share is available for buffer construction in certain instances. The Sawyer County Land and Water Division provides technical support including restoration advice and a listing of native vegetation, shrubs and trees that would be appropriate for a site.
- Lake Protection Grants are available to assist lake users, lake communities and local governments to undertake projects that protect and restore lakes and their ecosystems. This program is administered under Wisconsin Administrative Code NR 191, and typically provides up to 75% state cost sharing assistance up to $200,000 per project. These projects may include watershed management projects, lake restoration, shoreland and wetland restoration, or any other projects that will protect or improve lakes.
- If a system is deemed not compliant with county code, the Sawyer County Conservation Department issues an "Order of Correction" letter requiring land owners to correct any identified issues with their septic systems within 12 months. A survey to determine septic system compliance was completed for properties around LCO in 2013.

- One option that should be considered to assure compliance with the TMDL is a memorandum of agreement (MOA) between WDNR and the cranberry bog owners in the LCO drainage area similar to the MOA that was developed in Massachusetts between state resource management agencies and the cranberry industry (Commonweath of Massachusetts Department of Agricultural Resources, et al., 2009). In this agreement, the cranberry growers committed to the goal of closed systems (i.e. use of recirculation systems and holding ponds that do not discharge to surface waters). The agreement was developed in support of a TMDL for nutrients for a waterbody impacted by bog discharges.
- The Environmental Quality Incentive Program (EQIP) is a federal cost-share program administered by the Natural Resources Conservation Service (NRCS) that provides farmers with technical and financial assistance. Farmers receive flat rate payments for installing and implementing runoff management practices. Projects include terraces, waterways, diversions, and contour strips to manage agricultural waste, promote stream buffers, and control erosion on agricultural lands.
- USDA Farm Service Agency's (FSA) Conservation Reserve Program (CRP) is a voluntary program available to agricultural producers to help safeguard environmentally sensitive land. Producers enrolled in CRP plant long term, resource conserving covers to improve the quality of water, control soil erosion, and hance wildlife habitat. In return, the FSA provides participants with rental payments and cost share assistance.
- Wisconsin's Managed Forest Law (MFL) is a landowner incentive program that encourages sustainable forestry on private woodlands in Wisconsin. Together with landowner objectives, the law incorporates timber harvesting, wildlife management, water quality and recreation to maintain a healthy and productive forest. To participate in the MFL program, landowners designate property as "Open" or "Closed" to public access for recreation, and commit to a 25 or 50 year sustainable forest management plan. The plan sets the schedule for specific forestry practices which landowners must complete. In return, MFL participants make a payment in lieu of regular property taxes plus a yield tax on harvested trees. Yield taxes go to the local municipality to help offset the annual property taxes that are deferred while properties are enrolled in the MFL.
- The Wisconsin Forest Landowner Grant Program (WFLGP) was created to encourage private forest landowners to manage their lands in a manner that benefits the forest resources and the people of the State. The WFLGP assists private landowners to protect and enhance their forested lands, prairies, and waters. The program allows qualified landowners to be reimbursed up to 50 percent of the eligible cost of eligible practices.

Public Participation

The LCO TMDL was developed with direct input from COLA and the LCOCD. The TMDL was presented at the COLA Annual Meeting on June 28, 2014.

A public review period was held for the TMDL from XX to XX. The review period was advertised by XX on XX. The advertisement provided information on the public comment period, including its dates and how to obtain copies of the public notice and draft TMDL. The news release, public notice, and draft TMDL were also placed on WDNR's website: http://dnr.wi.gov/org/water/wm/wqs/303d/Draft_TMDLs.html.

A total of XX letters of support…

6 Implementation

Water quality goals, wasteload allocations, and load allocations are established for LCO in this TMDL. This section presents an implementation plan that describes the steps to be taken and expected timelines needed to achieve the water quality goals.

Implementation will focus on six phosphorus loading sources:

1. Shoreline/ riparian landowners
2. In-lake management of Musky Bay sediments and curly leaf pondweed
3. Agriculture
4. Forest management practices
5. Small communities, rural residential, and new development
6. Cranberry bog discharges

Another key component of implementation discussed further in this section is continued monitoring and adaptive management based on new understanding and lessons learned.

COLA has prepared and adopted the "Lac Courte Oreilles Lake Management Plan" (Wilson, 2011; Appendix F), which lays out goals and implementation targets that address many of the phosphorus reduction implementation steps discussed .

LCO Shoreline/Riparian Landowners

Shoreline and riparian landowners have a direct impact on water quality based purely on proximity. These individuals play an important role in reducing phosphorus export to LCO through thoughtful decision making at a small scale. Oftentimes, shoreline and riparian landowners do not realize the negative impact that their everyday household management practices may have on water quality. Such practices may include misuse of fertilizers, inadequate buffers between developed land and surface waters, failing or damaged septic systems and runoff from impervious surfaces that they construct. The degree of impairment to water bodies as a result of these practices will vary depending upon the magnitude and frequency of each action. Shoreline areas in Wisconsin are protected to a certain degree by the enforcement of shoreline ordinances established at state and local levels. These rules limit shoreline and riparian landowners to specific building codes, vegetation management and possible detrimental activities within riparian areas. Small-scale changes in land use practices can have large impacts on overall water quality in LCO.

