Site-Specific Phosphorus Criterion Proposal for: Lac Courte Oreilles

AU ID: 15368

WBIC: 2390800

Sawyer County, Wisconsin

COLA

Lac Courte Oreilles
Pride of the Ojibwe

March, 2016

LimnoTech
Water Environment | Scientists Engineers

Blank Page

LimnoTech
Water Environment | Scientists Engineers

7300 Hudson Blvd.
Suite 295
Oakdale, MN 55128
651.330.6038
www.limno.com

Site-Specific Phosphorus Criterion Proposal for:

Lac Courte Oreilles
AU ID: 15368
WBIC: 2390800
Sawyer County, Wisconsin

Requestor:

The Courte Oreilles Lake Association (COLA)

612-839-8558
garylindapulford@charter.net
15790 West Victory Heights Circle
Stone Lake, WI 54876

In association with:

The Lac Courte Oreille Band of Lake Superior Chippewa Indians

715-634-0102
dan.tyrolt@lco-nsn.gov
LCO Conservation Department
13394W Trepania Rd. Bldg. 1
Hayward, WI 54843

March, 2016

Prepared by:
LimnoTech, Inc.

Blank page

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1
Site-Specific Criterion Proposal Overview

This document presents the basis for a site-specific phosphorus criterion (SSC) for Lac Courte Oreilles (LCO) located in Sawyer County, Wisconsin (Figure 1). LCO is a multi-lobed waterbody (AUID 15368, WBIC 2390800), comprised of three basins (West, Central, and East). A number of bays are also commonly recognized by name, including Musky, Stuckey, Chicago, Anchor, Northeast (also known as Barber Town), and Brubaker Bays. LCO has a total surface area of approximately 5,039 acres.

- LCO is designated as a deep (stratified) two-story cold-water fishery lake by the Wisconsin Department of Natural Resources (WDNR). A total phosphorus criterion of 15 µg/L is applied to these lakes in Wisconsin, as defined in the Wisconsin Administrative Code (WAC) for the Department of Natural Resources (NR) 102.06.
- WDNR has considered Musky Bay a separate, physically distinct, upland lake and characterized it as a shallow (non-stratified) drainage lake. The applicable total phosphorus criterion for this class of lakes is 40 µg/L (NR 102.06).

The criteria currently applied by WDNR to LCO and Musky Bay are not sufficient to restore and protect the "existing" aquatic life and recreational uses for this waterbody. An "existing" use is defined in Chapter 40 of the Code of Federal Regulations (CFR) 131.3(e) as a use that was attained in the waterbody on or after November 28, 1975. Therefore, the Lac Courte Oreille Band of Lake Superior Chippewa Indians, in association with the Courte Oreilles Lakes Association (COLA), is proposing a SSC for LCO.

The proposed total phosphorus SSC for LCO, to be applied to LCO as a lake-wide average in its entirety including Musky Bay, is 10 µg/L. This is more protective than the existing water quality criterion of 15 µg/L applied to LCO and the 40 µg/L criterion applied separately to Musky Bay by WDNR. This document presents the basis for the adoption of the proposed SSC, including:

- LCO is of exceptional spiritual, cultural and subsistence importance to the Lac Courte Oreille Band of Lake Superior Chippewa Indians, due to cultural and natural heritage attributes historically provided by LCO. One-third of LCO is located within reservation boundaries, with the rest of the lake located within the ceded territory.
- Designated and existing beneficial uses have been identified as impaired or threatened;
    - Recreational and subsistence uses in Musky Bay of LCO are impaired as a result of excess macrophyte growth. Algal mats and excessive aquatic vegetation have prevented or negatively impacted boating, swimming and fishing during summer open water months. Excess phosphorus is the cause of the increased macrophyte growth and algal mats.
    - Musky Bay has experienced recent winterkills of fish, with the most frequent observations of any Sawyer County lake.
    - The cisco and lake whitefish fishery in LCO is threatened. Historically, LCO is one of only 5 inland lakes in Wisconsin to have both cisco and lake whitefish reported present (Lyons et al., 2015). 188 individual lakes have had cisco, while 9 lakes have had whitefish. A recent WDNR survey in 2013 indicated cisco abundance was medium and lake whitefish were not present. However, recently documented LCO whitefish mortality was observed in 2015. Cisco and lake whitefish are part of the Salmonidae family, a family that also includes trout and salmon. Cisco and lake whitefish require a combination of cold water and high oxygen levels. This combination of conditions is referred to as oxythermal habitat. Even marginal increases in algal productivity can cause

  significant reductions in the oxythermal habitat in LCO that these fish require, especially during late summer and early fall conditions. Excess phosphorus is the limiting nutrient in LCO and is the cause of increased algal productivity. Phosphorus from one lobe of LCO is transported to adjacent lobes. As an example, phosphorus loads to Musky Bay and Stuckey Bay impact algal growth in the West Basin, where cisco and whitefish habitat is severely threatened. Trends in West Basin eventually impact Central and East Basins as well.
  - The muskellunge population in LCO, once self-sustaining, is now limited by poor levels of reproductive success. Current LCO muskellunge populations are estimated to be only 20%-30% of the targeted goal for the lake. Muskellunge are native to LCO and the lake has been known for producing trophy-size fish, including a one-time world record. Musky Bay is LCO's primary muskellunge spawning area. Spawning habitat, specifically sufficient dissolved oxygen levels, during early life stages is critical to reproductive success. Data demonstrate that spawning areas in Musky Bay experience depressed dissolved oxygen levels. Even a small decrease in survival of muskellunge eggs and larvae may be enough to significantly inhibit natural muskellunge reproduction. Dissolved oxygen depletion in Musky Bay is caused primarily by excessive inputs of phosphorus leading to increased algal productivity, and subsequent settling and decay on the bottom substrate.
  - The trophy musky and walleye fisheries in LCO are threatened. Trophy sized fish require sufficient forage fish to support growth. Cisco are a critical component of the food-web supporting the growth of trophy musky and walleye in LCO. As adequate oxythermal habitat for cisco is reduced as a result of increasing algal productivity driven by phosphorus loads, trophy fisheries are threatened.
- The water quality required for full attainment of the designated and existing uses is not supported by the existing 15 µg/L total phosphorus criterion for cold water two-story fishery lakes such as LCO, nor are the uses supported by the 40 µg/L total phosphorus criterion applied by WDNR to Musky Bay;
- LCO, in its entirety, is a designated Outstanding Resource Water (NR 102.10). This designation has been in place since 1993 and affords LCO special protection through the implementation of antidegradation policies. The intent of these policies is to prevent water quality from becoming worse than it has historically been by preventing new or expanded sources of pollution, such as phosphorus;
- WDNR's current assessment approach (WisCALM; WDNR, 2015) would require being 95% sure that total phosphorus is averaging greater than 22.5 µg/L in LCO to list it as impaired based on phosphorus data. This is an extremely high bar for determining impairment and taking needed steps to restore and protect the resource, especially considering LCO is an ORW. The current WisCALM approach leads to a high probability that LCO will not be listed as impaired until it has already undergone significant degradation; and
- The impact of a changing climate, through warmer temperatures and a higher frequency of intense rainfall events, threatens to further exacerbate algal productivity and reduce habitat with sufficient dissolved oxygen.

Continued degradation and further loss of beneficial uses, including cultural and natural heritage aspects of this rare ORW, will continue unless revised standards are adopted and implemented.

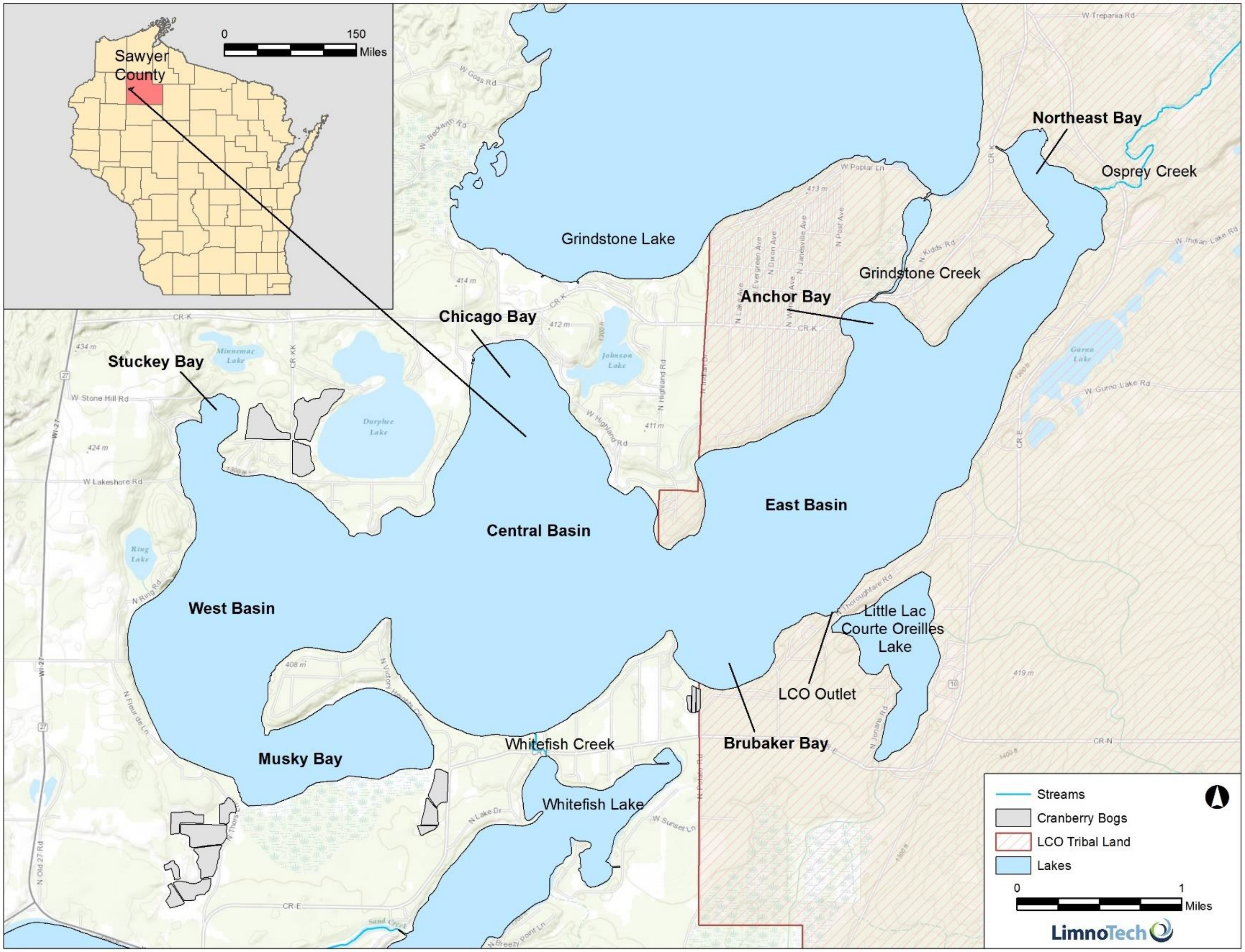

Figure 1. Location and map of LCO.

1.1 Potentially Interested Parties

LCO is central to Tribal culture. It is also 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, Wilson, 2011). Therefore, parties anticipated to be interested in this phosphorus SSC proposal for LCO include:

- The Lac Courte Oreilles Band of Lake Superior Chippewa Indians;
- COLA members;
- The Great Lakes Indian Fish and Wildlife Commission (GLIFWC);
- Lake, watershed and local residents;
- Visitors to the lake for recreational activities;
- The Hayward Chamber of Commerce;
- Local resorts;
- Local cranberry bog owners; and
- The full spectrum of regional businesses and service providers (grocery stores, trades, home and recreation industry services, recreational fishing guides and outfitters).

1.2 Downstream Waterbodies

Because the proposed SSC for LCO is more protective than the current applicable water quality criterion, a benefit to downstream waterbodies is expected. Waterbodies downstream of LCO include: Little Lac Courte Oreilles (WBIC 2390500), Billy Boy Flowage (WBIC 2389700), Couderay River (WBIC 2384700), and Grimh Flowage (WBIC 2385100). Downstream of the Grimh Flowage, the Couderay River flows into the Chippewa River (WBIC 2050000), which forms Lake Wissota near Chippewa Falls. A Total Maximum Daily Load (TMDL) for phosphorus exists for Little Lake Wissota, which is an embayment of Lake Wissota (WBIC 2152800). Further downstream the Chippewa River flows into Lake Pepin (WBIC 731800). Minnesota Pollution Control Agency is preparing a phosphorus TMDL for Lake Pepin but it has not been finalized. While downstream waterbodies will benefit from improved water quality in LCO, significant impacts should not be anticipated, especially in waterbodies further downstream.

2
Significance to Lac Courte Oreilles Band

> *"Water, as it flows the rivers, lakes and streams, seeps underground passageways, or spurts out of the Earth's surface as an artesian well – the Earth's water system is compared to the human circulatory system in Ojibwe thought. So, the wellbeing of water, which affects every other living part of the Earth, is of vital importance to the Ojibwe people and to all people. Water, known as nibi in Ojibwemowin, is the source of life and, as such, becomes the responsibility of women. Nibi must be protected, kept pure, for all life now and to come."*[1]

The Lac Courte Oreilles Band of Lake Superior Chippewa Indians includes approximately 7,600 members. The Lac Courte Oreilles Reservation, consisting of a land base of 76,500 acres in northwest Wisconsin, contains tremendous water resources. Numerous rivers, streams, lakes, ponds, and wetlands, as well as groundwater, make up the water resources landscape of the Reservation. In fact, nearly 20% of the total Reservation area, or just over 15,000 acres of surface waters make the Reservation a "water rich" environment. All of these waters are located entirely within the Upper Chippewa River Basin. More than forty-three miles of rivers and streams, as well as all or portions of 26 named lakes can be found on the Reservation. Additionally, over 7,500 acres of the Reservation territory are classified as wetlands.

These water resources have had cultural, subsistence and ecological significance to many generations of Lac Courte Oreilles Ojibwe. The significance of LCO to the Tribe is described further below:

- Cultural significance: The Lac Courte Oreilles Ojibwe have resided in the area prior to the signing of the 1854 treaty. Wild rice, Manoomin, drew bands to look for the food that grows on the water. The Reservation area was chosen because of the vast wild rice beds, plentiful fish, berries and game. Lac Courte Oreilles, primarily Musky Bay, was once a highly productive wild rice water, a main staple and highly prized food and economic source for LCO Tribal members, and also a required staple for traditional ceremonies. Today, the wild rice is near extirpation within the boundaries of the Reservation primarily due to damming and possibly eutrophication. Fish as a food is not only nourishing but also culturally important to the Ojibwe and required for traditional ceremonies.
- Subsistence harvest significance: Lac Courte Oreilles is an accessible source of healthy fish for sensitive populations in the community. From a subsistence and human health standpoint, of the on-reservation lakes, Lac Courte Oreilles could be considered the safest lake to consume walleye and pike for Lac Courte Oreilles communities. According to GLIFWC's 2014 mercury maps, walleye harvested from Lac Courte Oreille have the lowest levels of mercury of the major lakes that were assessed. Therefore, these walleye are the safest for pregnant women, women of childbearing age, and children to consume (up to 2 meals per month).
- Ecological significance: This healthy and thriving ecosystem, including the cold water, recreational and trophy fishery, brings in tourism and economic opportunities to this rural area. Historically it is an important wild rice water evidenced by many stories that describe its remarkable robustness that date back to the 1940's, 50's and 60's. Musky Bay is a "date-regulated" wild rice water and has been recognized since the list was created in 1964.

---

[1] Integrated Resource Management Plan 2010 Lac Courte Oreilles Band of Lake Superior Ojibwe, pg. 25. Quoting: Seasons of the Ojibwe, 2002 Edition, Published by the Great Lakes Indian Fish and Wildlife Commission.

The lakes of the Reservation and the surrounding ceded territories, which includes LCO, contribute to Sawyer County's status as one of the premier tourist areas in Wisconsin.

One-third of LCO, including the outlet, is located within Reservation boundaries, with the rest of the lake located within the ceded territory. Water quality degradation resulting from excessive levels of phosphorus in any portion of LCO impacts the waters within the Reservation boundaries due to mixing occurring between the various bays and basins.

The Lac Courte Oreilles Tribal Conservation Department (LCOCD) has been monitoring LCO since 1996 with routine monitoring beginning in 2002. The majority of the data presented in this document were collected by or in partnership with LCOCD.

3
Description of Lac Courte Oreilles

This section describes the location, drainage areas, and physical characteristics of LCO, which is located in Sawyer County, Wisconsin. Significant additional information is contained in the LCO Lake Management Plan (Wilson, 2011).

The lake has a total surface area of approximately 5,039 acres, with approximately 25 miles of shoreline. The maximum depth of LCO is 90 feet, its mean depth is 34 feet, and approximately 28% of the lake is less than 20 feet deep. LCO includes three basins (West, Central, and East) (Figure **2**). A number of bays are also commonly recognized by name, including Musky, Stuckey, Chicago, Anchor, Northeast (also known as Barber Town), and Brubaker Bays. LCO is identified by the waterbody identification code (WBIC) #2390800. A lake map is available at http://dnr.wi.gov/lakes/maps/DNR/2390800a.pdf.

The total drainage area to LCO is 68,990 acres (99.5 square miles). Three tributaries drain 80% the watershed: Grindstone, Osprey, and Whitefish Creeks (Figure 3). Land cover / use in the watershed is presented in Figure 4. Land use in the watershed is described below:

- Forested (61% of total, 84% is deciduous)
- Agricultural (12% of total)
  - Corn (45% of agricultural land use, 5% of total)
  - Alfalfa (22% of agricultural land use, 3% of total)
  - Soybeans (24% of agricultural land use, 3% of total)
  - Other agriculture (9% of agricultural area, 1% of total)
- Developed (9% of total, 97% of which is open space)
- Grassland/Pasture (5% of total)
- Shrubland (0.14% of total)
- Open Water (7% of total)
- Wetlands (6% total, 98% of which is woody wetlands)

Five cranberry bogs totaling 169 acres are located within the direct drainage areas of Musky Bay, Stuckey Bay, West Basin, and East Basin (Figure **2**). Additional cranberry bogs totaling 111 acres are located in the direct drainage to Sissabagama Lake (Figure 4).

