Lac Courte Oreilles Lake Management Plan

C. Bruce Wilson
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Executive Summary

This report and its companion effort "Lac Courte Oreilles Economic Survey and Assessment", have been prepared for the Wisconsin Department of Natural Resources via Lake Planning Grants awarded to the Courte Oreilles Lakes Association (COLA).

Lac Courte Oreilles (LCO) with its four main bays and Little Lac Courte Oreilles, are regionally exceptional lakes in terms of their size, water quality, including LCO's historical two story fishery and general habitat. These same qualities make these lakes sensitive to: (1) discharges from cranberry operations; (2) watershed land uses that increase loads of phosphorus, sediment and organic-laden waters; (3) effects of variable climate; and (4) non-native invasive infestations such as curly leaf pondweed. All of these factors mean LCO will be extremely sensitive to phosphorus (P) and organic loading (e.g. turbid runoff from urban and agricultural sources) that can induce internal lake sediment P recycling mechanisms, and hence, several actions are being recommended. If degraded, rehabilitation measures will be extremely difficult and prohibitively expensive to implement.

Variable climate has been noted over the past two decades, going from relatively wet years (1996 and 2002) to drought conditions (2005-2009), intense storms, reduced stream flows and longer growing seasons. Over the past 40 years, there has been a declining regional runoff pattern (about 18% less) for the Chippewa River at Winter, WI. Recent years have seen a dramatic increase in the number of tornados with tornados noted in Wisconsin 46 including the rare November 22, 2010and about 125 noted in adjacent Minnesota in 2010.

The 'Northwood Charm' is a significant, in a business sense, 'product', of the region. Competing for and sustaining future travel and tourism will be dependent upon maintaining the quality of the product, otherwise discretionary travel dollars will be spent elsewhere. And in a long-term business sense, this will require re-investing in forested land areas and restoring and protecting the water assets that cover 84% of the LCO watershed. The intensity of stormwater runoff and future development pressures will require additional proactive operation and maintenance rather than an 'it will take care of itself approach'.

Key challenges include maintaining forests & waters in an increasingly variable climate with droughts, fires, wet periods, intense storms (damage, erosion and shock loads to lakes and streams) and longer growing seasons. A balance must be achieved between limiting the amount of pollutants flowing into waters and conflicting water uses (e.g. cranberry discharges and development) so the lakes stay healthy and maintain present beneficial uses. This will mean (1) working with the owners to eliminate cranberry operation discharges; (2) enforcement of existing land use ordinances and minimizing variances for nonconforming structures and practices (Losing our lakes: Part 1. Rules skirted and lakes under attack, Minneapolis Star Tribune, July 6, 2010); (3) buffering 100% of the LCO shoreline; (4) installation, and maintenance and oversight of agricultural and forestry Best Management Practices (BMPs); and (5) adopting new low impact development ordinances to treat stormwater from new development runoff on site. Stormwater volume control standards have the most promise of minimizing stormwater runoff by requiring new developments to treat runoff from impervious surfaces on-site via infiltration, storage, or reuse.

As land is converted from forest into urban or agricultural land uses, there will be an increased loss of nutrients and sediments to the lakes. For comparison, present day average watershed total phosphorus in runoff typically contains very low levels (on the order of 10-40 parts per billion) versus much higher concentrations in agriculture and urban runoff (on the order of 150 – 600 parts per billion). The cumulative effects of the pounds of phosphorus reaching LCO is significant as each part per billion increase in LCO average summer total phosphorus can result in a loss of about one foot of average summer water clarity, particularly in the deep LCO bays. For example, increasing average summer total phosphorus from 9 to 15 ppb can translate into a loss of transparency of about 6 feet (e.g. average Secchi would drop from ~18 feet to 12.5 feet) based on regional phosphorus:Secchi relationships.

In sum, variable climate, as defined in this Plan, can be expected to generally favor lake degradation patterns unless additional management actions are taken. The non-native infestations, such as Curly Leaf Pond Weed (CLPW) will be a growing issue. New challenges from other infestations of LCO's lands and waters will require vigilance, monitoring and actions.

Water Quality Goals for Lac Courte Oreilles

For the purpose of providing definitive objectives that will drive COLA lake management strategies and activities, COLA should establish the following water quality goals for Lac Courte Oreilles:

Classification and One Lake Determination

a. Classification

Pursuant to Wisconsin Rule NR 102, Lac Courte Oreilles is: 1) a stratified two story lake/fishery and 2) is classified as an Outstanding Resource Water (ORW). COLA has and will continue to undertake lake management strategies and activities that will maintain these classifications.