Several reduction strategies exist that are designed to attenuate the amount of phosphorus entering adjacent surface waters. Many of these strategies are cost-effective and small-scale.

- Installation/construction of shoreline buffers
- Reduction/elimination of fertilizer application
- Repair failing/damaged septic systems
- Installation of rain gutters along rooftops to limit soil erosion around buildings

- Erosion control measures
    - Plant trees/shrubs to stabilize shoreline & riparian areas, especially along steep slopes
    - Limit land clearing/grading near shorelines
- Increase infiltration
    - Remove/reduce impervious surfaces near shoreline/riparian areas
        - Gravel driveways/walk paths in place of pavement
        - Use of paving stones for walkways in place of concrete
    - Installation of rain gardens to absorb water runoff from buildings/houses and paved areas thereby promoting slow infiltration

Continued education of and outreach to shoreline residents will be conducted by COLA. In addition, COLA will work to implement the goal in the Lac Courte Oreilles Lake Management Plan (Wilson, 2011) to complete buffers on 100% of riparian land. Compliance with septic system regulations for system design, operation and maintenance is also expected to be 100%.

The following websites contain information on lakeshore ordinances and best management practices for shoreline and riparian landowners.

- EPA's Lake Shoreland Protection Resources
- Wisconsin DNR Safeguarding Our Shorelands for the Future
- Minnesota DNR Shoreland Management Resources
- University of Minnesota - Extension Shoreland Best Management Practices (BMPs)

In-Lake Management

In-lake management techniques will be applied to control curly leaf pondweed throughout the lake and sediment phosphorus release in Musky Bay. Curly leaf pondweed will be controlled with the ongoing management program sponsored by COLA. Methods for sequestering phosphorus in the sediments of Musky Bay will be evaluated. Consideration of the sediment response time to incoming load reductions will be given; depending on implementation timeframes, sediments in Musky Bay may equilibrate to reduced loading within an acceptable time period without the need for intensive control measures.

COLA will engage lake associations for Whitefish and Grindstone Lakes to promote watershed and lake management techniques for those waterbodies, including septic surveys, shoreline buffer surveys, and buffer installation. In addition, COLA will assist in the review of agricultural sources of phosphorus and to help promote implementation of BMPs.

Agriculture

Agriculture comprises approximately 4% of the land use in the LCO watershed. Significant improvements in agricultural practices, such as nutrient management, conservation tillage, and buffer strips, have provided opportunities for farmers to make changes that can reduce the amount of phosphorus leaving their lands and entering the adjacent waters. However, additional efforts should be continually assessed and implemented to reduce phosphorus loads to surface waters. Cropland and livestock operations, if not managed properly, can create conditions resulting in increased phosphorus entering surface waters. Some of the biggest factors affecting phosphorus export from agricultural lands include soil erosion, animal waste and overuse or improper timing of fertilizer applications.

Throughout much of the basin, agricultural production systems and practices have changed significantly over the past twenty years. This evolution is largely due to the development and utilization of best management practices with respect to agricultural operations. These practices include:

- Use of conservation tillage and no-till practices
- Construction and maintenance of sedimentation ponds
- Vegetative filter strips and field buffers among row crops
- Implementation of rotational grazing pastures
- Implementation of crop rotation
- Cover crops
- Nutrient management plans - proper use (i.e., amount) and timing of fertilizer (manure) applications
- Ditch management to mitigate phosphorus/sediment inputs to surface waters
- Proper containment and management of animal waste
- Vegetative filters strips near barnyards and milkhouses
- Exclusion of livestock from sensitive areas
- Installation of riparian buffers between crops/livestock areas and adjacent surface waters
    - Prevention of animal grazing in these areas
    - Plant trees/shrubs to stabilize banks thereby preventing erosion
- Retirement of cropland located in areas known to have a disproportionately high contribution to phosphorus export.
- Wetlands restoration.

The following sources contain an abundance of information regarding phosphorus reduction strategies and best management practices for the agricultural community.

- Wisconsin Department of Agriculture Trade and Consumer Protection
- Discovery Farms
- University of Wisconsin Ag. Extension

Forest Management Practices

Approximately 53% of the LCO watershed is forested. Forestry management activities can represent a significant phosphorus load contribution to surface waters. Increased phosphorus loadings from forestry are typically the result of accelerated erosion from land surface and riparian areas as well as increased terrestrial organic matter inputs directly to surface waters. There are numerous opportunities to reduce phosphorus inputs to waterways in forested areas. Careful planning of forest management activities and mindful consideration of potential water quality impacts during road construction, harvesting, and other management practices can significantly reduce phosphorus inputs to surface waters from forestry related activities. As with agriculture, phosphorus reduction strategies for forestry are known, but financial support is needed to identify, conduct outreach to, and provide technical assistance for forest managers within critical source areas.