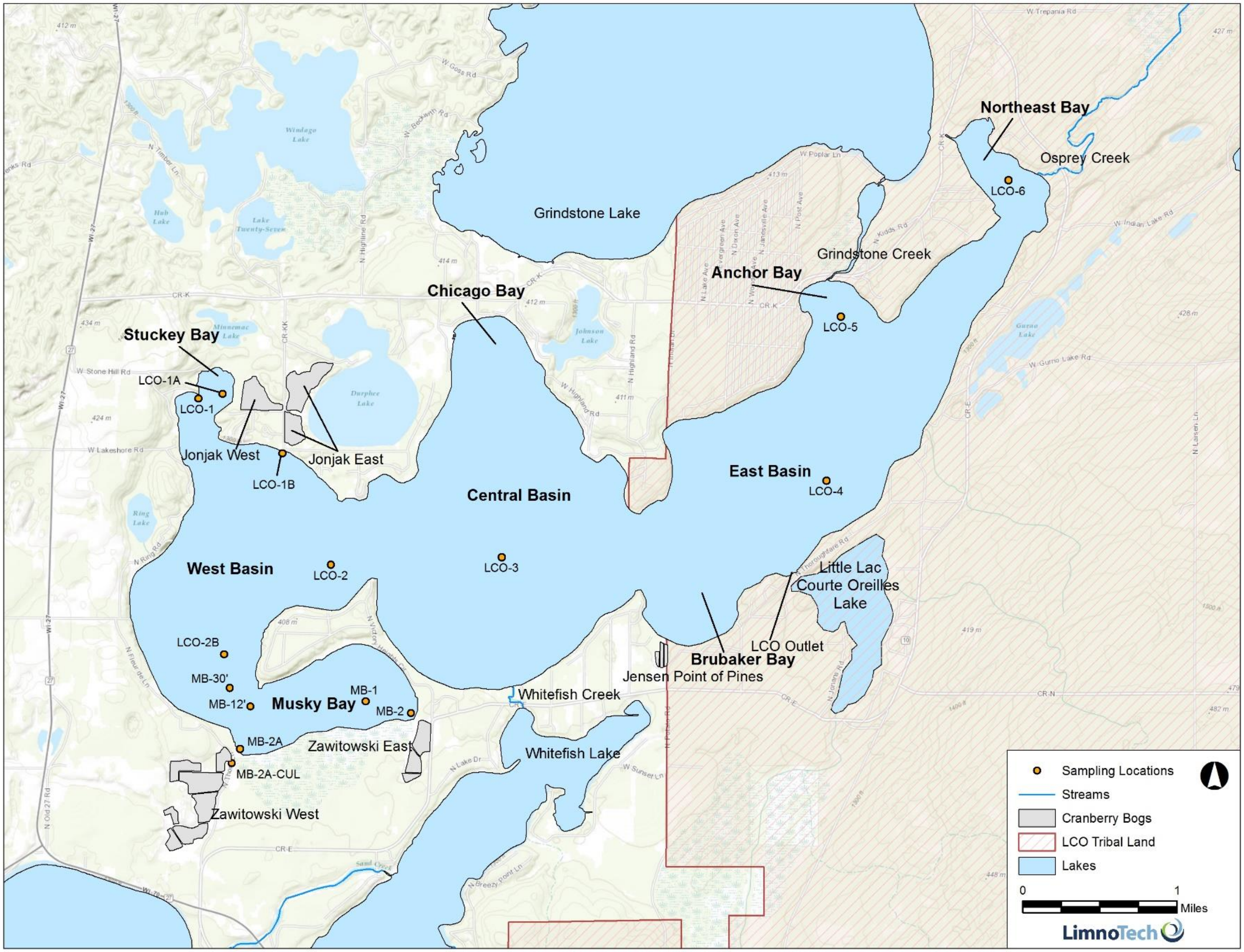

Figure 2. LCO map showing tributaries, sampling stations, and cranberry bog locations.

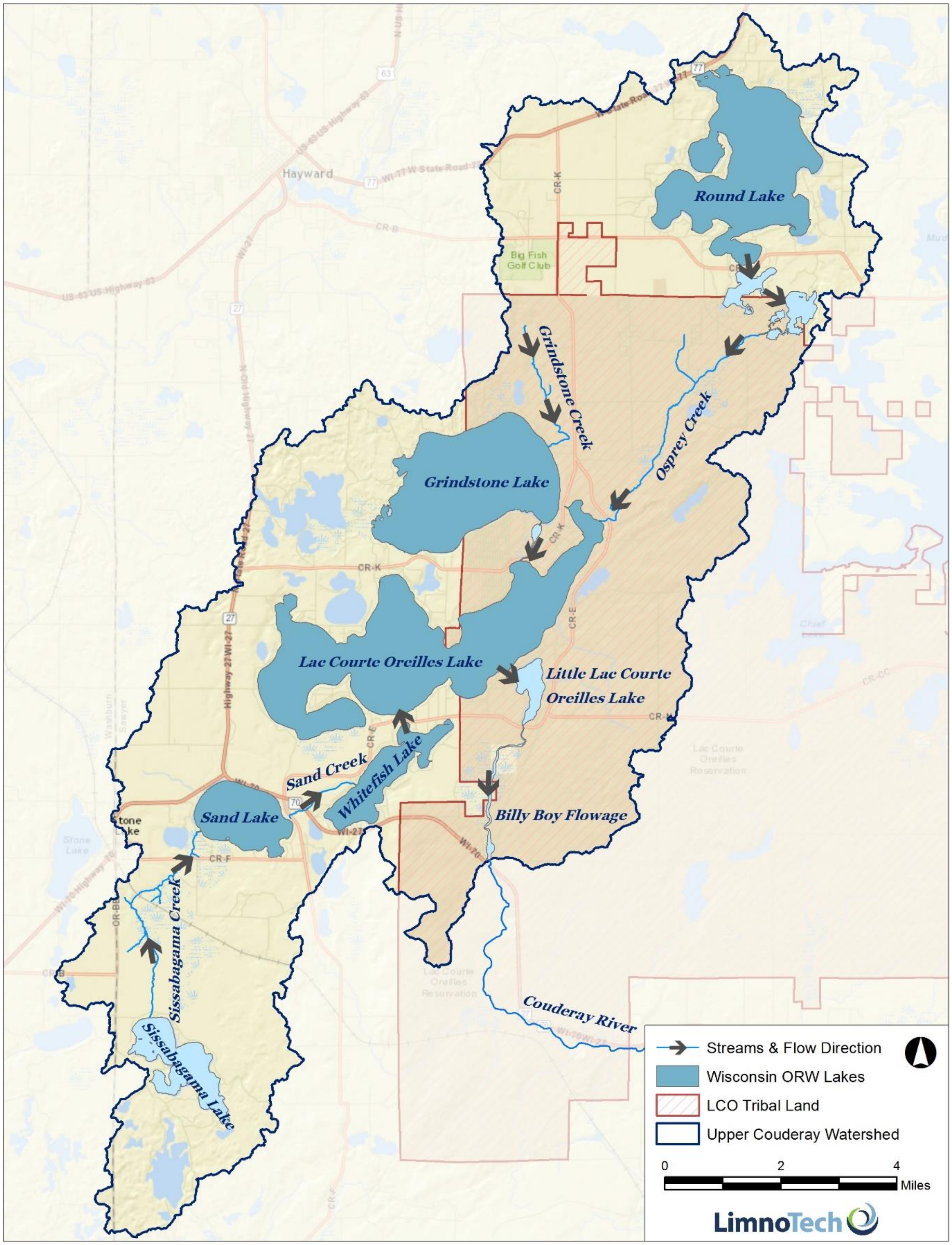

Figure 3. Upper Couderay Watershed and Drainage Network.

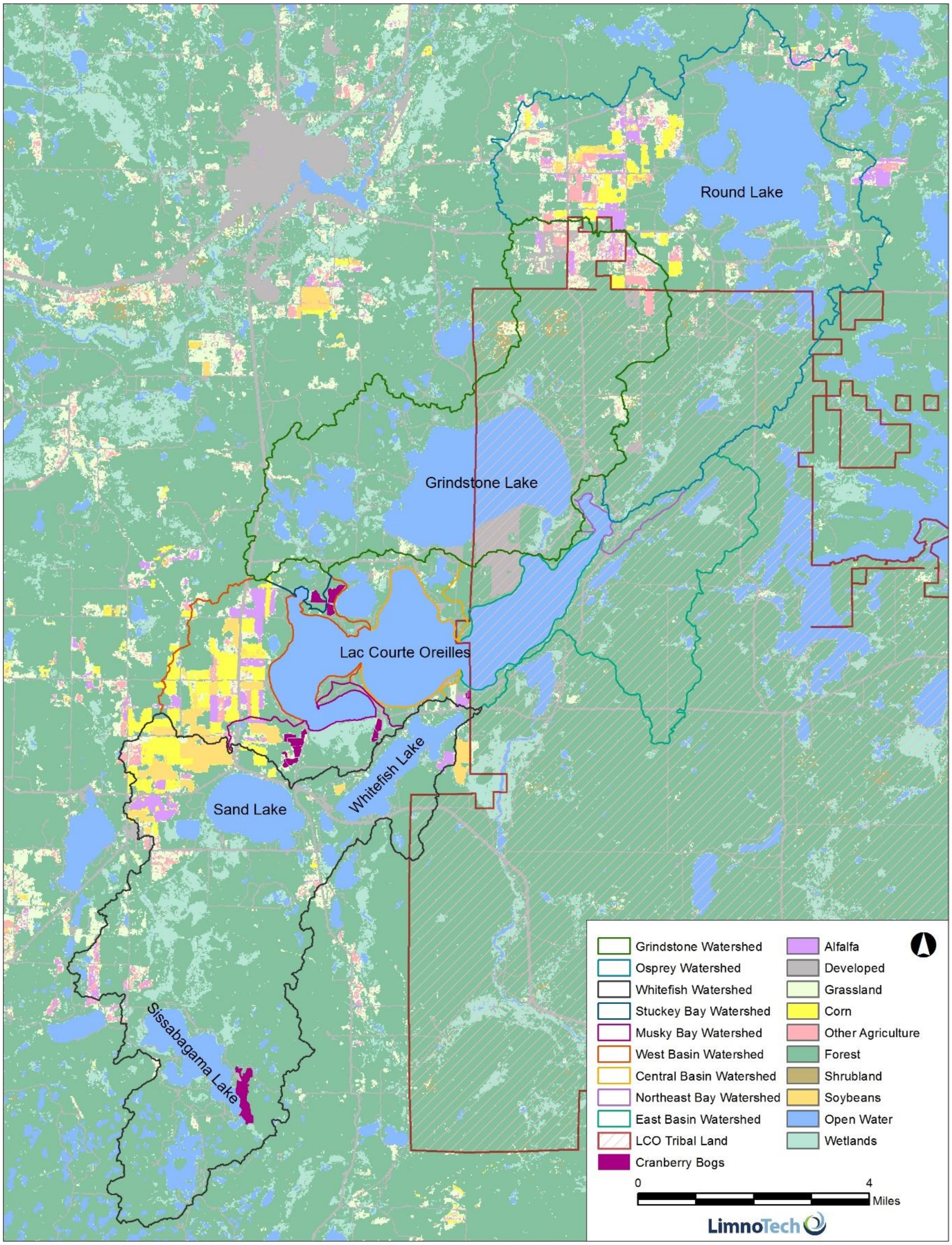

Figure 4. Upper Couderay Watershed Land Use.

3.1 Whole Lake Assessment

WDNR notes that, as a rule, a lake is a mixed system that functions as a single, contiguous unit (WDNR, 2013). Following commonly accepted limnological practice and terminology, the three basins (West, Central, and East) comprise one lake referred to as Lac Courte Oreilles. All of the basins and bays are inter-connected and share one water level (relative to sea level except for short-term variations caused by wind, seiche, storm inflows, etc.). The bays are not physically distinct upland lake basins. Their connection to other lobes of LCO is not characterized by a predominant unidirectional streamflow or outlet structure. There are no physical barriers separating one lobe or bay from another. Rather, these bays share expanses of open water and hence, directly influence each other via advective and dispersive mixing. The lengths of open water interfaces between basins and bays are given in Table 1.

Table 1. Length of open water interface between LCO bays and basins.

Bay/Basin Interface	Length of Interface (ft)
Musky Bay/West Basin	1,980
Stuckey Bay/West Basin	770
Central Basin/West Basin	3,150
Central Basin/East Basin	2,565
East Basin/Northeast Bay	1,050

From a statewide policy consistency perspective, assigning separate upland lake standards to Musky Bay would suggest assignment of the same standards to Stuckey Bay and Northeast Bay, which would clearly violate antidegradation provisions of state and federal water rules.

3.1.1 Hydrodynamic Modeling

A fine-scale hydrodynamic model of LCO was developed to directly predict the amount of mixing between bays and basins in support of the proposed SSC.

The hydrodynamic model was based upon the Environmental Fluid Dynamics Code (EFDC), a U.S. 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

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 (100 mg/L; ~500 million grams total) 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. The volumes of Musky Bay and West basin are 4.9 and 39 million cubic meters, respectively.

Results from the dye simulation are provided in Figure 5, where predicted dye concentrations are given in two-week intervals. As seen in Figure 5, the concentration of the dye slug spreading through West basin is over 9 mg/L for much of the western portion of the basin within 2 weeks, and in 10 weeks the dye has impacted nearly all of the West basin with concentrations as high as 22 mg/L.

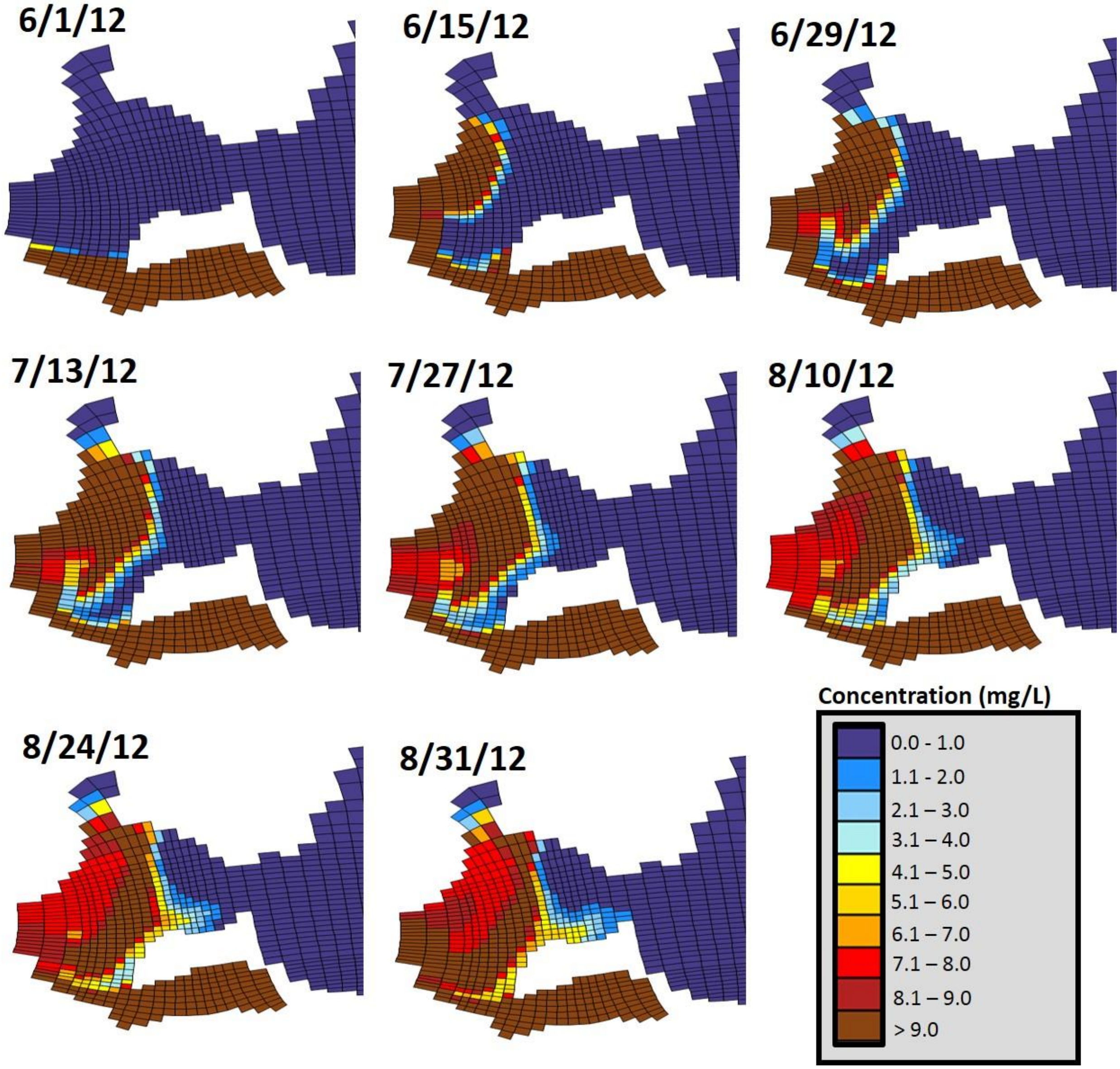

Figure 5. Predicted dye concentrations in LCO at two-week intervals following release of 100 mg/L in Musky Bay on June 1.

Figure 6 shows the time series of the predicted mass of the dye slug in Musky Bay and West basin as the percent of the mass of dye released. After one month, 38% of the dye slug has moved into West basin from Musky Bay. After two months, almost half (48%) of the dye mass has moved into West basin.

The hydrodynamic model clearly shows the influence of loads entering Musky Bay on the West basin, and clearly shows that LCO is one integrated aquatic system.

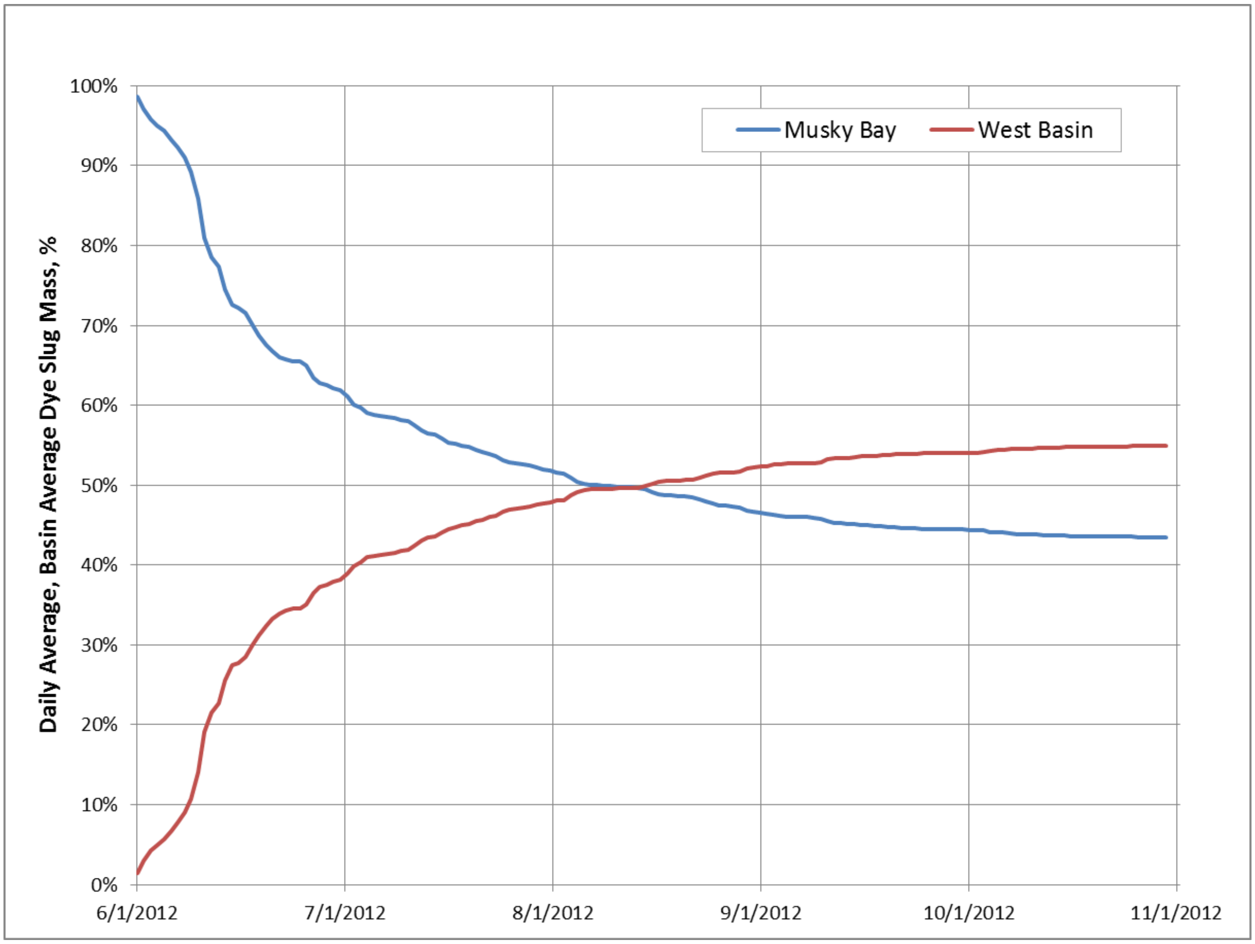

Figure 6. Predicted daily average mass of dye slug in Musky Bay and West Basin (percent). Dye was released in Musky Bay at 100 mg/L on June 1.