The anti-degradation provisions of state and federal statutes and rules will be relied upon to serve as the legal framework that will drive COLA lake management actions intended to maintain the current NR 102 classifications.

b. One Lake Determination

COLA intends that the NR 102 classifications and associated applicable water quality criteria, standards and the goals set forth in this Lake Management Plan be uniformly and equally applied to all the natural bays of LCO. To assume that LCO bays are separate upland lakes that drain into LCO via streams, ignores inter-bay advection and dispersive mixing. Assigning higher upland P standards to Musky Bay could also result in assignment of the same standards to Stuckey Bay and perhaps NE Bay, that will directly cause degradation of the open-water connected deeper bays. There can be no effective P management in west, central and east bays without control of smaller bay phosphorus levels. Hence, COLA will resist any efforts or interpretations that attempt to distinguish one LCO bay from another for the purposes of setting and applying water quality classifications, criteria, standards and goals. Lac Courte Oreilles is one lake and must be managed accordingly.

Total Phosphorus

c. **Lac Courte Oreilles**
   The long term total phosphorus goal for all natural bays of LCO is 10 +/- 2 parts per billion (ppb). Achieving the long term goal will rely upon anti degradation management actions.

d. **Musky Bay**
   As a result of excessive phosphorus loading, Musky Bay has much higher total phosphorus concentrations than the rest of LCO. To reverse the degradation of Musky Bay will require establishment of both short and long term total phosphorus goals for the bay. Therefore, the short-term total phosphorus goal for Musky Bay is 20 ppb. COLA intends to take those lake management actions necessary to achieve the short term goal by 2016. The long-term goal for total phosphorus for Musky Bay is 10+/-2 ppb.

Lac Courte Oreilles Lake Management Plan

In order to achieve the specified water quality goals of maintaining LCO's current water quality into the future, COLA must address five management areas over the coming decades. The five management areas are: 1) cranberry discharges; 2) changing land uses in the LCO watershed; 3) LCO shore land development and buffer areas; 4) invasive species management; and 5) lake and stream monitoring. COLA intends to take the following specific actions to address the five management areas.

1. **Cranberry Discharges**
   a. COLA will work with the three cranberry growers on LCO to eliminate their discharges of organic and phosphorus loading to LCO.
   b. To reduce sediment phosphorus recycling in Musky Bay and to a lesser extent in Stuckey Bay, COLA will investigate and determine if dredging and/or alum or iron chemical treatment would be effective in reducing sediment phosphorus recycling in the two bays.
   c. COLA will work with the LCO Band of Ojibwe and WDNR to develop and implement a plan of action to re-establish muskellunge spawning habitat in Musky Bay.

2. **Changing Land Use in the LCO Watershed**
   a. COLA will evaluate formation of a lake management district to advance long-term improvement and protection of LCO water quality and associated economic resources.
   b. COLA will seek to acquire lands on the south side of LCO's east bay where intensive agriculture is practiced within the LCO direct drainage area.
   c. COLA, working closely with the LCO Band of Ojibwe will seek to acquire land and easements along Osprey Creek. Osprey Creek drains through the heart of present-day and likely future new urban and agricultural areas, land use in this part of the LCO watershed will play a prominent part in the future of LCO water quality.. Maintenance of wetlands and creek buffer areas are a high priority with COLA.
   d. COLA will work with other affected lake associations, Sawyer County, LCO Band of Ojibwe, WDNR and land owners to implement forest Best Management Practices (BMPs) within the LCO watershed.

e. COLA will work with other affected lake associations, Sawyer County, LCO Band of Ojibwe and WDNR to monitor and advance agricultural BMPs for row crop and animal operations within the LCO watershed (particularly operations on the west side of LCO), including providing cost share for innovative approaches that may not be covered by existing state and federal programs.

f. Runoff from new development can be largely prevented with the adoption of stormwater volume control practices via the use of low impact development techniques and better site designs. COLA will work with other affected lake associations, Sawyer County to adopt a county low impact development ordinance that applies to the LCO watershed. The county ordinance should include the following requirements:

    i. The first 1.25 inches of runoff from new development impervious surfaces should be required to be treated on site. Nearly two-thirds of the LCO watershed soils have reasonably high infiltration capacity (e.g. Hydrologic Soil Group A & B soils). Using these soils for infiltration & on-site treatment can be accomplished by a variety of techniques such as pervious pavers/pavement, native vegetation and rain gardens while placing more impervious surfaces on the lesser infiltrating C and D soils.

    ii. New developments should be required to minimize soil compaction practices and in D soils, minimal soil disturbance practices should be required during construction along with requiring better site designs that preserve forest and stream buffer areas.