State and national tax incentive programs and third party certification groups also provide opportunities for improved forestry practices:

- Wisconsin Managed Forest Law Program
- Sustainable Forestry Initiative
- Forest Stewardship Council
- American Tree Farm System
- Wisconsin's Forestry BMPs for Water Quality

Small Communities, Rural Residential, and New Development

Small communities, rural residential areas, and new development provide opportunities for reducing phosphorus loads in the basin. Development has the potential to significantly alter the hydrology of the landscape resulting in significant changes to the flow and volume of stormwater runoff. Impervious surfaces are widely distributed in urban environments leading to reduced rates of infiltration and increased opportunities for incorporation of phosphorus into stormwater runoff. Other factors that contribute to increased phosphorus loadings in developed areas:

- Overuse of fertilizers
  - Golf courses, commercial and private lawn care
- Pet/animal waste
- Lawn and yard waste (i.e., retention of leaves/grass on pavement, car washing)
- Sediment erosion/erosion from small construction sites
- Failing septic systems
- Road construction and maintenance activities

There are also many small-scale modifications to practices in developed environments that provide opportunities to reduce phosphorus loadings to surface waters. These include:

- Stormwater pollution prevention planning and implementation for small communities and towns
- Proper use of fertilizers or use of fertilizers with no phosphorus
- Proper disposal of pet waste
- Reduced impervious surfaces
- Installation of rain gardens/wetlands/retention basins that absorb excess runoff and promote ground infiltration
- Installation of rain gutters that control flow from rooftops thereby redirecting stormwater away from impervious surfaces
- Proper containment/prevention of sediment erosion
- Collection and disposal of lawn waste
- Inspection and proper maintenance of septic systems
- State of the Art BMPs for street and road construction, reconstruction, subdivision development, and redevelopment in small communities

The water resource education techniques needed to reduce runoff from urban and rural residential areas include:

1) Education, commercial advertising and social marketing to residents and other key audiences within the community to reduce widespread, small sources of phosphorus such as fertilizers and lawn waste.

2) Outreach and technical assistance to private landowners within the community to support implementation of targeted BMPs within critical source areas.

3) Training/Workshops for county and municipal staff, contractors and builders on how to reduce phosphorus from construction and development / redevelopment (both public and private), parks and public grounds maintenance, road work and other common practices.

4) Education, Training/Workshops and Technical Assistance for county and city elected and appointed officials to support the development and implementation of policies, ordinances, standards and practices that will reduce phosphorus loading.

The following resources provide additional guidance:

- University of Wisconsin - Extension Home & Yard Publications
- University of Minnesota - Extension Lawn Care
- Clean Water Minnesota Yard Care

Cranberry Bog Discharges

Best management practices (BMPs) for cranberry farming have been identified and the best available technology (BAT) economically available should be considered for surface waters receiving phosphorus loading from cranberry bog discharges. Some of these BMPs and BATs are being implemented in Massachusetts to help reduce phosphorus loading from cranberry bogs (Demoranville and Howes, 2005) and include:

- Use of recirculation systems or holding ponds to retain water;
- Avoid overuse of fertilizer;
- Avoid fertilizer application to waters that will exit the bogs; and
- Limit fertilizer applications prior to flooding events.

BMP practice guides for various elements of cranberry production are available from the UMass Cranberry Station, including a guide on nutrient management:
http://www.umass.edu/cranberry/pubs/bmps.html

Monitoring and Adaptive Management

Water quality monitoring will continue to be conducted annually by the LCOCD at the seven primary monitoring stations in LCO over the summer period. In addition, monitoring of tributary inflows will be conducted at Grindstone, Osprey, and Whitefish Creeks following the onset of implementation efforts. An efficient water quality monitoring program is essential for successful implementation. A comprehensive, well-planned monitoring program supports implementation by answering the following questions:

- *Where do we stand today and how much further do we have to go?*
- *Where should we prioritize our efforts?*
- *How effective are the implementation efforts and are refinements to the plan called for to improve efficiency?*
- *How will we know when we get there and if we continue to maintain our goals?*

It should be understood that the water quality goals, phosphorus loads, and needed reductions presented are estimates based on the best available science and continued state-of-the-art monitoring spanning over 10 years by LCOCD. Adaptive implementation is an approach that allows TMDL implementation to proceed in the face of uncertainties, by allowing for the implementation plan to be adjusted in response to information gained from future monitoring data. The adaptive implementation process begins with initial actions that have a relatively high degree of certainty associated with their water quality outcome. Future actions are then based on continued monitoring.

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