Blank Page

4
Outstanding Resource Water Designation and Current Applicable Water Quality Criteria

This section describes how LCO is currently classified in Wisconsin water quality standards, the water quality criteria currently applied to the lake by WDNR, and WDNR's current assessment of the status of LCO in attaining these criteria.

4.1 General Criteria

State water quality standards include provisions for the general protection of surface waters. NR 102.04(1) defines these general criteria for Wisconsin surface waters, and notes:

> *"To preserve and enhance the quality of waters, surface water uses and criteria are established to govern water management decisions. Practices attributable to municipal, industrial, commercial, domestic, agricultural, land development or other activities shall be controlled so that all surface waters including the mixing zone meet the following conditions at all times and under all flow and water level conditions:*
>
> *(a) Substances that will cause objectionable deposits on the shore or in the bed of a body of water, shall not be present in such amounts as to interfere with public rights in waters of the state.*
>
> *(b) Floating or submerged debris, oil, scum or other material shall not be present in such amounts as to interfere with public rights in waters of the state.*
>
> *(c) Materials producing color, odor, taste or unsightliness shall not be present in such amounts as to interfere with public rights in waters of the state.*
>
> *(d) Substances in concentrations or combinations which are toxic or harmful to humans shall not be present in amounts found to be of public health significance, nor shall substances be present in amounts which are acutely harmful to animal, plant or aquatic life.*

Objectionable deposits, floating or submerged material, materials producing unsightliness, and substances present in amounts which are harmful to aquatic life, as included in NR 102.04(1), include algae in the form of algal mats, excessive attached macrophytes, or enriched organic sediments resulting from algae die-off, settling, and decay.

4.2 Dissolved Oxygen Criteria

For cold waters in Wisconsin, such as LCO, NR 102.04(4)(b) prescribes that dissolved oxygen may not be altered from natural background levels to such an extent that trout populations, including cisco and lake whitefish, are adversely affected. Specific numeric criteria for cold water lakes are not provided.

Dissolved oxygen in surface waters of warm water fishery lakes may not be lowered to less than 5 mg/L at any time (NR 102.04(4)(a)). Dissolved oxygen in classified trout streams shall not be artificially lowered to less than 6.0 mg/L at any time, nor shall the dissolved oxygen be lowered to less than 7.0 mg/L during the spawning season (NR 102.04(4)(b)(1)).

The Wisconsin Consolidated Assessment and Listing Methodology for 2014 (WisCALM; WDNR, 2013) specifies that for two-story lakes, the impairment threshold for dissolved oxygen is 5 mg/L in the epilimnion, and not less than 6 mg/L in the hypolimnion, where cold water species may be found. If 10% or more of all dissolved oxygen values are below the thresholds, the impairment threshold is exceeded.

The U.S. EPA has issued guidance for establishing dissolved oxygen criteria (USEPA, 1986). For salmonid, or cold water fish, beyond the early life embryo and larval stages, 3 mg/L is the limit to avoid acute mortality, and 5 mg/L is the criteria for moderate production impairment.

Further discussion of appropriate oxythermal habitat conditions for cisco and whitefish, which includes consideration of both dissolved oxygen and temperature, are presented in Section 5 of this report.

4.3 Total Phosphorus Criteria

LCO has been designated by WDNR as a deep (stratified) two-story cold-water fishery lake for purposes of applying water quality criteria for phosphorus. The State's most protective total phosphorus criterion, 15 µg/L (NR 102.06), has been applied by WDNR to LCO.

WDNR relied on a few sources of information in developing these criteria (WDNR, 2010). Notably, WDNR considered:

- The Minnesota Pollution Control Agency's (MPCA) approach for developing lake nutrient criteria (Heiskary and Wilson, 2008). MPCA selected 12 µg/L total phosphorus to protect lakes in Minnesota with lake trout. However, the supporting information in MPCA's assessment of lake nutrient criteria indicated a range of phosphorus concentrations to protect cold water fisheries, such as:
  - 5 µg/L to 15 µg/L total phosphorus in British Columbia, Canada (Nordin, 1986);
  - 10 µg/L, above which oxygen depletion generally begins to occur and is often considered the upper boundary for oligotrophy (Nurnberg, 1996);
  - 6 µg/L to 12 µg/L total phosphorus related to peak abundance of cold water fisheries, including lake trout, whitefish and cisco (Schupp and Wilson, 1993);
- EPA guidance which indicated 10 µg/L – 12 µg/L based on the 25th percentile of reference lakes in the northern lakes and forests (NLF) ecoregion; and
- Data from Wisconsin two-story lakes. The 15 µg/L criterion for two-story lakes is based on the mean concentration of reference lakes plus one standard deviation. This means that 84% of the lakes with data have measured phosphorus concentrations less than 15 µg/L.

WDNR also noted the following:

- The Carlson Trophic Status Index, one of the most commonly used systems to describe the trophic status of lakes, includes a description of what best characterizes LCO:
  - Oligotrophic – Mesotrophic – Deeper lakes still exhibit classic oligotrophy, but some shallower lakes will become anoxic (no oxygen) in the hypolimnion during the summer. Phosphorus concentrations of 6 to 12 µg/L. Chlorophyll a concentrations of 1 to 3 µg/L.
- Variations in the physical characteristics of lakes may lead to different responses to phosphorus concentrations. For example, at equal phosphorus concentrations, a lake with a smaller hypolimnion will tend to show lower dissolved oxygen in the hypolimnion as compared to a lake with a larger hypolimnion.

The WDNR recognized that the 15 µg/L total phosphorus criterion for two-story lakes is higher than the 10 µg/L associated with classic oligotrophic lakes and the 12 µg/L promulgated by MPCA. For this reason, WDNR notes that two-story lakes may be likely candidates for site-specific criteria.

4.3.1 Musky Bay Classification and Applicable Total Phosphorus Criteria

WDNR has considered Musky Bay a separate, physically distinct, upland lake and characterized it as a shallow (non-stratified) lowland drainage lake using the partial lakes assessment in WisCALM. Therefore, WDNR currently applies 40 µg/L as the total phosphorus criterion for Musky Bay (NR 102.06).

Consideration of Musky Bay as a separate, physically distinct, upland lake and not a part of LCO is not appropriate, as discussed in Section 2.1.1. Consideration of Musky Bay by WDNR as a shallow, non-stratified lake is also inappropriate. WDNR presumably identified Musky Bay as a shallow lake due to the automatically generated lake classification determined using the Lathrop/Lillie equation included in WisCALM. Given a surface area of 301.8 acres and a maximum depth of 18 feet for Musky Bay, a ratio of 2.6 results. Since this value is less than 3.8, the bay would be classified as shallow by this equation.

However, WisCALM guidance characterizes shallow (unstratified or mixed) lakes as well-oxygenated and deep (stratified) lakes having the potential for anoxic conditions. Temperature and dissolved oxygen profiles for 2013 Musky Bay data are presented in Figure 7. As indicated in Figure 7, Musky Bay exhibits persistent low levels of dissolved oxygen at the bottom, often less than 3 mg/L and approaching 0 mg/L, with intermittent mixing during this period. These low levels of dissolved oxygen strongly and negatively influence habitat and the biological integrity of Musky Bay and LCO in its entirety. These periods of anoxia in Musky Bay are influenced by the degree of nutrient loading, with phosphorus as the primary stressor.

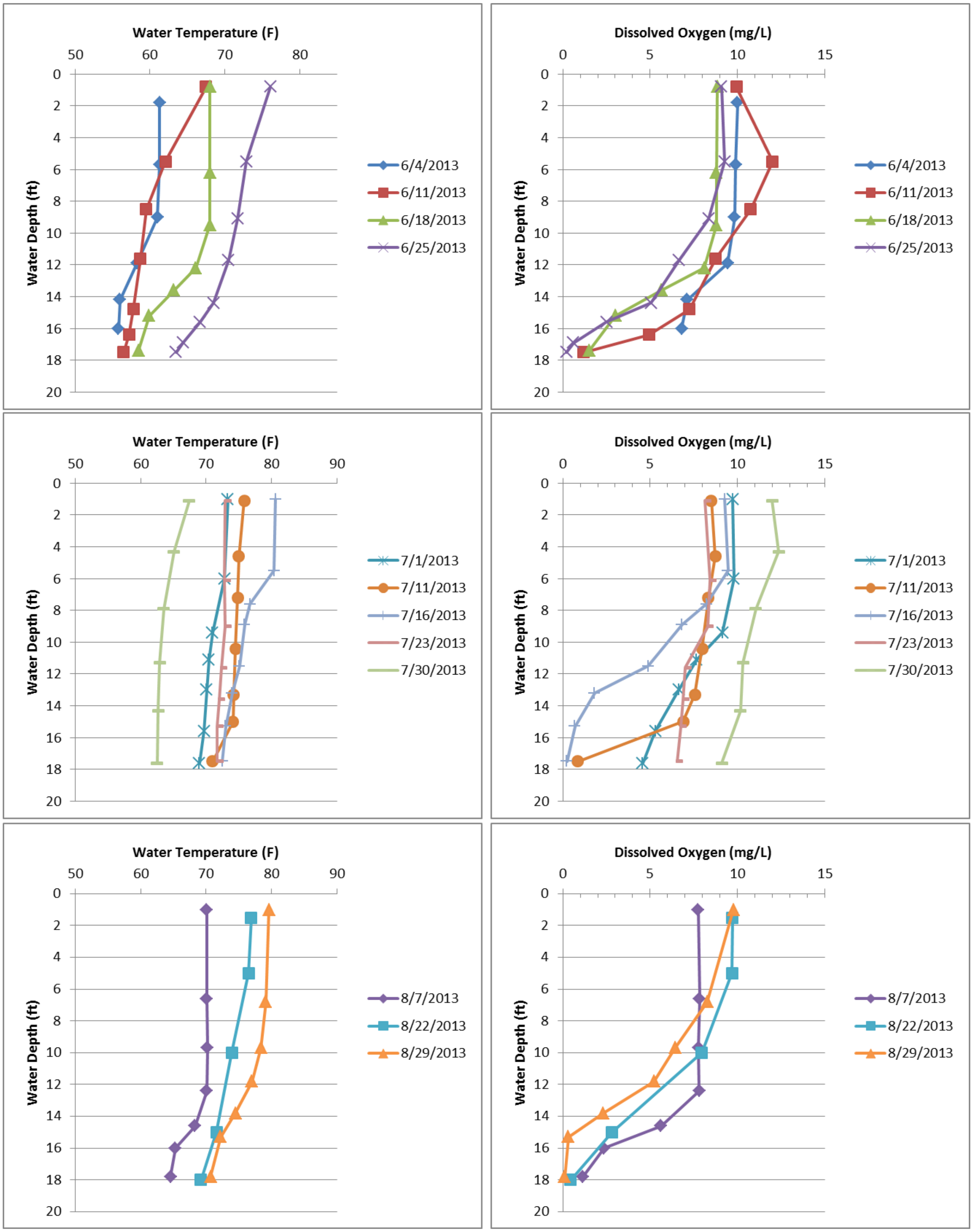

Figure 7. Temperature and dissolved oxygen profiles in Musky Bay (station MB1), June through August 2013.

4.4 Provisions for Site-Specific Criteria

WDNR recognizes that the statewide criteria provided in State water quality standards may not be appropriate in site-specific circumstances. Therefore, NR 102.06(7) explicitly provides for the development of site-specific phosphorus criteria.

> *"Site-Specific Criteria. A criterion contained within this section may be modified by rule for a specific surface water segment or waterbody. A site-specific criterion may be adopted in place of the generally applicable criteria in the section where site-specific data and analysis using scientifically defensible methods and sound scientific rationale demonstrate a different criterion is protective of the designated use of the specific water segment or waterbody."*

NR 102.06 also notes that two-story fishery lakes may be one of the most appropriate water bodies for site-specific criteria. Additional provisions for site-specific criteria are included in NR 105.02(1).

4.5 Anti-Degradation and Outstanding Resource Water (ORW) Classification

Wisconsin's anti-degradation policy is intended to maintain and protect existing uses and high quality waters, specifically "to prevent water quality from sliding backwards and becoming poorer without cause, especially when reasonable control measures are available," (WDNR, 2013). NR 102.05(1) states:

> *"No waters of the state shall be lowered in quality unless it has been affirmatively demonstrated to WDNR that such a change is justified as a result of necessary economic and social development, provided that no new or increased effluent interferes with or becomes injurious to any assigned uses made of or presently possible in such waters."*

Lac Courte Oreilles is classified as a high quality outstanding resource water (ORW) by WDNR. The lake was first listed as such in Wisconsin Administrative Code (WAC) for the Department of Natural Resources (NR) 102.10 in 1993 (WAC, 1993). Less than 1% of Wisconsin's lakes are designated as ORWs. These waters provide outstanding recreational opportunities, support valuable fisheries and wildlife habitat, have good water quality, are not significantly impacted by human activities, and do not typically have nay dischargers (WDNR, 2013). Wisconsin's antidegradation rule (NR 207.03(3)) protects ORWs by only allowing new or expanded discharges if current water quality is maintained:

> *"If the department determines that a WPDES permit application proposes a new or increased discharge to outstanding resource waters, effluent limitations for substances in the new or increased portion of the discharge will be set equal to the background levels of these substances, upstream of, or adjacent to, the discharge site…."*

WDNR recognizes that "Anti-degradation is an important aspect of pollution control because preventing deterioration of surface waters is less costly to society than attempting to restore waters once they have become degraded" (WDNR, 2013).

The U.S. EPA reiterates the importance of a State's antidegradation policy in a recent memorandum (http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/2014-memo.cfm#memo). The U.S. EPA recognizes the need to identify outstanding resource waters as impaired when degradation of water quality has occurred even if pollutant concentrations do not exceed existing water quality criteria levels:

> *Most State water quality assessments have focused on whether numeric and narrative water quality criteria are being attained, and typically, these assessments capture where waters are most in need of restoration. However, it is possible that some waters are not meeting the antidegradation portion of water quality standards. For example, it is possible that available data and information for a water identified by a State as an*

> *Outstanding National Resource Water (ONRW) indicates degradation in water quality. If those data and information indicate that the water is not meeting the State's requirement for maintenance and protection of the water quality of the ONRW under the antidegradation portion of its water quality standards, in accordance with CWA and EPA regulations, the waters would be listed on the State's Section 303(d) list even if pollutant concentrations do not exceed water quality criteria levels.*

4.6 Assessment Status

Musky Bay was included on Wisconsin's 303(d) list in 2012 as impaired for recreational uses due to phosphorus criteria exceedances. Three of ten average annual phosphorus concentrations exceeded the listing threshold applied by WDNR for a shallow lowland lake (≥40 µg/L). WDNR staff also used professional judgment in assessing the observed macrophyte density in Musky Bay and based on this assessment, in conjunction with the phosphorus data assessment, determined the recreational use of the bay is impaired (WDNR, 2012). U.S. EPA approved the WDNR 2012 proposed list of impaired water in Wisconsin in June 2014. Musky Bay remained on the U.S. EPA approved 2014 303(d) list and is again on the proposed 2016 303(d) list.

WDNR has not included LCO on the 303(d) list to-date. The WisCALM assessment approach currently applied by WDNR (WDNR, 2015) requires an evaluation of the confidence interval around the mean of monthly average total phosphorus concentrations during the growing season (June 1 through September 15). For a lake to be included on the 303(d) list as impaired and to have priority put on the development of a TMDL, using only total phosphorus data, the lower 90th percentile of the confidence interval around the mean must exceed the phosphorus criterion by more than 1.5 times (Figure 8). This basically means that for LCO to be listed as impaired based solely on total phosphorus data, there must be 95% certainty that the average monthly total phosphorus concentration is more than 150% of the current 15 µg/L criterion, or greater than 22.5 µg/L. Being 95% sure that total phosphorus is averaging greater than 22.5 µg/L in LCO is a high bar for determining impairment and taking needed steps to restore and protect the resource, especially considering LCO is an ORW. The current WisCALM approach leads to a high probability that LCO will not be listed as impaired until it has already undergone significant degradation. This is clearly not the intent of the impairment thresholds, which, as stated in WisCALM, "*must be in line with the intent of the water quality criteria in code*." This further heightens the need to establish a site-specific criterion protective of this unique resource.

A lake can also be listed as impaired, using the WisCALM methodology, if total phosphorus data is shown to exceed the current criterion, but not to the extent discussed above. If supporting information is available that identifies a biological impairment, the lake can be listed and priority put on developing a TMDL. If supporting biological information is not available, the lake can be listed as impaired but with low priority (Category 5P) for development of a TMDL. If the data do not demonstrate clear exceedance of the total phosphorus criterion, but biological indicators indicate impairment, the lake can be listed as well. The WisCALM matrix for assessing phosphorus and biology in combination is shown in Figure 9 below. This approach emphasizes the need to consider data other than phosphorus in determining whether or not existing and designated beneficial uses are being attained in LCO. Additional dissolved oxygen and fishery data included in this SSC proposal are intended to address this need.