3. **LCO Shoreland Development and Buffer Areas**:
    a. COLA will support the Sawyer County shore land development ordinances by actively reviewing and taking a position on all variance requests that affect LCO.
    b. COLA will work with Sawyer County and WDNR to achieve establishment of shoreline buffer zones on 100% of LCO lake shore properties. Continuing education of shore land owners of the importance of shore land buffering is a high priority for COLA.
    c. COLA will work with Sawyer County to develop periodic surveys of all LCO's on-site treatment systems for compliance with septic system requirements.

4. **Invasive Species Management:**
    a. COLA will continue to work with the LCO Band of Objibwe, Sawyer County, and the WDNR to carry out herbicide treatments to control the curly leaf pondweed infestations in LCO.
    b. COLA will maintain the Clean Boat Program. Additional control measures will be needed to prevent and minimize new invasive infestations such as Viral Hemorrhagic Septicemia and zebra mussels. In addition COLA will investigate new approaches such as consideration of boat washing stations above the access ramps for incoming and outgoing boat cleaning.
    c. COLA will work with Sawyer County via the forest management plan and assist in tracking of forest invasive species such as the European night crawler <u>Lumbricus terrestris</u>. This night crawler can alter forest floor conditions dramatically causing increased water and nutrient runoff. Sawyer County ordinances may also be considered prohibiting disposal of bait night crawlers.

5. Lake and Stream Monitoring

a. COLA will consider additional monitoring of lake outlet and primary inlet stream (Grindstone Creek, Whitefish Creek and Osprey Creek) volumes and sampling to better define annual loading rates, water flow patterns and better estimate the magnitude of groundwater influence on LCO. Detailed monitoring recommendations have been provided in the Recommendations of this Lake management Plan
    i. Contract with the USGS to begin gauging LCO's outlet and Osprey Creek in cooperation with the LCOCD and local partners. Other water monitoring recommendations have been detailed in the last part of the Plan.

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b. Work with other lake associations in the watershed to have Secchi disk transparency monitoring conducted on each lake, particularly Durphee, Osprey, Grindstone, Sand, and Whitefish Lakes.

c. COLA will assist the Tribe to insure that 10-12 paired TP, chl-a, DO/temp measurements and Secchi readings are taken in accordance with the Tribes sampling plan during each growing season (May to October)

Introduction

Courte Oreilles Lakes Association (COLA) is focused on efforts to reduce pollution, particularly phosphorus pollution, protect and restore critical habitat, research water quality issues and protect the water quality of Big and Little LCO. This report and its companion effort "Lac Courte Oreilles Economic Survey and Assessment" have been prepared for the Wisconsin Department of Natural Resources by Lake Planning grants awarded to the Courte Oreilles Lakes Association (COLA).

Lac Courte Oreilles (LCO), located in Sawyer County, is Wisconsin's eighth largest natural lake (Pratt, 1977), has been classified as an oligotrophic lake (Garrison and Fitzgerald, 2005), covering 5,039 acres and represents about 9% of the County's lake acreage. The LCO watershed is located in the Northern Lakes and Forest ecoregion and lies in Sawyer County with a small portion extending into Washburn County. Native soils consist of sandy loam, sand and silts with native vegetation consisting of deciduous/hardwood and coniferous forests. Forests and water/wetland land uses cover over 84% of the LCO watershed with agriculture and urban land uses comprising about 4%, each, of the watershed.

Presently, there are three operating cranberry bogs that withdraw water from and discharge water to Stuckey Bay, Musky Bay and East bay of Lac Courte Oreilles, ranging in size from approximately 3 to 39 ha. Collectively the three operations cover an area of about 85 ha (or 212 acres). The two largest operations discharge to Stuckey Bay (about 39 ha or 97 acres) and Musky Bay (about 32 ha or 79 acres) with a smaller operation of about 7.5 acres discharging to the East bay. The two largest cranberry operations began about 1939 with expansions occurring between 1950 and 1962 and again in Musky Bay between 1980 and 1998 (Fitzpatrick etal, 2003).