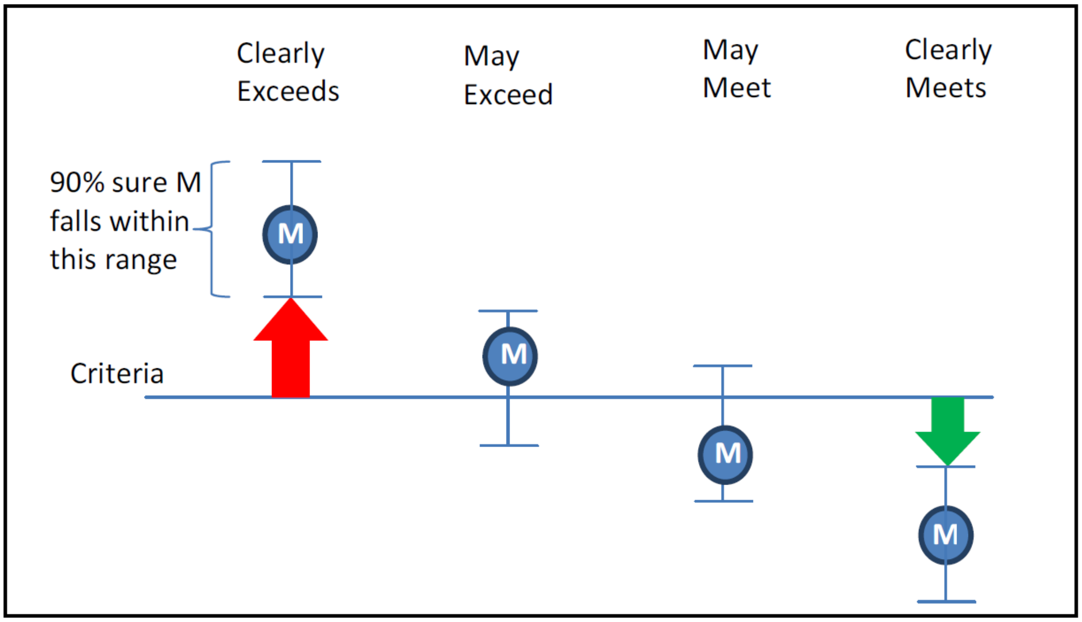

Figure 8. WisCALM approach for assessing exceedance of phosphorus criteria. (Source: WDNR, 2015)

	Biological Response Indicators	Overall Assessment Result & EPA Listing Category	Pollutant
Meets TP criteria	None indicate impairment	Not Impaired (Fully Supporting) Category 2	NA
	One or more indicate impairment	Impaired – Biology Only (Not Supporting) Category 5A	Unknown
Exceeds TP criteria (not an overwhelming exceedance)	One or more indicate impairment	Impaired – TP & Biology (Not Supporting) Category 5A	TP
	None indicate impairment	Impaired – Exceeds TP but has insufficient or conflicting biological data (Not Supporting) Category 5P	TP
Exceeds TP criteria by an overwhelming amount	None needed	Impaired – TP Only (i.e. Overwhelming exceedance) (Not Supporting) Category 5A	TP

Figure 9. WisCALM matrix for assessing phosphorus and biological indicators in combination. (Source: WDNR, 2015)

Blank Page

5
Fishery Impairment and Threats

A two-story fishery is a lake capable of supporting warm water species like walleye, bass, northern pike and muskellunge in its warm, “top story”. It also can support cold-water species like cisco or whitefish in its deeper, colder, well-oxygenated “lower story” (Figure 10). In Wisconsin, 188 individual lakes within the approximately 15,000 lakes are known to support two-story fisheries. Of these, only five inland lakes are known to support or have supported both the cold-water species of cisco and whitefish (Lyons et al., 2015). One of these five is LCO. Of the warm water species, muskellunge and walleye have been highly sought after fish in LCO.

Interaction occurs between the warm water and cold water fish species. Cisco and to a lesser extent lake whitefish are the prey of gamefish such as walleye, muskellunge, and northern pike (Lyons et al., 2015). Abundant cisco and whitefish populations help produce trophy walleye, northern pike and muskellunge. LCO produces world record muskellunge and large walleye, smallmouth, and northern pike, due to the presence of cisco and whitefish as food sources. Without the cold water species, gamefish would be smaller and slower growing, if not less abundant. The angling public would view this as a significant impairment (Pratt and Neuswanger, 2006). Populations of cisco and whitefish are threatened in LCO, while muskellunge populations are impaired. The status of the LCO fishery is discussed further below.

5.1 Winterkill

Winterkill data from WDNR’s Hayward fisheries files indicates that Musky Bay accounts for two-thirds of the recorded fish kills in Sawyer County since 1996 (Pratt, 2013). Overall, there has been a decline in winterkills in Sawyer County from the 1960-1979 and 2000-2012 time periods from 35 to three. The trend in winterkills in Musky Bay is opposite of the countywide trend, with no winterkills between 1960-2002 and two winterkills in the 2003-2012 period.

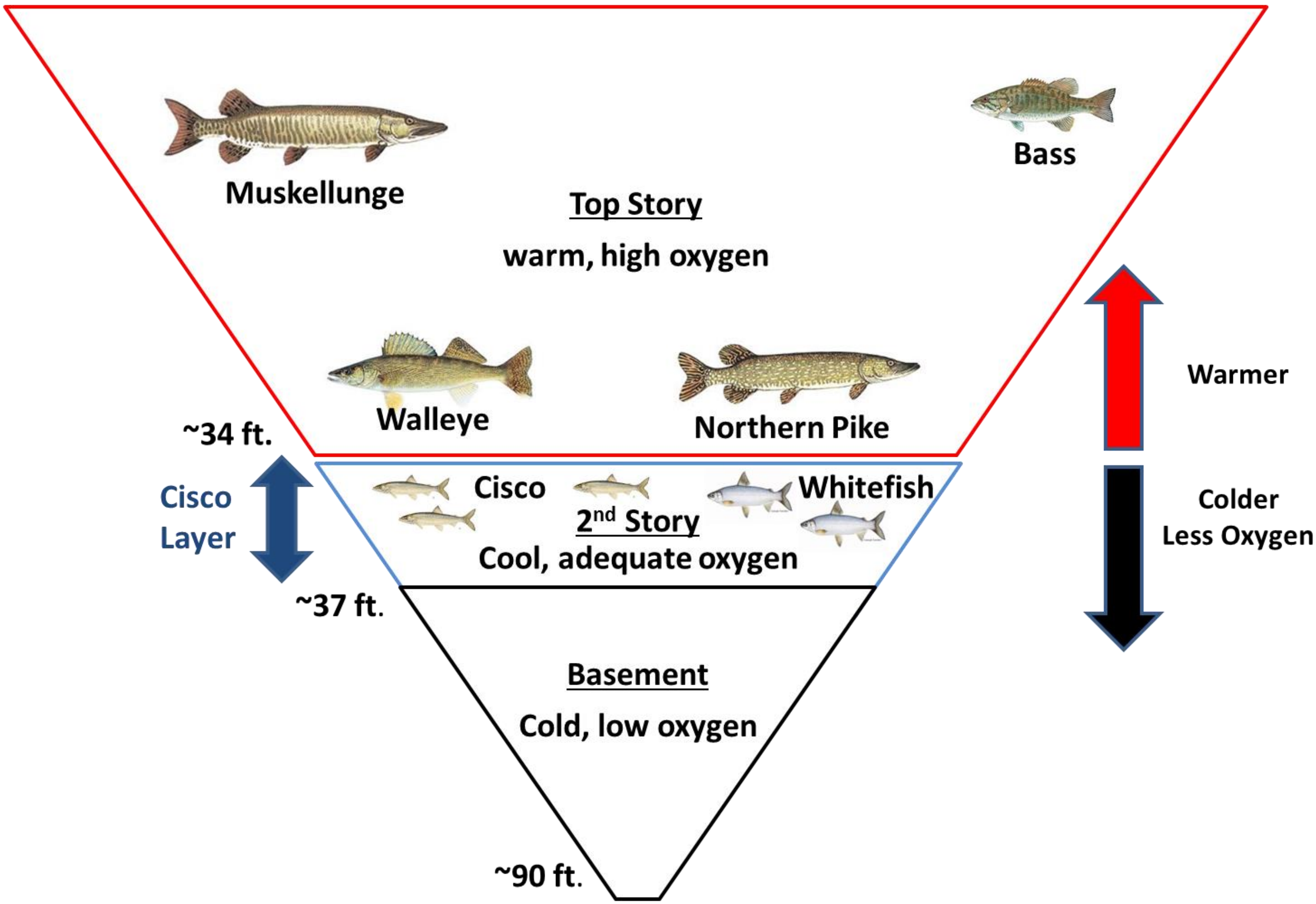

Figure 10. Typical two-story fishery in LCO, late summer.

5.2 Cisco and Whitefish

Cold water fisheries such as cisco and whitefish rely on sufficient dissolved oxygen concentrations in the cooler bottom waters, or hypolimnion, of a lake. Increased nutrient loading to a lake can result in a reduction of oxygen in the hypolimnion. Die-offs of cold water species may occur as these populations are driven into warmer surface waters.

As mentioned previously, LCO is one of only five of Wisconsin's approximately 15,000 lakes that is known to support both whitefish and cisco populations (Lyons et al., 2015). During 2011 to 2014, WDNR conducted a study of inland two-story fishery lakes across Wisconsin. For the study, standardized vertical gill net sampling was conducted in 133 of the 141 lake systems known to have supported cisco and all nine of the lakes known to have supported whitefish. Results of the vertical gill net sampling in LCO, as well as for Grindstone and Whitefish Lakes (which both drain to LCO) are given in Table 2. Relative abundance of cisco in LCO was rated as "medium" for the study, and the cisco catch per night gang of 11.3 ranked among the top 37% of the lakes studied. For both Grindstone and Whitefish Lakes, cisco relative abundance was rated as "high". Whitefish were not found either LCO or Grindstone Lake, which are two of the five lakes known to have had both cisco and whitefish historically; Whitefish were present with a "low" relative abundance in Whitefish Lake.

Table 2. 2011-2014 WDNR cisco and lake whitefish survey (Lyons et al., 2015).

Lake or Lake System	Species Historically Reported	Sample Date	Total Nights and Net Gangs	Cisco Catch per Night-Gang	Cisco Relative Abundance	Lake Whitefish Catch per Night-Gang	Lake Whitefish Relative Abundance
Lac Courte Oreilles (Big & Little)	Both Species	07/15/2013	3	11.3	Medium	0.00	None
Grindstone	Both Species	08/27/2013	1	26.0	High	0.00	None
Whitefish	Both Species	08/07/2012	3	47.7	High	0.67	Low

The study conclusions reached by biologists from WDNR's Fisheries and Aquatic Research Section speak to the importance of cisco and whitefish species in LCO (Lyons et al., 2015):

> *Cisco and lake whitefish lakes are uncommon in Wisconsin. There are about 15,000 inland lakes greater than 2 acres in surface area in the state, but only 188 of these lakes, or about 1.25% of the total, are likely to have once had cisco, and only nine, or 0.06%, are likely to have once had lake whitefish. Just five of these lakes (0.03%) had reports of both cisco and lake whitefish. Thus, collectively, cisco or lake whitefish occupy no more than 192 lakes representing only about 1.3% of the inland lakes in Wisconsin.*
>
> *Cisco and lake whitefish populations still persist in most of the inland lakes in Wisconsin where they occurred historically, but overall their distribution appears to have shrunk, especially in southern Wisconsin. Statewide, 29% of the lake systems that once had cisco and 33% of those that once had lake whitefish did not yield any individuals during the 2011-2104 vertical gill net survey. Thus, it is possible that a substantial portion of the range of these two species in the state has been lost.*

Cisco populations are faring relatively well; however, there is evidence that cisco habitat is being compressed by lower dissolved oxygen levels and increased temperatures. During the WDNR vertical gill net surveys, dissolved oxygen levels were measured in the bottom waters of all three lakes that were lower than the levels cisco are reported to prefer or able to withstand (Table 3). A suitable oxythermal habitat range for cisco would be > 5 mg/L dissolved oxygen and < 17 °C. Marginal habitat would include > 3 mg/L dissolved oxygen and < 22 °C. Dissolved oxygen levels less than 3 mg/L or temperatures greater than 22 °C are considered lethal to cisco. Dissolved oxygen thresholds for whitefish are similar to cisco, however, temperatures for suitable habitat are lower. A suitable temperature range for whitefish is between 4 °C and 11 °C, with an upper lethal bound of 19 °C.

Table 3. Summary of unpublished data from WDNR two-story lake survey.

Lake	Survey Date	Water Depth (ft)	Temp. (°C)	DO (mg/L)
Lac Courte Oreilles	7/16/2013	22-75	7-13	2.8-8.0
Whitefish	8/06-09/2012	35-83	7-9	1.6-6.3
Grindstone	8/28/2013	28-40	9-20	1.0-5.8

Summary of data from Jeff Kampa, WDNR (Personal communication, January, 2014).

A review was conducted of historical fish survey data from the WDNR SWIMS database and the Hayward Fishery Files (Table 4). This data includes information from a number of gear types: seines, gill nets, fyke nets, boom-shocker electrofishing, creel census observation, and SCUBA observation. While it is difficult to discern trends from the limited data available, it appears the abundance of cisco has declined.

Table 4. Coregonid sampling history in Lac Courte Oreilles, 1966-2014

Species	Gear	Dates	No. (CPE)	Type	Additional Information
Cisco	Boom-shocker	Nov. 1966	344 (134)	Targeted cisco survey	Cisco spawning Vicinity of Whitefish Creek
	Boom-shocker	Sept. 1976	42 (15)	Walleye survey	Pre-spawn Vicinity of Whitefish Creek
	Boom-shocker	Sept. 2005	1 (<<1)	Walleye survey	Victory Heights. Only cisco shocked since 1976.
	Seine	Nov. 1976	423 (42)	Targeted cisco survey	Vicinity of “KK” ditch- algae from cranberry effluent observed
	Fyke net	April 2006	1 (<<1)	Walleye survey	The only cisco, ever fyke-netted in LCO
	Gill net	Aug. 2008	1 (0.7)	Targeted cisco survey	WDNR Fisheries Mgt.- Diagonal sets
	Gill net	July 2013	28(9)		WDNR “Two Story” Research-Vertical sets.
Lake Whitefish	Creel observation	July 1977	1(NA)	Angler caught	12+ lb. witnessed by local Fisheries Manager
	SCUBA observation	Aug. 2011	1(NA)	Non-Agency	8+ lb., Observed dying and photographed by local resident, vicinity Thoroughfare

CPE= catch per effort

Whitefish, the presence of which is much rarer in general than cisco, are far more sensitive to dissolved oxygen and temperature levels than cisco. Whitefish prefer lower temperatures than cisco and therefore have an affinity to bottom waters. Their preferred summer habitat is approximately 10% or less by volume of cisco habitat (Pratt, personal communication, May 2014). Depressed dissolved oxygen levels in deeper waters can stress whitefish. Two whitefish were found dead floating in LCO by fishermen in August of 2015 (Figure 11). Additional data on the cisco and whitefish populations in LCO should be available as a result of net and bio-acoustic survey conducted by WDNR in August of 2015.

Figure 11. Two dead whitefish found floating in LCO by fishermen in August, 2015. (Source: WDNR)

5.3 Muskellunge

Muskellunge are native to LCO and the lake has been known for producing trophy-size fish, including a one-time world record. Musky Bay is LCO's primary muskellunge spawning area (Johnson 1981). The muskellunge population in LCO, once self-sustaining, is now limited by poor levels of reproductive success. WDNR's goal for the muskellunge population in LCO is 0.20-0.30 adults per acre (Max Wolter, WDNR, email communication December 21, 2015). The most current estimate of the population, based on marking and recapture surveys conducted between 2011 and 2014, is 0.06 adults per acre, or 297 estimated adult muskellunge in LCO. This estimate is based on the best available information as of 2015. There is a considerable amount of variance associated with this estimate as a result of the low overall sample size (46 marked in 2011, 37 captured in 2014, 5 recaptures). This estimate incorporates only adult muskellunge that are sexually mature and using traditional spawning areas in LCO (Max Wolter, WDNR, email communication December 21, 2015).

Annual stocking of muskellunge began in 1956 to maintain the population (Johnson 1986). Based on communications with WDNR's current fishery manager for LCO, there is a compelling case to be made for the importance of natural reproduction over stocking. There are strong indications from genetics studies as well as general fisheries surveys that stocking has only minimal long term impact on the muskellunge population. Over the last several decades, and including several differing stocking strategies, stocking efforts have been relatively unsuccessful at increasing the overall size of the muskellunge population in LCO. The limited success with stocking then places increased importance on natural reproduction of muskellunge as the primary means to sustain this historic population (Max Wolter, WDNR, email communication December 15, 2015).

Habitat during early life stages may be critical to reproductive success (Zorn et al., 1998). Muskellunge commonly spawn in shallow bays (<1 m) with muck substrate and woody debris, similar to Musky Bay (Murphy, 2009; Zorn et al., 1998). Dissolved oxygen is a key component of spawning habitat. Nonadhesive eggs are broadcast in a spawning area and settle to the bottom. Eggs incubate over 10-21 days, depending on water temperature. While the first days of embryonic development can progress with low dissolved oxygen, egg survival until hatching is low, with mortality rates estimated around 97%-99% (Zorn et al., 1998). This high rate of mortality may be attributed partially to insufficient dissolved oxygen. Larvae hatch and remain inactive at the bottom for another 10 days until the yolk sac is absorbed. Yolk sac larvae survival declines at dissolved oxygen levels below 2.0 mg/L for northern pike. Similar impacts from low dissolved oxygen can be expected with muskellunge yolk sac larvae (Zorn et al., 1998). Following absorption of the yolk sac, larvae utilize decaying aquatic vegetation and new emergent plants for cover (Murphy, 2009). Northern pike larvae survival declines below 4.0 mg/L and, again, similar impacts can be expected for muskellunge larvae.

In a study of muskellunge spawning habitat in four Wisconsin lakes (Zorn et al., 1998), including LCO, dissolved oxygen levels at the substrate-water interface were significantly lower in LCO than the other three lakes (Lower Clam, Mineral, and Brunet Flowage). The median dissolved oxygen level in LCO at the interface was 1.4 mg/L compared to 1.5 to 6 mg/L for the other three lakes. At 5 cm above the bottom, LCO dissolved oxygen was 1.5 mg/L compared to 7.6-8.3 mg/L for the other lakes. At 10 cm above the bottom, LCO dissolved oxygen was 3.5 mg/L compared to 8.1 – 8.7 mg/L for the other lakes. In a study of muskellunge spawning areas in eight lakes in northern Wisconsin and Minnesota in May of 1982 and 1983, the lowest dissolved oxygen measurements were also found in LCO (Figure 12, Dombeck et al., 1984). The low levels of dissolved oxygen in LCO can be expected to negatively impact egg and larvae survival.

While even low egg and larvae survival rates may be adequate to replace adult stock, even a small decrease in survival may be enough to inhibit natural muskellunge reproduction in a lake (Zorn et al., 1998).

Dissolved oxygen levels in spawning areas is critical for reproductive success, especially because muskellunge lack means of avoiding low dissolved oxygen at the substrate interface. Reproductive failure is associated with spawning areas having deep accumulation of organic matter and dense macrophyte growth (Dombeck et al., 1984).

Oxygen depletion in Musky Bay, which has been shown to occur during spawning, may be a contributing cause of muskellunge population decline in LCO. Dissolved oxygen depletion in Musky Bay is caused primarily by excessive inputs of phosphorus leading to increased algal productivity, and subsequent settling and decay on the bottom substrate. Improvement in the dissolved oxygen levels in Musky Bay will help restore and attain the desired muskellunge fishery in LCO (Dombeck et al., 1984).

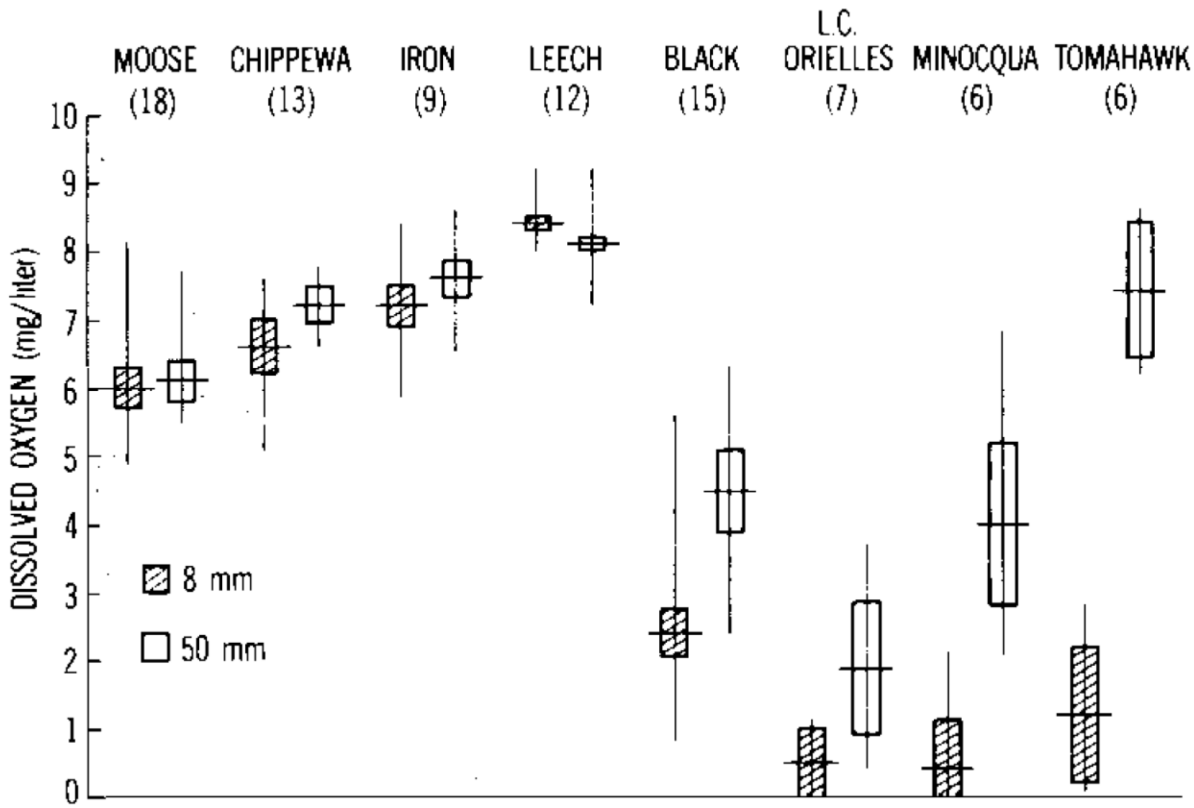

Figure 12. Dissolved oxygen concentrations 8 and 50 mm above the substrate-water interface in muskellunge spawning sites. (Source: Dombeck et al., 1984)
Horizontal lines are means, boxes enclose ±2 standard error, and vertical lines are ranges. Sample sizes are indicated in parentheses.

Blank Page

6 Loss of Recreational Designated Use

LCO draws thousands of visitors each year from Wisconsin, Minnesota, Illinois, and other states (Wilson, 2010). Approximately 20,000 fishing trips are conducted at LCO annually, with approximately 12% (2,400 trips) conducted in Musky Bay. The total minimum value of these trips is estimated at $700,000 per year, with $75,000 per year in Musky Bay (Pratt and Neuswanger, 2006). However, recreational use of Musky Bay is impaired due to excessive aquatic plant growth and the presence of dense algal mats, as well as curly leaf pondweed, an aquatic invasive species.

Annual fish surveys have been conducted in the fall by WDNR and Great Lakes Indian Fish and Wildlife Commission (GLIFWC). Notes from the field surveys indicate whether navigation of Musky Bay was possible in the boom-shocker boat used in fisheries assessments, and therefore serve as a measure of fishing, boating, and swimming accessibility of Musky Bay. The WDNR and GLIFWC survey notes document two levels of impairment to a successful fish survey: 1) survey made harder and less effective; and 2) survey cancelled or not completed. Since the surveys were conducted in the fall and not during the height of the growing season, they underestimate the level of impairment to navigation. Based on the fish survey field notes from 1992 to 2008, surveys at Musky Bay were completed with some difficulty in 1992, 1996, and 1997. In 1998, 2003, and 2008, surveys were not able to be completed (field notes for these years were: "heavy weeds", "not navigable", and "motor fouling").

Algal mats, which are a manifestation of the excess phosphorus concentrations in Musky Bay, also periodically limit swimming, boating, and fishing in the bay (Figure 13 - Figure 15).

Increasing nuisance algal growth is also being observed in Stuckey Bay (Figure 16 - Figure 18).

Curly leaf pondweed, first identified in the lake in 2005, is now established throughout Musky Bay. Its presence hinders or completely impairs recreational use of this portion of LCO for much of the year. While WDNR does not list waters as impaired due to invasive species, such as curly leaf pondweed (WDNR, 2015), its presence contributes to impairment of LCO, including affecting native aquatic plant species and contributing increased nutrient levels during die off, which occurs in mid-summer (UW Extension, 2013). The increased nutrient levels subsequently lead to lowering of dissolved oxygen levels.

COLA and WDNR have spent approximately $40,000 per year on curly leaf pondweed control since 2010 in an effort to mitigate the phosphorus release/algal bloom and dissolved oxygen slump associated with curly leaf pondweed die off and to facilitate navigation in Musky Bay. Aquatic plant surveys were conducted in Musky Bay in 2007 and then in 2011 to assess the effectiveness of curly leaf pondweed control. Between 2007 and 2011, 48% of native species declined, 14% disappeared, and 65% remained stable in the bay (Stantec, 2012).

Figure 13. Algal mats in Musky Bay in September, 1999. (Source: Fitzpatrick et al., 2003. Photo by Paul Garrison, WDNR)

Figure 14. Algal mats in Musky Bay in July, 2014. (Source: COLA.)

Figure 15. Algal mats in Musky Bay near cranberry bog outlet in July 2014. (Source: COLA)

Figure 16. Algal growth in Stuckey Bay near cranberry bog outlet in June, 2015. (Source: LCOCD)

Figure 17. Algal mat and curly leaf pondweed in Stuckey Bay in June, 2015. (Source: LCOCD)

Figure 18. Algal growth in Stuckey Bay in June, 2015. (Source: LCOCD)

7
Assessment of Water Quality Conditions

This section presents a summary of water quality conditions in LCO based on quality assured monitoring data collected by the Lac Courte Oreilles Conservation Department (LCOCD). Data presented here are focused on the most recent 5 year period, 2011-2015. Monitoring stations are indicated on Figure **2**. Total phosphorus, chlorophyll *a*, macrophyte, and dissolved oxygen conditions in LCO are presented. In addition, an oxythermal metric is presented. The data assessments were conducted based on methodologies presented in WDNR's draft Site-Specific Criteria Framework for Wisconsin (2014) and the 2014 WisCALM guidance (WDNR, 2013). The focus of the presented data is on total phosphorus as well as biological endpoints in LCO as defined for deep (stratified) two-story fishery lakes.

7.1 Total Phosphorus

This section presents an analysis of current ambient total phosphorus conditions in LCO and historical total phosphorus conditions based on sediment cores.

7.1.1 Current Ambient Conditions

Surface (top 2 m or 6 ft) total phosphorus data for eight LCO sampling stations (LCO 1 thru 6 and MB1; Figure **2**) were analyzed according to the assessment protocols for fish and aquatic life uses described in 2014 WisCALM (WDNR, 2013) for the June 1 to September 15 season. While data are available dating back to 2002, the most recent five-year period for each station was chosen. Therefore, data used in the analysis span the time period of 2011 to 2015. The results of the assessment, including the individual monthly averages and the mean for each location, and the associated confidence interval are given in Table 5 and presented in Figure 19.

Based on the assessment, total phosphorus concentrations are highest in Musky Bay, averaging 32 µg/L. The Central Basin has the lowest average total phosphorus concentration of 11.6 µg/L. A decreasing trend in concentrations is observed in moving from the west end of LCO, including Musky Bay and Stuckey Bay, through the West Basin to the Central Basin. A slight decreasing trend is also observed in moving from the east end of LCO, starting in Northeast Bay, through Anchor Bay and the East Basin to the Central Basin.

Based on the methods and criteria that have been applied by WDNR in the past, including a 15 µg/L criterion in LCO and a 40 µg/L in Musky Bay, as well as a requirement that the lower 90th percent confidence interval exceed 1.5 times the criterion, none of the locations would be considered impaired based solely on total phosphorus concentrations. The observed impairments in the fishery and recreational use, as discussed in previous sections, indicate a critical need to establish a SSC for total phosphorus.

Table 5. Total phosphorus condition assessment by LCO basin and bay. Values represent the period of June 1 – September 15.

		Monthly Average Total Phosphorus (µg/L)							
		Musky Bay	Stuckey Bay	West Basin near Musky Bay	West Basin	Central Basin	East Basin	Anchor Bay	Northeast Bay
Year	Month	MB 1	LCO 1	LCO 2B	LCO 2	LCO 3	LCO 4	LCO 5	LCO 6
2011	6	26.3			22.0	9.0	17.0	8.0	13.0
2011	7	42.3			8.8	8.3	8.2	8.3	6.3
2011	8	50.0					12.5		
2011	9	21.5							
2012	6	34.0	13.5		10.5	12.0	12.5	10.0	12.5
2012	7	49.0	10.9		11.0	7.4	8.3	7.4	7.4
2012	8	43.0	34.3		8.7	7.2	10.8	9.2	5.5
2012	9	34.0	15.3		13.5	12.5	10.3	14.0	12.0
2013	6	26.0	11.5	14.8	18.8	11.0	12.5	19.8	13.3
2013	7	47.6	98.6	77.0	66.6	36.6	23.4	27.8	26.0
2013	8	30.3	27.0	20.3	12.8	11.5	18.0	15.0	20.8
2013	9	24.0	11.0	8.5	9.0	9.5	9.0	9.5	11.0
2014	6	33.0	12.0	8.0	15.0	8.0	10.0		8.0
2014	7	33.0	12.8	10.3	11.0	12.0	11.7	13.0	17.5
2014	8	26.3	12.5	15.0	14.5	14.5	12.0	15.0	13.5
2014	9	20.0	11.0	17.0	12.0	11.0	12.0	11.0	18.0
2015	6	25.3	14.3	11.7	11.0	9.0	12.3	11.7	9.3
2015	7	31.0	16.0	11.0	9.0	8.5	8.0	8.0	10.0
2015	8	22.8	11.0	10.0	12.0	11.0	12.0	12.0	12.0
2015	9	20.7	10.0	13.0	11.0	10.0	10.0	7.0	8.0
Count		20	16	12	18	18	19	17	18
Average		32.0	20.1	18.0	15.4	11.6	12.1	12.1	12.4
Upper 90%		34.4	20.4	19.4	16.0	12.4	13.0	13.2	13.6
Lower 90%		27.4	12.1	10.4	10.8	9.2	10.5	9.7	9.7

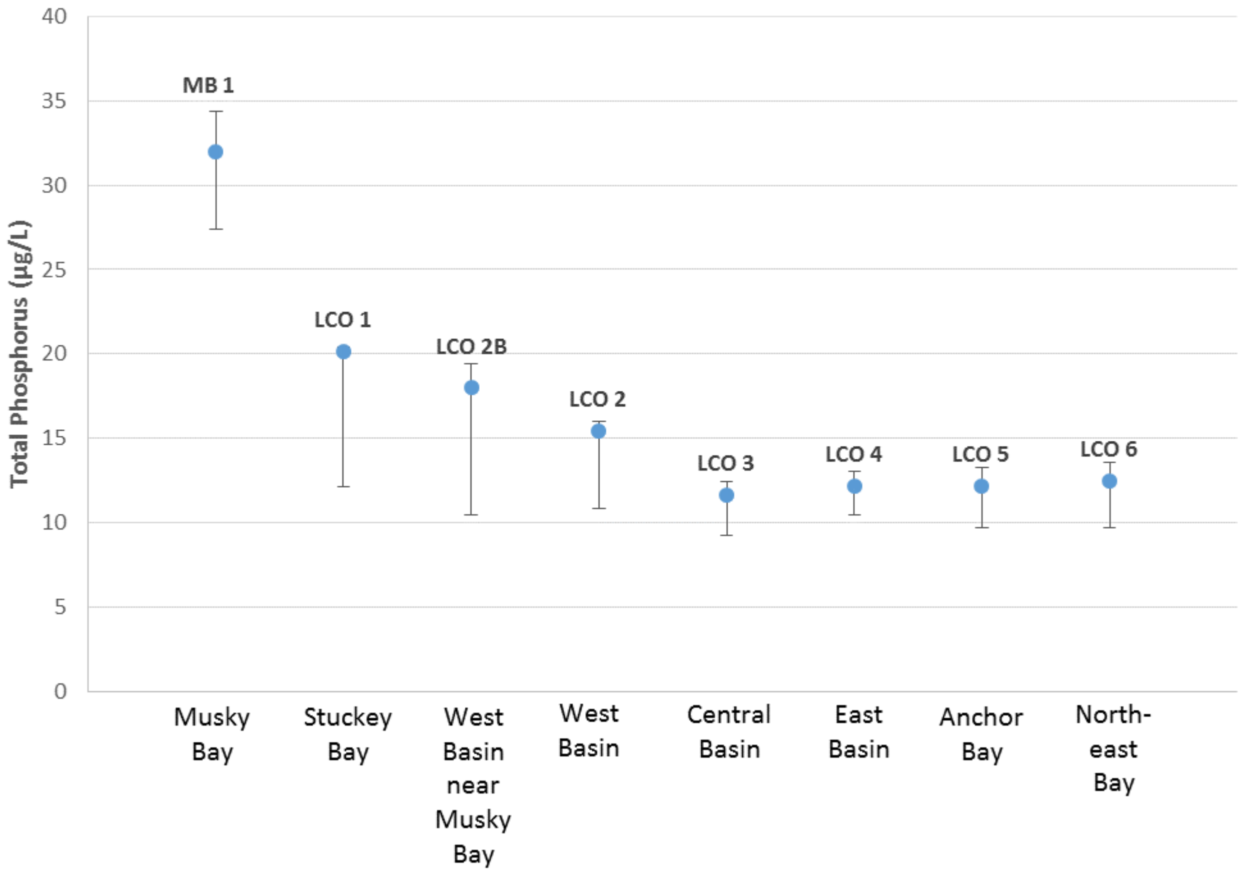

Figure 19. Monthly average total phosphorus (June 1-Sept 15) in major bays and basins of LCO (2011-2015).

Errors bars indicate the 90th percentile confidence interval around the mean assuming a lognormal distribution.

7.1.2 Historical Conditions

Historical water quality patterns in LCO were examined by USGS based on analyses of sediment cores collected in 1999 and 2001 (Fitzpatrick et al., 2003). Cores were collected in Musky Bay (five locations), Northeastern Bay (two locations), Stuckey Bay, and the center of the lake (deep hole). Samples from the cores were analyzed for minor and trace elements, nutrients, biogenic silica, diatoms, pollen, and radioisotopes.

The cores from one of the Musky Bay sites in the study (MB-1) indicated that since the 1980's, phosphorus levels increased dramatically in the bay while iron levels decreased almost as dramatically (from approximately 7:1 to approximately 1:1). The lower phosphorus to iron ratios indicate a likelihood of internal phosphorus release (Fitzpatrick et al., 2003). Study results indicated that the histories of several elements in Musky Bay, including phosphorus, were confounded by organic-matter decomposition and chemical redistribution (possibly by macrophytes) after deposition, thus limiting their use for reconstructing historic nutrient inputs. Dating of the cores from Northeastern Bay was not possible due to disturbances that happened after deposition as indicated in the radioisotope profiles. Total phosphorus core profiles for Musky Bay and Northeastern Bay from the USGS study are shown in Figure 20 (Fitzpatrick et al., 2003).

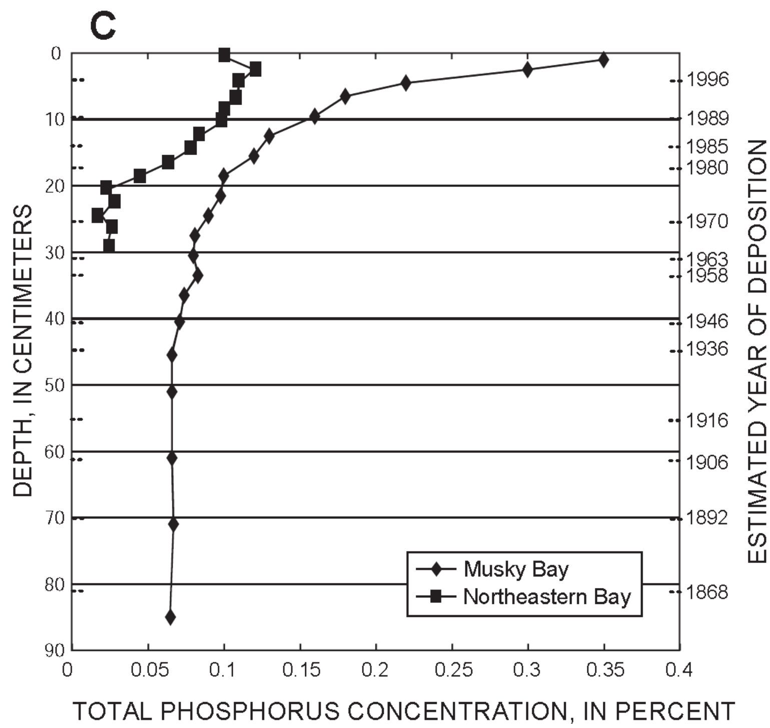

Figure 20. Total phosphorus concentrations in sediments of Musky Bay and Northeastern Bay, LCO with estimated date of deposition for the Musky Bay profile only. (Source: Figure 11; Fitzpatrick et al., 2003).

Evaluation of the silica, diatom, and pollen data from the Musky Bay sediment cores indicated an increased growth of aquatic plants during the 25 years preceding the study and establishment of floating algal mats in the preceding decade. Increased nutrient inputs to Musky Bay were indicated after approximately 1940 and also in the 1990s by several lines of evidence (Fitzpatrick et al., 2003).

WDNR's draft guidance for site-specific criteria (WDNR, 2014) points to the use of a sediment core to establish historical water column total phosphorus concentrations in cases where total phosphorus concentrations are not exceeding statewide criteria but the biology is impaired and a more stringent SSC is sought. The guidance specifies that the core is to be collected from the deepest part of the lake.

Paul Garrison at WDNR was contacted regarding the possibility of discerning a pre-development total phosphorus concentration for LCO based on the deep hole sediment core collected for the USGS study. Based on this request, diatoms in both the top and bottom sample from the top/bottom core collected at the deep hole location were re-counted and the results run through a weighted average model for deep lakes (Birks, et al., 1990). A concentration of 10 µg/L was predicted in the top sample. The model was not able to accurately predict total phosphorus concentrations in the deep hole bottom sample due to limitations in the model (Garrison, 2014). Collection of new samples would not improve the ability to predict pre-development total phosphorus concentrations (Garrison, personal communication, May 2014).