Annual precipitation for the area averages about 34.5 inches with about one-half occurring in the growing season of June through September. Winter snow fall has typically been about 55 inches with considerable variability as regional values have varied from about 46 inches to 76 inches. Substantial wet and dry period variability is occurring with recent dry years (e.g. 2005 with 2009 with ~ 6+ inches below average rainfall) resulting in very low surface water flows. There are very few stream continuous flow monitoring stations in Northwest Wisconsin. The closest two stations were summarized and used as the basis for developing flow estimates for LCO and included : Chippewa River at Winter and Namekagon River at Leonards, Wisconsin. The Chippewa River (at Winter) had very low flows or about 3rd percentile in 2009. In contrast, 1996 had peak runoff (high flows) for the 40 year period.

LCO is a soft water (low alkalinity) lake with four main bays stretching approximately six and one-half miles in a predominantly southwest to northeast orientation. LCO has an overall mean depth of about 34 feet, a maximum depth of 92 feet and a shoreline length of 25.4 miles. Two of the lake's main tributaries, Grindstone and Osprey Creeks enter on the east bay along with Spring Creek on the south side. Whitefish Lake discharges into the southern side of central bay. The lake outlets from the east bay through a short passage to Little Lac Courte Oreilles, then to the Billy Boy Flowage, the Couderay River and then the Chippewa River. The outlet on Billy Boy Flowage is controlled by a dam with a head of about 3 m (10 feet) that raised historical water levels in the Billy Boy flowage by about 2 m (7 feet). Today, water levels in LCO , Little LCO and Billy Boy Flowage are quite similar (Fitzpatrick etal, 2003). Ultimately Lac Courte Oreilles flows into the Mississippi River at Lake Pepin.

Most water flows into and out of LCO through the east bay - except for bay-to-bay wind mixing. The central and west bays have much longer water residence times (e.g. estimated 5 and >100 years, respectively versus the east bay's estimated residence time of ~ 2 years during the dry year of 2009). This will tend to make the west and central bays more sensitive to runoff from direct drainage areas (shore land development, cranberry discharges, agriculture, and other urban development).

The LCO watershed at the lake outlet, covers 68,990 acres and includes other significant Wisconsin natural lakes: Round Lake (3,054 acres) and Grindstone Lake (3,116 acres) that drain into the east bay; and (2) Sand Lake (928 acres) and Whitefish Lake (786 acres) that drain into the central bay. The eastern ~half of the lake is located in the Lac Courte Oreilles Indian Reservation. LCO has an abundance of sports fisheries and is considered a two story fishery (meaning it supports both cold, cool and warm water fish species). Being a popular recreational resource it draws visitors from Wisconsin, Minnesota, Illinois and states as far away as Hawaii (Wilson, 2010).

There are no municipal wastewater discharges into streams or lakes of the watershed, however, there are three cranberry operations with pipe, culvert and ditch discharges directly into LCO Bays: two discharges into Musky Bay, one into Stuckey Bay, one into the west bay, and one into the east bay. In the past, Musky Bay, located in the southwestern portion of the Lake, supported musky spawning/rearing habitat and the legacy crop, wild rice back in the ~1920's.

Now, the nuisance exotic aquatic Curly leaf pondweed and algal masses can cover significant portions of Musky Bay. The US Geological Survey (Fitzpatrick etal, 2003) collected and assessed sediment cores from Musky Bay, Lac Courte Oreilles, and from surrounding areas and determined the water quality of Musky Bay has degraded during the last ~25 years with increased growth of aquatic plants and the onset of a floating algal mats. LCOCD and COLA are working with Sawyer County and the Wisconsin Department of Natural Resources (WDNR) to control curly leaf pondweed infestations in Musky Bay via chemical treatments. Curly leaf pondweed has spread beyond Musky Bay to other parts of the lake, that at this writing include Stuckey Bay, Barbertown Bay and the Grindstone channel.