7.2 Biologic Condition

LCO's biologic condition was assessed based on its classification as a deep lake and a two-story fishery. Chlorophyll *a*, macrophytes, and dissolved oxygen conditions in the lake are described below.

7.2.1 Chlorophyll *a*

As with the total phosphorus analysis described in Section 7.1, surface chlorophyll *a* data for eight LCO sampling stations were analyzed according to the assessment protocols for fish and aquatic life uses described in 2014 WisCALM (WDNR, 2013) for the July 15 to September 15 season.

While data are available dating back to 2002, the most recent five-year period for each station was chosen. Therefore, data used in the analysis span the time period of 2011-2015. The results of the assessment are given in Table 6 and presented in Figure 21.

Based on the assessment, chlorophyll-a concentrations are highest in Musky Bay, averaging 9.2 µg/L. The Central Basin and Anchor Bay have the lowest average chlorophyll-a concentrations at 2.1 µg/L. Similar to phosphorus, a decreasing trend in concentrations is observed in moving from the west end of LCO, including Musky Bay and Stuckey Bay, through the West Basin to the Central Basin.

Based on the methods and thresholds that are applied by WDNR in WisCALM, including a 10 µg/L threshold for chlorophyll-a to protect fish and aquatic life uses, and a 20 µg/L threshold to protect recreational uses, none of the locations would be considered impaired based on chlorophyll-a measurements. The observed impairments in the fishery and recreational use, as discussed in previous sections, indicate the WisCALM thresholds for chlorophyll-a are not protective of LCO. At a minimum, thresholds should be established that are no higher than existing concentrations as LCO is an ORW. However, based on the observed impairments to the fishery and recreation in the lake, thresholds below existing levels are needed to restore and protect the beneficial uses.

Table 6. Chlorophyll *a* condition assessment by LCO basin and bay. Values represent the period of July 15-September 15.

		Monthly Average Chlorophyll a (µg/L)							
		Musky Bay	Stuckey Bay	West Basin near Musky Bay	West Basin	Central Basin	East Basin	Anchor Bay	Northeast Bay
Year	Month	MB 1	LCO 1	LCO 2B	LCO 2	LCO 3	LCO 4	LCO 5	LCO 6
2011	7	20.0	2.9		3.5	2.1	2.9	2.9	3.1
2011	8	23.7	4.0				1.9		
2011	9	3.5	3.7						
2012	7	21.0	2.4		2.2	1.8	2.8	1.6	2.0
2012	8	19.3	3.0		2.8	2.1	2.1	1.6	2.3
2012	9	8.2	3.0		3.0	2.2	2.4	2.2	2.8
2013	7	5.1	1.8	1.6	1.3	1.3	1.2	1.2	1.4
2013	8	4.4	1.7	1.4	1.4	1.4	1.3	1.6	2.0
2013	9	2.4	1.7	1.1	0.9	1.1	1.2	1.1	1.7
2014	7	8.9	3.4	3.4	2.7	2.4	2.5	3.0	2.6
2014	8	3.5	2.2	2.5	2.6	1.8	2.0	2.0	2.6
2014	9	2.4		3.6	3.2	2.4	2.8	1.6	3.3
2015	7	6.7	2.6	3.1	2.3	2.3			
2015	8	4.3	3.2	3.9	3.2	2.4	3.2	2.6	2.5
2015	9	4.8	4.7	4.6	4.7	3.4	3.7	3.6	2.8
Count		15	14	9	13	13	13	12	12
Average		9.2	2.9	2.8	2.6	2.1	2.3	2.1	2.4
Upper 90%		9.7	3.2	3.5	3.0	2.3	2.6	2.4	2.7
Lower 90%		4.7	2.3	1.8	1.9	1.7	1.8	1.6	2.0

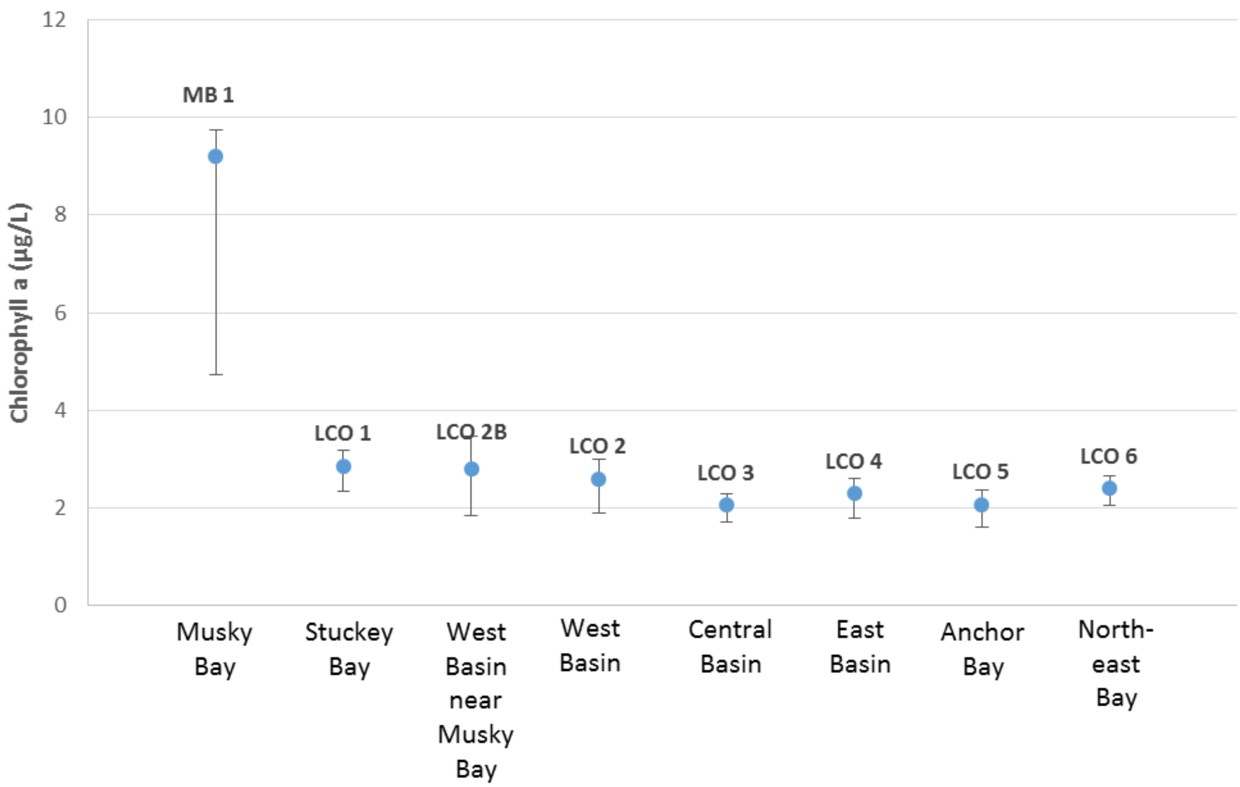

Figure 21. Monthly average chlorophyll-a (July 15-Sept 15) in major bays and basins of LCO (2011-2015).

Errors bars indicate the 90th percentile confidence interval around the mean assuming a lognormal distribution.

7.2.2 Macrophytes

Point intercept surveys were conducted in LCO in 2007 (Musky Bay) and 2010 (lakewide) following WDNR protocols. In addition, a visual shoreline survey was completed in June 2010 to look for the presence of invasive species. The results of these surveys are documented in Macrophyte Survey Musky Bay-Lac Courte Oreilles (Harmony, 2007) and Appendix B of the Lac Courte Oreilles Aquatic Plant Management Plan (Tyrolt, 2011).

The 2010 point-intercept survey was conducted in August using a 2,254 point grid generated by WDNR. Based on this survey, LCO has a very diverse plant community with a total of 36 species (35 native and one exotic). Species abundance is balanced between the different types of plants. The Simpson's diversity index of 0.94 calculated based on 2010 study results indicates a healthy ecosystem and a high degree of diversity (Tyrolt, 2011).

The floristic quality index (FQI) calculated for LCO was 36.0 with 33 species used. The mean conservatism value was 6.27. The number of species and FQI are greater than the median values for lakes in the same eco-region (Northern Lakes and Forests), while the mean conservatism value is slightly lower. The high FQI is indicative of a plant community that is healthy, intolerant to development and other human disturbances in the watershed, and has changed little in response to human impact on water quality and habitat changes. This value also indicates a high degree of water quality (Tyrolt, 2011).

Musky Bay has a robust and diverse plant community (Tyrolt, 2011); however, the community structure is being negatively influenced by curly leaf pondweed infestation as described in Section 6. Several other areas of LCO are impacted by curly lead pondweed, including Northeast Bay (Barbertown Bay) and

Stuckey Bay. Anchor Bay is being watched due to the presence of curly lead pondweed in Little Grindstone Lake, which flows into the Bay (Tyrolt, 2011).

7.2.3 Dissolved Oxygen

WisCALM (WDNR, 2013) includes an impairment indicator threshold for dissolved oxygen of 6 mg/L in the hypolimnion of two-story lakes. If greater than 10% of the dissolved oxygen measurements in the hypolimnion are less than the threshold during the ice-free period, the lake is to be assessed as impaired and included in Category 5A, indicating development of a TMDL is a priority.

An analysis of the last 5 years (2011-2015) of dissolved oxygen data suggests that LCO is impaired. Table 7 and Table 8 summarize the assessment of the dissolved oxygen measurements in the hypolimnion of LCO. The hypolimnion was determined as the lower layer of the lake, bounded above by the profile interval with the highest rate of change in temperature (degrees F/unit depth) for ice-free periods when monitoring was conducted. Based on this assessment, LCO is impaired in accordance with WisCALM. Excess algal productivity resulting from anthropogenic phosphorus loads to LCO is very likely contributing to dissolved oxygen depletion. As an Outstanding Resource Water, LCO requires immediate attention to restore water quality and protect it from further degradation. LCO is one of only 5 inland lakes in Wisconsin to have both cisco and lake whitefish reported present. Sufficient dissolved oxygen in the hypolimnion is critical to protecting this fishery.

Despite the majority of LCO meeting current total phosphorus criteria, LCO has an impaired biologic condition evidenced by low dissolved oxygen (<6 mg/L) in the hypolimnion. This indicates that LCO may be more sensitive to total phosphorus inputs than typical lakes of its kind. This possibility is recognized by WDNR in their 2014 draft Site-Specific Criteria Framework for Wisconsin, which states "…waterbodies may be more sensitive to phosphorus and experience biological responses and use impairments at lower levels than usually expected" (WDNR, 2014).

Table 7. Percent of individual dissolved oxygen measurements in the hypolimnion during the ice-free period with concentrations less than 6 mg/L.

Location	Year					
	2011	2012	2013	2014	2015	2011-2015
LCO-2 (West Basin)	64%	85%	68%	60%	51%	66%
LCO-3 (Central Basin)	68%	82%	59%	55%	44%	62%
LCO-4 (East Basin)	34%	78%	62%	48%	33%	54%
Lake-wide (West, Central and East Basins)	53%	81%	63%	53%	41%	60%

Table 8. Percent of average hypolimnion dissolved oxygen concentrations during the ice-free period with concentrations less than 6 mg/L.

Location	Year					
	2011	2012	2013	2014	2015	2011-2015
LCO-2 (West Basin)	75%	88%	74%	71%	70%	77%
LCO-3 (Central Basin)	75%	88%	68%	57%	50%	70%
LCO-4 (East Basin)	50%	87%	68%	57%	50%	67%
Lake-wide (West, Central and East Basins)	67%	87%	70%	62%	57%	71%

7.3 Assessment of Oxythermal Habitat Conditions

WDNR has suggested that an average hypolimnetic dissolved oxygen concentration may not be the best way to characterize the conditions needed to support a two-story cold water fishery (WDNR, 2014b). Cisco and whitefish need a band of water that has both cold enough temperatures and high enough oxygen for them to survive. At the beginning of the summer, the hypolimnion usually has both; but by the end of the summer the dissolved oxygen has been depleted, squeezing the fish into a very narrow band in which they can survive (refer to Figure 10). Therefore, a measure that combines both dissolved oxygen and temperature may be a more useful metric for a two-story fishery.

7.3.1 Assessment of TDO3

A metric referred to as TDO3 has been used to characterize oxythermal habitat in cold water two-story lakes. TDO3 is defined as a vertical measurement of the water temperature at which the dissolved oxygen concentration is 3.0 mg/L. WDNR suggested an initial consideration for a suitable TDO3 for cisco might be somewhere between 4 °C and 17 °C, with 22 °C as the maximum tolerable (WDNR, 2014b). WDNR also noted that cisco can survive between dissolved oxygen concentrations of 3 mg/L and 5 mg/L but this level is sub-optimal and may reduce growth and survival (WDNR, 2014b). WDNR noted that 3 mg/L is a lower limit for a 24-hr period.

WDNR also considered temperature and dissolved oxygen conditions for whitefish and noted dissolved oxygen conditions are similar as for cisco. However, whitefish prefer lower temperatures, with a suitable range between 4 °C and 11 °C, and an upper limit of 19 °C. .

A review of literature was conducted on the required combination of dissolved oxygen and temperature conditions for lakes supporting cisco and whitefish fisheries. Key information was provided in Jacobson (2010) with consistent conditions as noted by WDNR. Three tiers of cisco lakes were described:

- Tier 1 - TDO3 ≤ 11 °C, "most suitable coldwater fish habitat;"
- Tier 2 - 11°C < TDO3 ≤ 17°C, "suitable coldwater fish habitat;" and
- Tier 3 - TDO3 > 17°C, "marginal or unsuitable for cisco."

Tiers 1 and 2 were identified as cisco refuge lakes, Tier 3 as non-refuge lakes for cisco. Jacobson (2008) included field estimation of lethal temperature / dissolved oxygen conditions for cisco: 24°C @ 8 mg/L; 23°C @ 5 mg/L; 22°C @ 3 mg/L; and 19.5°C @ 1.0 mg/L.

An evaluation of available data was conducted to identify the critical, or annual maximum TDO3 each year in the three major basins of LCO, West, Central and East. The results are presented in Table 9. The results indicate that West Basin consistently has the highest TDO3, and East Basin typically the lowest with values very similar to the Central Basin. Values are typically higher in 2011, 2012 and 2015 than 2013 and 2014, with 2012 being the highest. Both 2013 and 2014 were characterized by long, cold springs and late summers. In terms of coldwater refuge, all basins would be characterized as Tier 3, marginal or unsuitable habitat in 2011, 2012, and 2015, indicating severe stress on cisco and whitefish. None of the basins would qualify as Tier 1, most suitable habitat, in any year.

Table 9. Annual Maximum TDO3 Values in LCO Basins, 2011-2015.

All values in °C										
	2011		2012		2013		2014		2015	
Basin	TDO3	Date	TDO3	Date	TDO3	Date	TDO3	Date	TDO3	Date
West	20.2	Aug 27	20.5	Sep 5	16.1	Sep 24	17.5	Sep 9	19.8	Aug 21
Central	17.7	Aug 27	20.3	Aug 13	15.3	Sep 10	16.5	Sep 9	18.7	Aug 21
East	17.7	Aug 27	19.6	Sep 5	13.7	Sep 24	16.4	Sep 9	18.8	Aug 21

The seasonal trend in TDO3 is represented in Figure 22 for 2012, the year with the highest observed annual maximum TDO3 values. A gradual increase in TDO3 is experienced from March through July, with peak values occurring in August and early September. Then a sharp decline in September during the fall turnover of the lake.

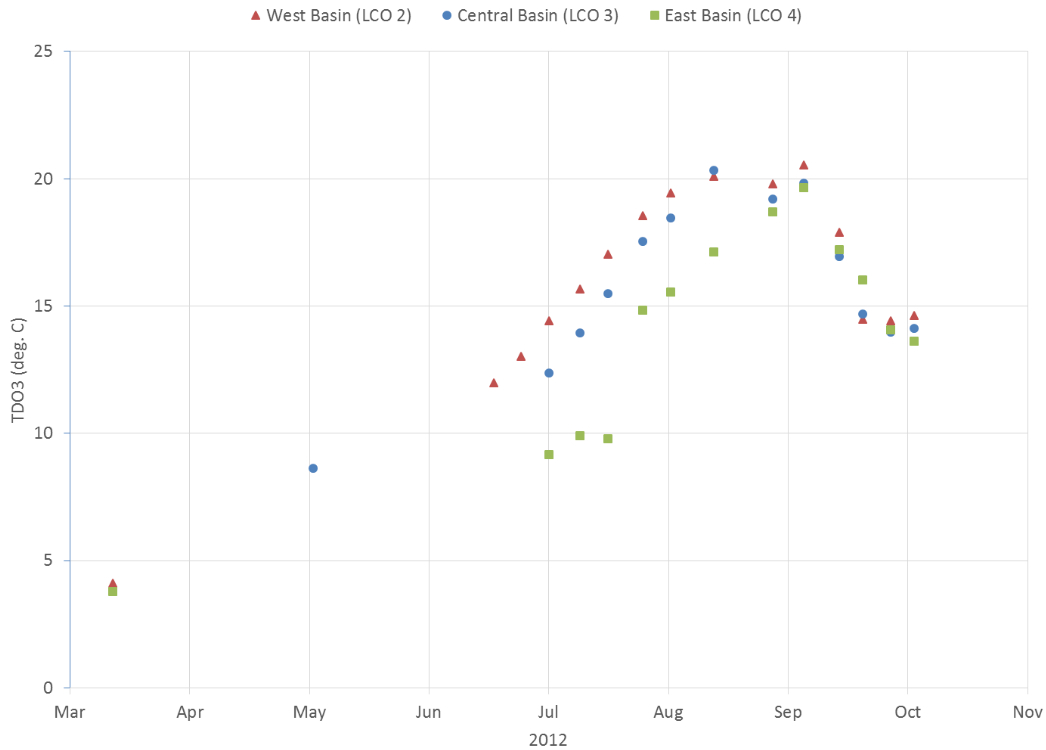

Figure 22. Seasonal TDO3 trend in 2012.

Figure 23, Figure 24 and Figure 25 present pie charts with the percent volume in each basin with suitable coldwater habitat. The pie charts include the following breakdown:

- Most Suitable: Water with temperatures lower than 17°C and dissolved oxygen greater than 5 mg/L (dark blue);
- Suitable: Water with temperatures 22°C or lower and dissolved oxygen greater than 3 mg/L, not including the Most Suitable conditions above (light blue);
- T>22: Surface water too warm for cisco and whitefish with temperatures exceeding 22°C (red); and
- DO<3: Hypolimnion water with dissolved oxygen levels lower than 3 mg/L.

As can be seen in the pie charts, the relative amount of habitat for cisco and whitefish is limited in each basin. The suitable habitat can also be assessed in terms of a stratum, the vertical band or depth of the layer with the suitable habitat. For the observations at the time of annual maximum TDO3 in 2012, the estimated suitable habitat layers were as follows in each basin:

- West Basin: 6.1 ft;
- Central Basin: 2.7 ft; and
- East Basin: 3.9 ft.

These small bands result in concentrating cisco and whitefish and limited ability for cisco and whitefish to escape predation.