Outstanding Resource Waters

Wisconsin's Outstanding Resource Waters (ORWs) include Grindstone Creek (trout), Grindstone Lake, Round Lake, Sand Lake, Whitefish Lake, Lac Courte Oreilles tributary at R39N R8W S5 and Lac Courte Oreilles. The following definition excerpts from the WDNR are provided:

- "Wisconsin has designated many of the state's highest quality waters as Outstanding Resource Waters (ORWs) or Exceptional Resource Waters (ERWs). Waters designated as ORW or ERW are surface waters which provide outstanding recreational opportunities, support valuable fisheries and wildlife habitat, have good water quality, and are not significantly impacted by human activities. ORW and ERW status identifies waters that the State of Wisconsin has determined warrant additional protection from the effects of pollution. These designations are intended to meet federal Clean Water Act obligations requiring Wisconsin to adopt an "antidegradation" policy that is designed to prevent any lowering of water quality – especially in those waters having significant ecological or cultural value."

- ORWs typically do not have any point sources discharging pollutants directly to the water (for instance, no industrial sources or municipal sewage treatment plants), though they may receive runoff from nonpoint sources. [Author's note nonpoint sources include crop/animal agricultural runoff and shoreland impervious surface/compacted soils runoff.] New discharges may be permitted only if their effluent quality is equal to or better than the background water quality of that waterway at all times—no increases of pollutant levels are allowed.
  http://dnr.wi.gov/org/water/wm/wqs/orwerw/ downloaded by CBW on 11/10/10.

Public Access

There are two public accesses on LCO (Appendix) with the WDNR site located on Highway K on Chicago Bay. This site has a double-wide concrete boat ramp, a barrier-free roll-out boarding dock, pit toilets, and a parking area for 50 car-trailer units

Fisheries

LCO is a two story fishery (Pratt, 1977) that has supported cold water species (trout), cool water species (tulibee) and warm water sports fisheries such as walleye, bass, and muskellunge. A recent WDNR strategic planning effort summarized in the document, "Fishery Management Plan Lac Courte Oreilles Sawyer County, Wisconsin" was completed by Pratt and Neuswanger (2006). This effort defined sports fisheries management strategies for muskellunge, smallmouth bass, walleye, black crappie, and northern pike.

The lake's littoral substrates are comprised of sand, gravel and rock except where replaced by soft organic muck in Musky and Stuckey Bays. Musky Bay was named for its historical significance as a muskellunge spawning area. In recent years, Musky Bay does not serve as a viable habitat for musky spawning due to the excessive organic matter and low oxygen concentrations along the bottom substrates (Pratt and Neuswanger, 2006). The LCO muskellunge genetic strain, widely propagated in Wisconsin and Minnesota waters, has been dramatically reduced in LCO due to loss of spawning habitat in Musky Bay and the introduction of the northern pike. LCO fish community characteristics were summarized by Pratt and Neuswanger with common species including smallmouth bass, yellow perch, bluegill and cisco.

Also noted to inhabit LCO were whitefish, white sucker, greater redhorse, bluntnose minnow, spottail shiner, blacknose shiner, and other small cyprinid species; trout perch, log perch, johnny darter, rainbow darter, and other small darter species; pumpkinseed, rock bass, longear sunfish, tadpole madtom, bullheads (black, yellow, and brown); slimy sculpin, longnose gar, and rainbow trout and brown trout**.** The later were documented by Pratt (1977) in 1976 fish surveys of LCO.

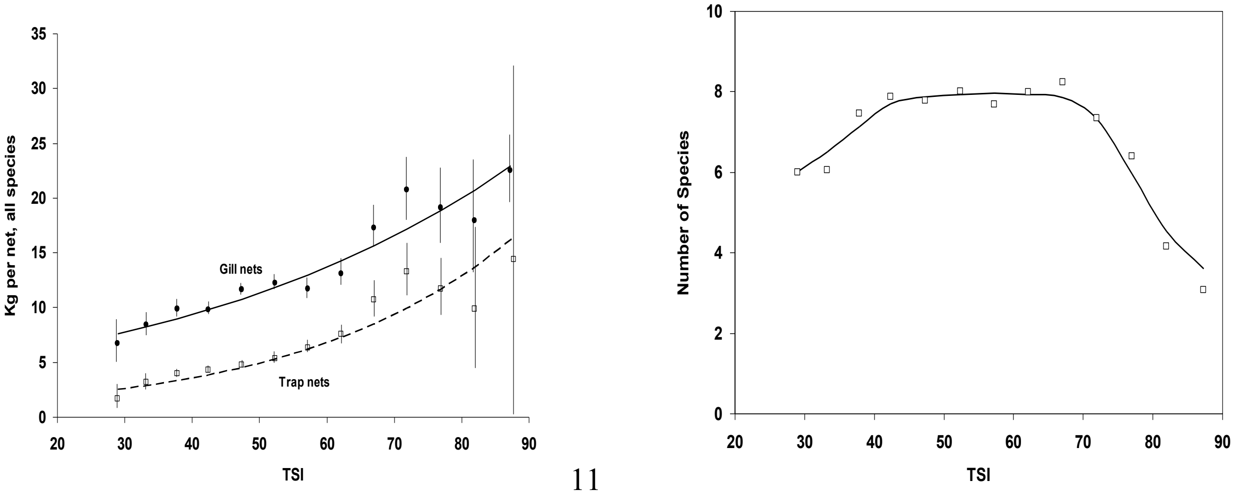
Studies have linked hypolimnetic oxygen depletion and phosphorus concentrations. Nordin (1986) proposed a range of surface average summer total phosphorus 5-15 ug P/L (or parts per billion or ppb) for the protection of coldwater fisheries. He noted that hypolimnetic oxygen depletions began when total phosphorus exceeded 10 ppb which is often used as the upper boundary for oligotrophy, along with chlorophyll-a concentrations less than 2 ppb and summer mean Secchi transparency of 4.5 m (14.8 feet). Two story fishery lakes generally

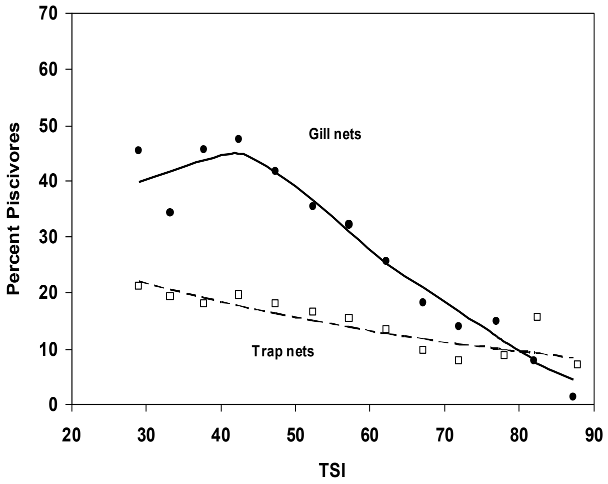
have average summer phosphorus less than 15 ppb with changes occurring when lakes exceed 10 ppb.
The influence of lake water quality upon fisheries has been examined by Schupp (1992), Schupp and Wilson (1993) as they compared the relative abundance and presence of various species and water quality as represented by trophic status index or TSI. The coldwater fishes: lake trout, whitefish and cisco exhibited peak abundance over a range of about 30-40 TSI (TP ~ 6-12 ppb). Lake trout were generally not observed in lakes with greater than ~17 ppb. Walleyes were abundant across a wider range of trophic state with abundance peaking at a TP range of about 12 – 24 ppb. Schupp and Wilson (1993) suggested that the best indicators of water quality are two of the three bullhead species with yellow bullheads found in the highest numbers in lakes with clear water. Black bullheads reach their highest abundance in very turbid eutrophic waters.

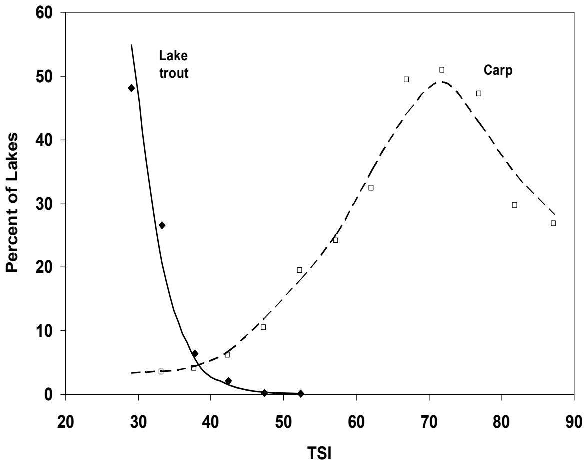
The relationships between piscivore species and lake TSI is depicted in Figure 1, which shows the number of species declining with TSI values greater than ~45. The relative abundance of northern pike and largemouth bass show a similar decline with increasing TSI values. The opposite relationship, however, was observed with carp, where relative abundance peaks at TSI values greater than ~70. These patterns reinforce lake management techniques that will return Musky Bay's clear water state for propagation of game fisheries while eutrophication favors the less desirable carp.