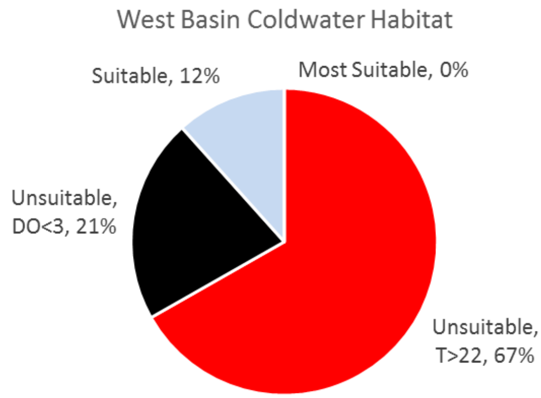

Figure 23. West Basin coldwater habitat, as a percent of basin volume, at time of annual maximum TDO3, September 5, 2012.

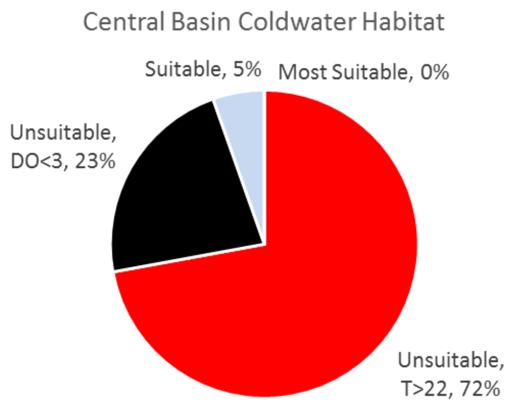

Figure 24. Central Basin coldwater habitat, as a percent of basin volume, at time of annual maximum TDO3, August 13, 2012.

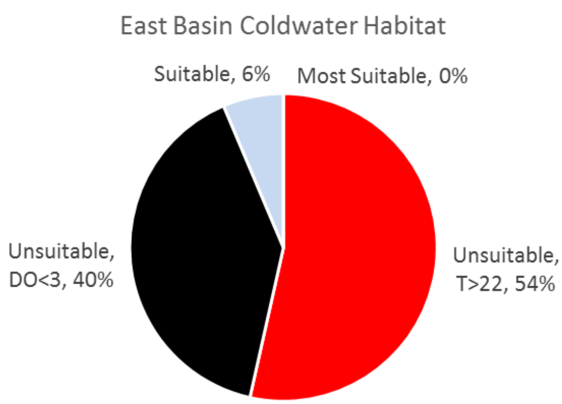

Figure 25. East Basin coldwater habitat, as a percent of basin volume, at time of annual maximum TDO3, September 5, 2012.

7.3.2 Linking Reduced Phosphorus to Improved Oxythermal Habitat

An important aspect of evaluating biologic conditions in LCO relates to improvements in TDO3 in response to reductions in total phosphorus concentrations. Therefore, an approach was developed to characterize and assess the linkage between total phosphorus (TP) inputs to LCO and resulting dissolved oxygen (DO) conditions at specific temperature layers in the lake, or the oxythermal habitat.

The approach combines the use of an equation documented in peer-reviewed literature with analysis of observed summer DO profiles in each basin of LCO. Chapra and Canale (1991) showed that hypolimnetic oxygen demand (HOD) varied across lakes as a function of $TP^{0.478}$. Therefore, the following equation can be used to project HOD based on observed depletion rates and baseline and future TP concentrations:

$$HOD_{future} = HOD_{present} * (TP_{future}/TP_{present})^{0.478} \text{ (Equation 1)}$$

Where,

HOD_{future} = projected hypolimnetic oxygen demand, mg/L/d

$HOD_{present}$ = current hypolimnetic oxygen demand, mg/L/d

TP_{future} = desired future water column total phosphorus, µg/L

$TP_{present}$ = current water column total phosphorus, µg/L

The following steps outline the approach:

1. Examine the shape of the vertical DO profiles in the observed data to define how HOD effects DO at different depths and time. Essentially, the DO at each depth is characterized using: 1) an initial DO at the onset of stratification ($DO_{initial}$); and 2) the difference ($DO_{deficit}$) between existing DO ($DO_{present}$) and initial DO ($DO_{initial}$) at each depth for the existing hypolimnetic oxygen demand predicted by the model. Future DO at any depth will be calculated by scaling the difference between existing DO and initial DO at that depth proportionally as a function of predicted future HOD.
2. Use the relationship defined above in conjunction with $\Delta TP^{0.478}$ to generate DO profiles for each basin as a function of TP; determine the extent of the improvement in TDO3 or oxythermal habitat with reductions in TP.
    a. Define HOD for current conditions ($HOD_{present}$)
    b. Define TP for future condition (TP_{future})
    c. Calculate HOD for future condition TP (HOD_{future}), using HOD proportional to $\Delta TP^{0.478}$ from Equation 1 above.
    d. Use revised HOD in Step 1 to generate DO profiles as a function of TP:
        i. $DO_{deficit} = DO_{initial} - DO_{present}$
        ii. $DO_{future} = DO_{initial} - DO_{deficit} * HOD_{future}/HOD_{present}$ (Equation 2)

The steps to determining TDO3 include:

1. Select base year of data upon which to make projections
2. Assume that the temperature profile remains constant across scenarios
3. Assume that for zero HOD, the DO profile in the hypolimnion remains constant at the value observed prior to stratification

4. For any interim HOD, scale projected DO proportionally between existing condition and zero HOD condition
5. Determine TDO3 for any scenario by mapping projected DO with existing temperature profile

To determine HOD for current conditions, profiles of temperature and dissolved oxygen were assessed at the primary station in each basin (LCO-2 in West, LCO-3 in Central, and LCO-4 in East). The greatest rate of change in temperature with depth was used to identify the start of the hypolimnion. Average hypolimnetic dissolved oxygen concentrations were calculated at these locations for each date and station. Rates of hypolimnetic oxygen demand were then determined using linear regression on the time series of average hypolimnetic dissolved oxygen concentrations. Generally strong correlations were found, R^2 values were typically greater than 0.9). Resulting HODs for 2011-2015are presented in Table 10.

Table 10. Estimated HOD Values in LCO Basins.

Basin	2011		2012		2013		2014		2015	
	HOD mg/L/d	R^2	HOD mg/L/d	R^2	HOD mg/L/d	R^2	HOD mg/L/d	R^2	HOD mg/L/d	R^2
West	0.064	0.72	0.100	0.81	0.093	0.96	0.128	0.96	0.170	0.90
Central	0.093	0.99	0.092	0.95	0.103	0.98	0.134	0.99	0.128	0.97
East	0.109	0.98	0.102	0.97	0.072	0.96	0.095	0.99	0.120	0.98

Using Equation 1 above, the calculated current HOD ($HOD_{present}$) from Table 10, and the average total phosphorus concentration ($TP_{present}$) from Table 5, an adjusted HOD (HOD_{future}) can be predicted for each basin for a specified year at an assumed reduction in total phosphorus (TP_{future}). The reduced HOD can then be used to scale the DO profile between the existing condition and the zero HOD condition using Equation 2. An Excel spreadsheet was developed to perform the calculations and create the adjusted DO profiles. The spreadsheet also calculates an estimate of the new TDO3 at the reduced total phosphorus concentration, as well as an estimate of the increase in suitable habitat volume and vertical band. These results are presented in Figure 26, Figure 27 and Figure 28 below for each basin using 2012 profiles at the time of critical or highest TDO3.

The results show that improvements in TDO3 and suitable habitat are gradual in the West Basin until total phosphorus is below 8 µg/L when dramatic improvements are simulated. Reductions below 6 µg/L result in no further improvement. Improvements in the Central Basin with reduced phosphorus are gradual until about 9 µg/L, and then improve at a faster rate down to 4 µg/L after which no further improvements are simulated. In the East Basin gradually increasing improvements are simulated down to 6 µg/L with dramatic improvements between 6 µg/L and 5 µg/L, and then no further improvments below 5 µg/L.

Based on these results, reducing total phosphorus concentrations to between 6 and 8 µg/L would lead to significant improvement in cisco and whitefish habitat. However, more modest reductions to 10 µg/L result in meaningful improvement which could mean the difference between sustaining a coldwater fishery or losing it. Reducing phosphorus from existing concentrations to 10 µg/L in the West Basin results is a 19% increase in habitat volume. Also, climate change impacts are anticipated to lead to additional stress on the coldwater habitat, as discussed in the next section. Therefore, efforts to hold-the-line and reverse the trend become critically important.

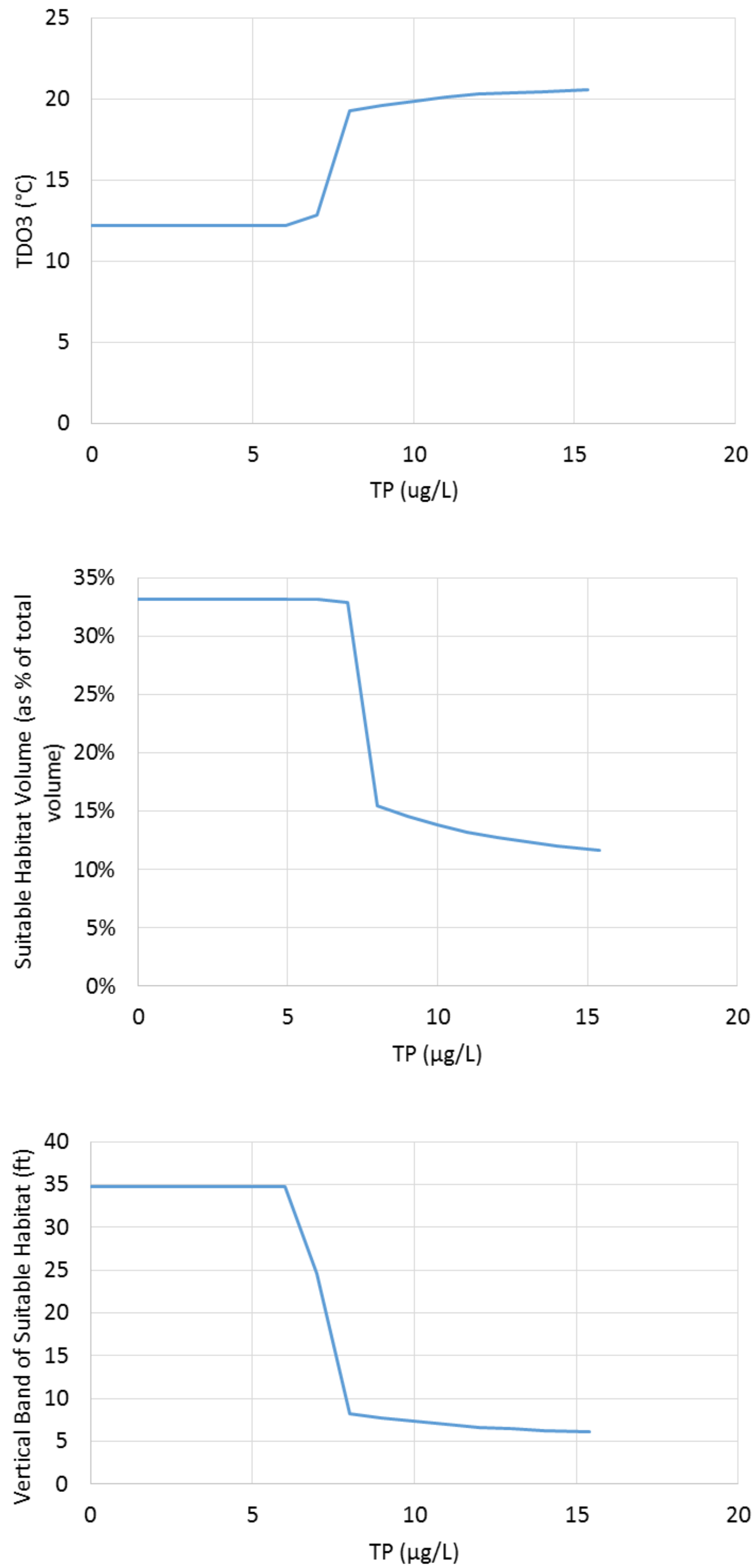

Figure 26. Estimates of improved TDO3 and suitable habitat at reduced phosphorus concentrations in the West Basin, September 5, 2012 conditions.

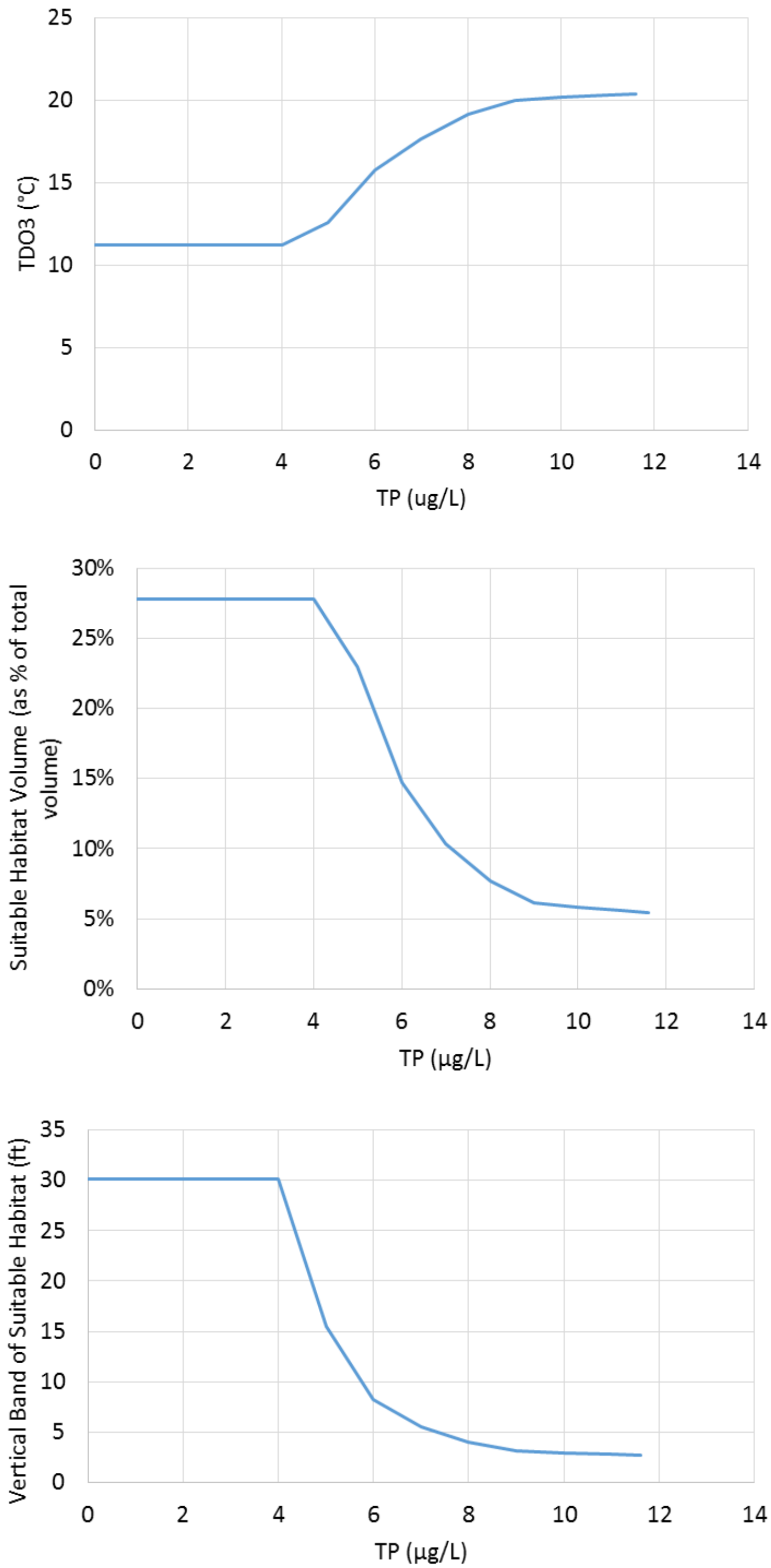

Figure 27. Estimates of improved TDO3 and suitable habitat at reduced phosphorus concentrations in the Central Basin, August 13, 2012 conditions.

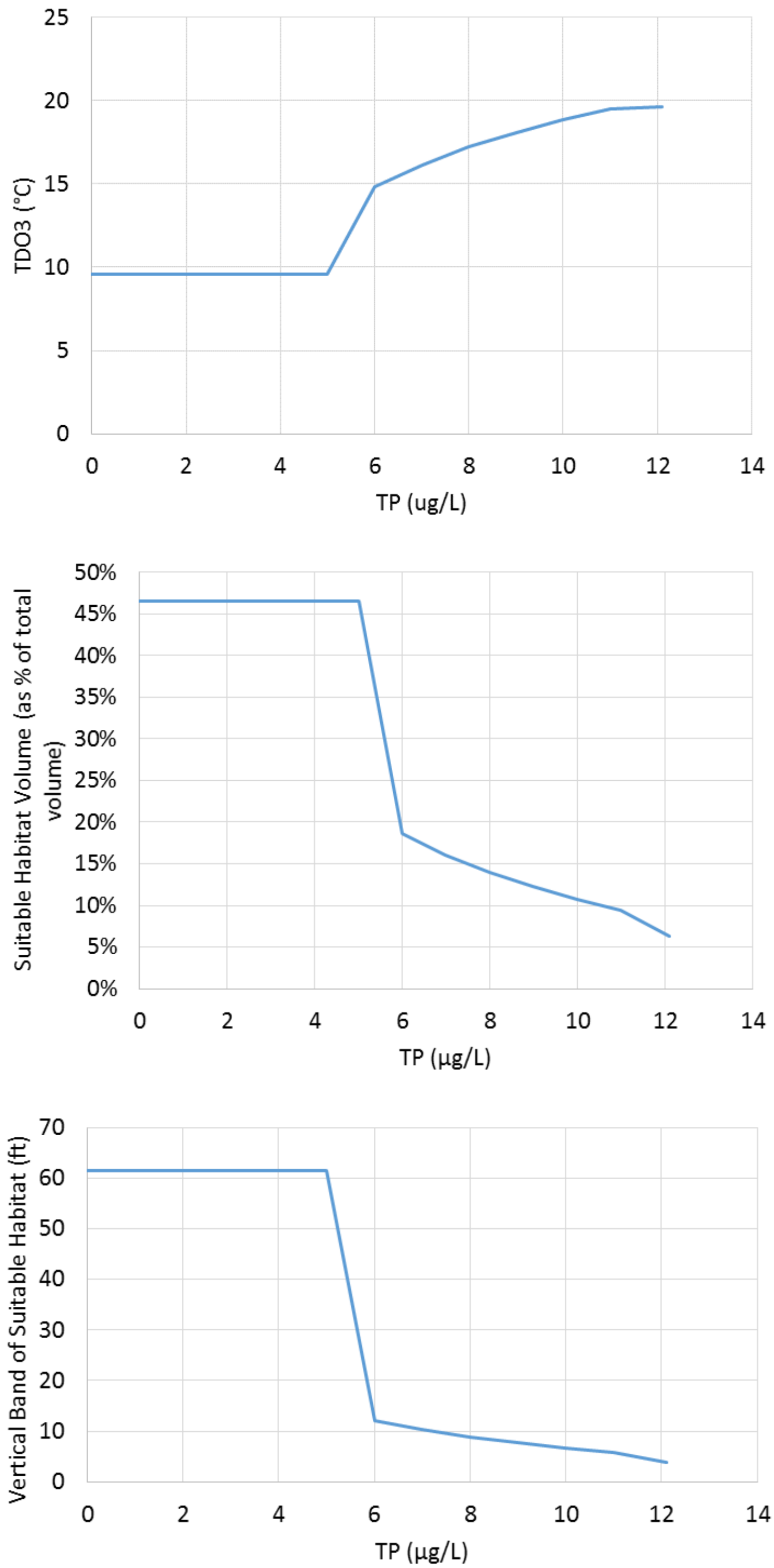

Figure 28. Estimates of improved TDO3 and suitable habitat at reduced phosphorus concentrations in the East Basin, September 5, 2012 conditions.