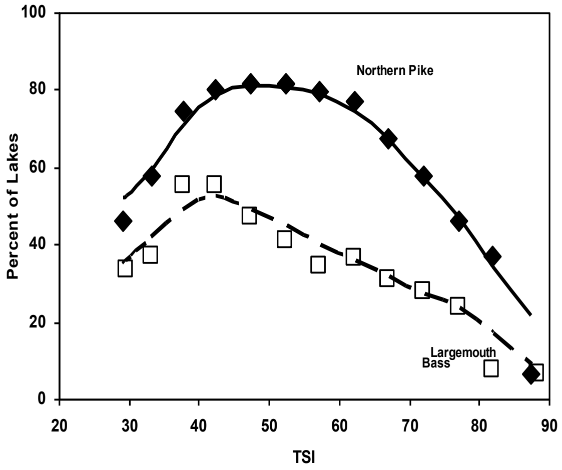
Eutrophication related oxygen depletion, warrants further consideration for effects upon natural recruitment of muskellunge in Musky Bay. As cited by Pratt and Neuswanger (2006), the LCO genetic strain of muskellunge deposit their eggs on the lake bottom and are dependent available oxygen along the sediment-water interface for survival. Eutrophic conditions may severely limit oxygen availability at this critical life cycle stage. Hence, lake management efforts should focus upon reducing P concentrations and other measures to increase muskellunge spawning habitat oxygen supply.

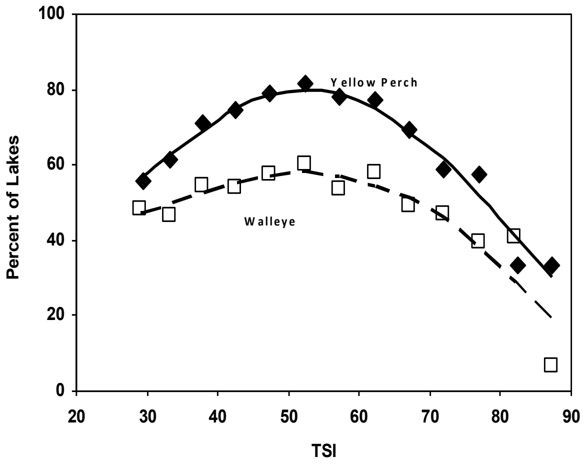
Figure 1. Lake Trophic Status and Fisheries
From Heiskary and Wilson, 2008. Relative fish abundance as compared to Secchi transparency-based lake trophic status (TSI). Derived from an analysis of MDNR fisheries records for 3,029 lakes (Schupp 1992). Graphics adapted from Schupp and Wilson (1993) and Schupp unpublished data: a) fish abundance vs. TSI; b) number of fish species vs. TSI; c) percent piscivorous fish vs. TSI; d) percent of lakes with lake trout and percent of lakes with carp vs. TSI; e) percent of lakes with northern pike and percent of lakes with largemouth bass vs. TSI; f) percent of lakes with yellow perch and percent of lakes with walleye vs. TSI.











Non-native Species Infestation Watch:
Zebra Mussels, Night Crawlers and Viral Hemorrhagic Septicemia.

Examples of exotic infestations to aquatic and terrestrial habitats are provided to indicate the scope of potential future threats to the watershed and not to provide a detailed list of potential infestations. Relatively recent infestation of curly leaf pondweed has rapidly expanded over larger portions of at least three LCO bays. Hence, resource management should be dedicated for evaluation, planning and implementation of measures to prevent, monitor and manage future outbreaks.

Zebra mussels

Dreissena polymorpha, is a small freshwater mussel that was originally native to the lakes of southeast Russia but has been spread through the Midwestern states including Wisconsin. Zebra mussels are very prolific and can spread quickly within a lake once introduced covering boats, docks and other substrates. Experts believe this invader has the potential to cause more economic damage than the Mediterranean fruit fly (Wisconsin Sea Grant, 2010) by affecting native species and influencing water quality.