Blank Page

8
Management for Climate Change

Climate change poses very real present and future threats to LCO's cold-water fishery. According to the Wisconsin Initiative for Climate Change Impacts (WICCI, 2011), northwest Wisconsin has experienced the largest gains across the state in growing season length, approximately two to three weeks since 1950 (see Figure 29); the largest increases in winter temperatures (up to 4.5 degrees F); and the largest increases in springtime temperatures of about 3.5 degrees F. In northern Wisconsin, mean annual air temperature is predicted to increase by 2.7 to 12.6 degrees F by 2100 (IPCC 2013; Palmer et al., 2014).

The WICCI report also concluded that between 1950 and 2006, northwest Wisconsin had increasing dry periods along with an increase in the number of intense precipitation events. The new National Oceanic and Atmospheric Administration (NOAA) Atlas 14 for Wisconsin (NOAA, 2013) estimated that the 24-hour storm with annual to 100 year recurrences ranged from 2.12 inches to 6.74 inches The magnitude of back-to-back storms occurring over two to ten day periods ranged from 2.8 to 4.5 inches (annually) to 4.56 to 6.73 inches (every 10 years). Hence, the wet periods can be expected to produce substantial runoff to LCO.

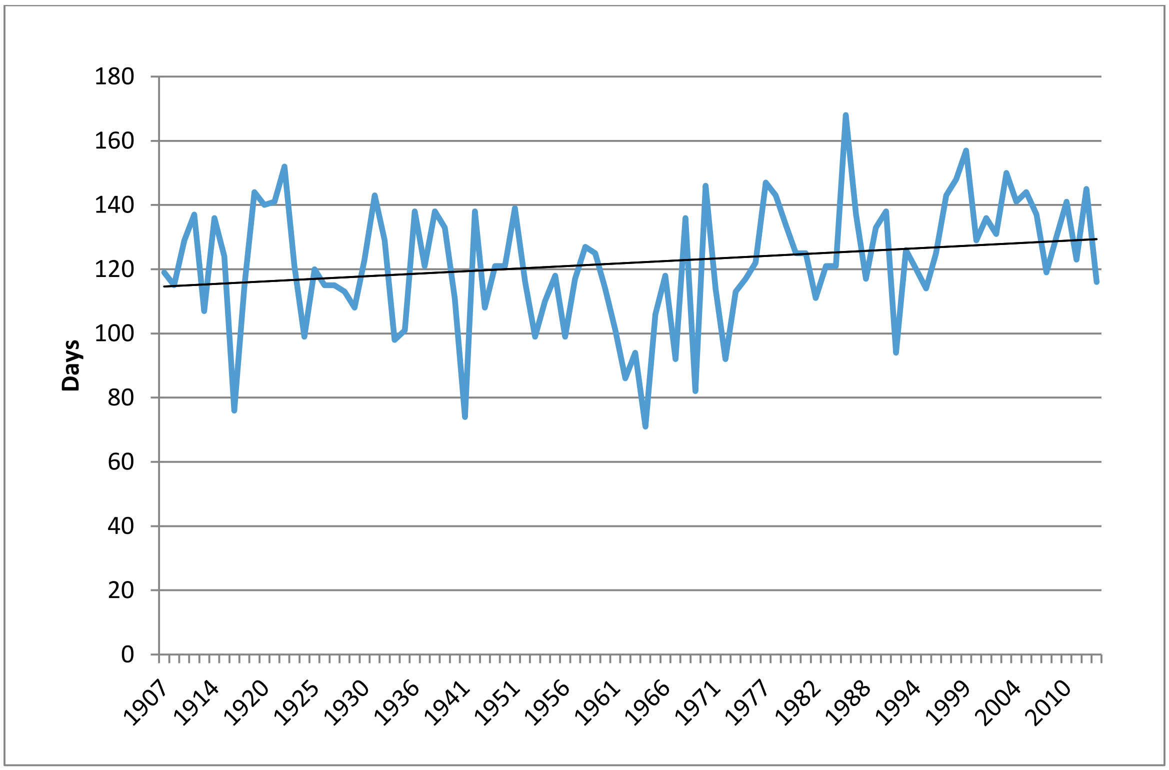

Figure 29. Growing season length for Spooner, Wisconsin (USC00478027)

8.1 Climate Change Effects on Hypolimnetic Dissolved Oxygen

Increased air and surface water temperature can lead to an earlier onset of stratification, which lengthens the summer stratification period (Sharma et al., 2011; Palmer et al., 2014). Additionally, increased average fall air temperature can delay turnover events. In Lake Mendota (Madison, Wisconsin), one study predicted that a 3-6°C increase in average fall air temperature would likely delay fall turnover by 5-10 days (Robertson and Ragotzke, 1990). These conditions can lead to a deeper, more stable thermocline and result in prolonged periods of hypoxic or anoxia conditions in the hypolimnion (Foley et al., 2012; Palmer et al., 2014).

In LCO, low hypolimnetic dissolved oxygen (≤ 6 mg/L) has been measured on multiple occasions in Musky Bay, Stuckey Bay, West Basin, Central Basin, East Basin and the Northeast Bay (2002-2013). Elevated total phosphorus in Musky Bay has contributed to nuisance algal growth leading to loss of beneficial uses and listing on the 2012 303 (d) impaired waters list. Progression to eutrophication through elevated total phosphorus inputs can be expected in this mesotrophic system, which would exacerbate current hypolimnetic dissolved oxygen conditions and likely amplify the complex effects of climate change in LCO.

8.2 Predicted Effects on Cisco and Lake Whitefish Populations

Late summer and early fall conditions can be particularly critical for cold water fisheries. As surface waters warm and hypolimnetic dissolved oxygen decreases, suitable habitat for cold-water fish like cisco and whitefish becomes squeezed (Fang et al., 2010). These conditions can lead to summertime fish kills and decreased growth rates for cisco (Sharma et al., 2011). Cisco have been studied as a sentinel of climate change and is a species of concern in Wisconsin (Sharma et al., 2011). A 5°C increase in mean annual air temperature in Wisconsin is projected to reduce cisco populations by as much as 50%. Loss of habitat through warmer waters and lower dissolved oxygen has resulted in declining cisco populations in several northern Wisconsin lakes (Sharma et al., 2011). Furthermore, increased rates of organic matter deposition driven by eutrophication can be devastating to cold water fisheries that depend on cold, well-oxygenated hypolimnetic waters for refugia during summer stratification (Jacobson et al., 2010).

Considering both increased air temperatures predicted by global climate models and potential land use changes, Herb et al. (2014) predicted most high quality cisco lakes will shift to lower quality yet suitable or adequate habitat, and about half of the adequate habitat lakes will shift to marginal habitat.

If cold water fisheries are not managed with consideration of these issues, many cisco and whitefish populations in this region may face extirpation by 2100 as a result of ongoing climate change (Sharma et al., 2011). As discussed in Section 5.2 of this report, whitefish are even more sensitive to changes in temperature and dissolved oxygen conditions than cisco, as they prefer colder waters. Climate change impacts to whitefish would therefore be greater than those predicted for cisco. As lake productivity is influenced by nutrient inputs from the surrounding landscape, management actions to reduce excessive nutrient inputs to cold water fisheries may limit degradation of suitable habitat for sensitive species.

9
Proposed SSC

A lake-wide average of **10 µg/L** is being proposed as the site-specific total phosphorus criterion for LCO in order to restore and protect the highest attainable aquatic life and recreational uses for this unique two-story fishery and ORW. This value must be applied to LCO in its entirety, including all of its natural basins and bays, which are one integrated aquatic system.

This SSC for LCO is based on multiple lines of evidence including the following:

1. Following commonly accepted limnological practice and terminology, the three basins (West, Central, and East) and the multiple bays comprise one lake referred to as Lac Courte Oreilles and are identified by one lake identification number (WBIC 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. Musky Bay's water quality has been degraded and designated beneficial uses have been impaired or threatened since passage of the federal Clean Water Act, even while the bay was meeting its WDNR-applied 40 µg/L total phosphorus criterion;
    a. The recreational use of Musky Bay has been determined to be impaired;
    b. The stratification status of Musky Bay should be regarded as "deep" based on temperature profiles collected in the bay;
    c. Depressed dissolved oxygen levels in muskellunge spawning areas of Musky Bay are likely negatively impacting muskellunge egg and larvae survival;
4. Musky Bay has a direct connection to LCO and, therefore, it has a significant influence on water quality in the West Basin, and subsequently influences other portions of the lake;
5. 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 and reduced oxythermal habitat for cold water fish, indicating negative impacts to the cisco and lake whitefish fishery in LCO which subsequently threatens to impair the trophy muskellunge, northern pike and walleye fishery and also threatens to impair tribal subsistence uses of those fisheries;
6. Evidence of significant increases in phosphorus loading to LCO since 1940, with accelerating increases in the mid-to late 1980s and early 1990s, based on the sediment diatom record; and
7. The need to proactively protect against future degradation due to climate change.

Ultimately, phosphorus loading to LCO must be reduced to restore the water quality and biologic conditions in this unique ORW. The threat of negative impacts from climate change heightens this need.

Blank Page

10 References

Birks, H.J.B. , J.M Line, S. Juggins, A.C. Stevenson, and C.J.F. Ter Braak. 1990. Diatoms and pH Reconstruction. *Phil. Trans. R. Soc. Lond. B* 327, 263-278.

Chapra. S.C. and R. P. Canale. 1991. Long-Term Phenomenological Model of Phosphorus and Oxygen For Stratified Lakes. Wat. Res. Vol. 25, No. 6, pp. 707-715. http://deepblue.lib.umich.edu/bitstream/handle/2027.42/29315/0000380.pdf?sequence=1

Dombeck, M.P, B.W. Menzel and P.N. Hinz. 1984. Muskellunge Spawning Habitat and Reproductive Success. Transactions of the American Fisheries Society, 113:2, 205-216.

Fang X., S.R. Alam, L. Jiang, P. Jacobson , D. Pereira and H. Stefan. 2010. Simulations of Cisco Fish Habitat in Minnesota Lakes Under Future Climate Scenarios. Project report No. 547 prepared by the University of Minnesota St. Anthony Falls Laboratory for the Minnesota Department of Natural Resources.

Fitzpatrick, F.A., P.J. Garrison, S.A Fitzgerald, and J.F. Elder. 2003. Nutrient, Trace-Element, and Ecological History of Musky Bay, Lac Courte Oreilles, Wisconsin, as Inferred from Sediment Cores. U.S. Geological Survey Water-Resources Investigations Report 02-4225.

Foley, B., I.D. Jones, S.C. Maberly, and B. Rippey. 2012. Long-term changes in oxygen depletion in a small temperate lake: effects of climate change and eutrophication. Freshwater Biology, 57, 278-289.

Garrison, Paul. 2014. Report on Sediment Core Analysis from Lac Courte Oreilles, Sawyer Co. WI Towards Estimating Historical Phosphorus Concentrations. Wisconsin Dept. of Natural Resources.

Garrison, Paul. May 2014. Wisconsin Department of Natural Resources. Personal communication with Virginia Breidenbach.

Harmony Environmental. 2007. Macrophyte Survey Musky Bay-Lac Courte Oreilles.

Heiskary, Steven A. and C. Bruce Wilson. 2005. Minnesota Lake Water Quality Assessment Report:

Heiskary, Steven and Bruce Wilson. 2008. Minnesota's Approach to Lake Nutrient Criteria Development. *Lake and Reservoir Management* 24:282-297, 2008.

Herb, W.R., L.B. Johnson, P.C. Jacobson, and H.G. Stefan. 2014. Projecting cold-water fish habitat in lakes of the glacial lakes region under changing land use and climate regimes. *Canadian Journal of Fisheries and Aquatic Sciences* 71: 1334-1348.

Intergovernmental Panel on Climate Change (IPCC). 2013. Summary for Policymakers. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the fifth assessment report of the IPCC. Cambridge University, Cambridge.

Jacobson, P.C., T.S. Jones, P. Rivers and D.L. Pereira. 2008. Field Estimation of a Lethal Oxythermal Niche Boundary for Adult Cicoes in Minnesota Lake. *Transactions of the American Fisheries Society*, 137:5, 1464-1474, DOI: 10.1577/T07-148.1.

Jacobson P.C., H.G. Stefan and D.L. Pereira. 2010. Coldwater Fish Oxythermal Habitat in Minnesota Lakes: Influences Of Total Phosphorus, July Air Temperature, and Relative Depth. *Canadian Journal of Fisheries and Aquatic Sciences* 67(12), 2003-2013.

Johnson, L. D. 1981. Comparison of muskellunge (Esox masquinongy) populations in a stocked lake and unstocked lake in Wisconsin, with notes on the occurrence of northern pike (Esox lucius). Wisconsin. Dept. of Natural Resources Research Report 110.
http://digital.library.wisc.edu/1711.dl/EcoNatRes.DNRRep110

Johnson, L. 1986. Population Dynamics of Stocked Adult Muskellunge (Esox Masqinony) in Lac Courte Oreilles, Wisconsin, 1961-77. Wisconsin Department of Natural Resources, Tech Bulletin No. 160; 12 pages.

Kampa, Jeff. January 2014. Wisconsin Department of Natural Resources. Personal communication with Frank Pratt.

Lyons, J., J. Kampa, T. Parks, and G. Saas. 2015. The Whitefishes of Wisconsin's Inland Lakes: The 2011-14 WDNR Cisco and Lake Whitefish Survey. WDNR Fisheries and Aquatic Research Station; 18 pages.

Murphy, E.L. 2009. Contemporary Muskellunge Genetic Resources in Northern Wisconsin: Impacts of Supplemental Stocking and Genetic Management Zones. Masters Thesis. University of Wisconsin-Stevens Point.

National Oceanic and Atmospheric Agency (NOAA). 2013. NOAA Atlas 14 Precipitation-Frequency Atlas of the United States Volume 8 Version 2.0: Midwestern States (Colorado, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Oklahoma, South Dakota, Wisconsin). http://hdsc.nws.noaa.gov/hdsc/pfds/index.html

Nordin, R.K. 1986. Nutrient water quality criteria for lakes in British Columbia. Lake and Reservoir Management. 2:110-113.

Nurnberg, G. K. 1996. Trophic state of clear and colored, soft-and hardwater lakes with special consideration of nutrients, anoxia, phytoplankton and fish. J. Lake and Reserv. Manage. 12(4):432-447.

Palmer M.E., N.D. Yan and K.M. Somers. 2014. Climate Change Drives Coherent Trends in Physics and Oxygen Content in North American Lakes. *Climatic Change* doi:10:1007/s10584-014-1085-4

Pratt, Frank. 2013. Loss of Beneficial Uses, Musky Bay, Lac Courte Oreilles.

Pratt, Frank. May 2014. Personal communication with Virginia Breidenbach.

Pratt, F. B. and D. Neuswanger. 2006. Lac Courte Oreilles Fishery Plan. Wisconsin Department of Natural Resources; 18 pages.

Robertson D.M. and R.A. Ragotskie. 1990. Changes in the Thermal Structure of Moderate to Large Sized Lakes in Response to Changes in Air Temperature. *Aquatic Science* 52: 360-380.

Schupp, D. and C.B. Wilson. 1993. Developing lake goals for water quality and fisheries. LakeLine. December, 1993. pp. 18-21.

Sharma S., M. Jake Vander Zanden, J.J. Magnuson and J. Lyons. 2011. Comparing Climate Change and Species Invasions as Drivers of Coldwater Fish Population Extirpations. *PLos ONE* 6(8): e22906. doi: 10.1371/journal.pone.0022906.

Stantec. 2012. 2012 Aquatic Plant Management Report for Lac Courte Oreilles. Cottage Grove, Wisconsin. Dec. 18, 2012 Report to COLA.

Tyrolt, Daniel D. 2011. Lac Courte Oreilles Lake Aquatic Plant Management Plan, Sawyer County, WI. WIBC: 2390800.

University of Wisconsin Extension (UW Extension). 2013. Aquatic Invasive Species Education Handbook. PDF file in www.uwex.edu. Chapter 7-Species Information.

Wilson, C. Bruce. 2010. Lac Courte Oreilles Economic Survey and Assessment. Prepared for the Wisconsin Department of Natural Resources under a Lake Management Grant to the Courte Oreilles Lakes Association.

Wilson, C. Bruce. 2011. Lac Courte Oreilles Lake Management Plan.

Wisconsin Administrative Code (WAC). 1993. Department of Natural Resources Chapter NR 102 Water Quality Standards for Surface Waters. https://docs.legis.wisconsin.gov/code/archive/1993/449b/insert/nr102.pdf.

Wisconsin Department of Natural Resources (WDNR). 2010. Wisconsin Phosphorus Water Quality Standards Criteria: Technical Support Document.

Wisconsin Department of Natural Resources (WDNR). 2012. Summary of Public Comments and WDNR Responses, 2012 Impaired Waters List. Second Round of Public Comments. http://dnr.wi.gov/water/wsSWIMSDocument.ashx?documentSeqNo=81199923

Wisconsin Department of Natural Resources (WDNR). 2013. Wisconsin 2014 Consolidated Assessment and Listing Methodology (WisCALM) for Clean Water Act Section 305(b), 314, and 303(3) Integrated Reporting. September 2013. http://dnr.wi.gov/topic/surfacewater/documents/2014/2014WisCALM.pdf

Wisconsin Department of Natural Resources (WDNR). 2014. Site-Specific Criteria Framework for Wisconsin. Draft. April 15, 2014.

Wisconsin Department of Natural Resources (WDNR). 2014b. TDO3 – An outline of a potential DO metric for Two-Story Fishery Lakes, using Lac Courte Oreilles (LCO) as an example. Draft. December 1, 2014.

Wisconsin Department of Natural Resources (WDNR). 2015. Wisconsin 2016 Consolidated Assessment and Listing Methodology (WisCALM) for CWA Section 303(d) and 305(b) Integrated Reporting. Guidance # 3200-2015-01. March 26, 2015.

Wisconsin Initiative for Climate Change Impacts (WICCI). 2011. Wisconsin's Changing Climate: Impacts and Adaptations. http://www.wicci.wisc.edu/report/2011_WICCI-Report.pdf

Zorn, Sarah A., Terry L. Margenau, James S. Diana & Claton J. Edwards, 1998. The Influence of Spawning Habitat on Natural Reproduction of Muskellunge in Wisconsin, Transactions of the American Fisheries Society, 127:6, 995-1005.