Viral Hemorrhagic Septicemia, known as VHS, is a deadly infectious fish disease caused by the *Viral hemorrhagic septicemia virus* (VHSV, or VHSv). It afflicts over 50 species of freshwater and marine fish and is an ***invasive infection*** that has been associated with European fish farms. Viral Hemorrhagic Septicemia (VHS) is a deadly fish virus and an invasive species that is threatening Wisconsin's fish. VHS was diagnosed for the first time ever in the Great Lakes as the cause of large fish kills in lakes Huron, St. Clair, Erie, Ontario, and the St. Lawrence River in 2005 and 2006. Thousands of muskies, walleye, lake whitefish, freshwater drum, yellow perch, gizzard shad, redhorse and round gobies died. Many Chinook salmon, white bass, emerald shiners, smallmouth bass, bluegill, black crappie, burbot, and northern pike were diseased but did not die in large numbers."

"Infected fish shed the virus in their urine and reproductive fluids. The virus can survive in water for at least 14 days. Virus particles in the water infect gill tissue first, and then move to the internal organs and the blood vessels. The blood vessels become weak, causing hemorrhages in the internal organs, muscle and skin. Fish can also be infected when they eat an infected fish. Fish that survive the infection will develop antibodies to the virus. Antibodies will protect the fish against new VHS virus infections for some time. However, the concentration of antibodies in the fish will drop over time and the fish may start shedding virus again. This may create a cycle of fish kills that occurs on a regular basis."

"The virus grows best in fish when water temperatures are 37-54°F. Most infected fish will die when water temperatures are 37- 41°F, and rarely die above 59 °F. Stress is an important factor in VHS outbreaks. Stress suppresses the immune system, causing infected fish to become diseased. Stressors include spawning hormones, poor water quality, lack of food, or excessive handling of fish." From the WDNR website http://dnr.wi.gov/fish/vhs/vhsfacts.html

Forest Invasive: European Night Crawler

Invasions of the European earthworms, particularly the nightcrawler Lumbricus terrestris, have been noted to dramatically alter deciduous forests, by eating the duff, thus changing the type of seedbed, and the species of plants that can germinate there in the future. This species of night crawler, lives in vertical burrows, and eats fresh forest leaf litter. They can prevent the forest floor from being reestablished by eating all of the litter that falls each year. Hence the forest duff can be rapidly consumed, increase soil bulk density and induce drying. This can be expected to generate additional loss of nutrients, sediments and water volumes. In short, earthworm can alter deciduous forest - part of the declining forest syndrome and is the subject of intense research (Frelich, 2010).

Lake and Watershed Characteristics

Lac Courte Oreilles Morphometric Characteristics (area, depth and orientation)

Lake bay surface areas were determined using a Los Angeles Scientific Instrument Company (Lasico) model series 20 polar planimeter based on the WDNR's Lac Courte Oreilles published lake map with a water datum of 1286.51 (WNDR, 1972). Individual lake depth contour areas were determined by bay subtracting island/shoal areas. Volumes were calculated by spreadsheet for each bay strata using frustrum of a circular cone: V = 1/3 *

H(A1 +A2+ SQRT(A1*A2)). Lake volumes were determined by contour area and summed for each bay. Island/shoal volumes were also determined and subtracted by bay and contour sequence. Lac Courte Oreilles lake areas totaled 5030 acres or 0.2% less than previously determined 5039.8 acres noted by the WDNR. Total estimated volume was 168,739 acre feet versus the WDNR published value of 168,840 or a difference of 0.06%. Bay surface areas, volumes and fetch lengths used in lake modeling are summarized in Table 1 below.

Table 1. LCO Lake Morphometry

Basin	Area	Volume acre feet	Mean Depth Z feet	Area km2	Vol Hm3	Z m	Fetch mi	Fetch Km	Direction
Musky	270.7	1488	5.5	1.12	1.8	1.7	1.04	1.68	EW
Stuckey	96.6	1400	14.5	0.40	1.7	4.4	0.57	0.91	NS
West	1039.0	36134	34.8	4.31	44.6	10.6	1.70	2.74	NS
Central	1757.5	53862	30.6	7.29	66.4	9.3	2.75	4.42	NS
East	1763.4	74410	42.2	7.32	91.8	12.9	3.69	5.95	EW
NE Bay	102.4	1445	14.1	0.43	1.8	4.3	0.52	0.84	NS
LLCO	240	3672	15.3	1.0	4.5	4.7	0.76	1.2	EW

m = meters: Hm3 = million cubic meters, ft = feet. Zm=mean depth.

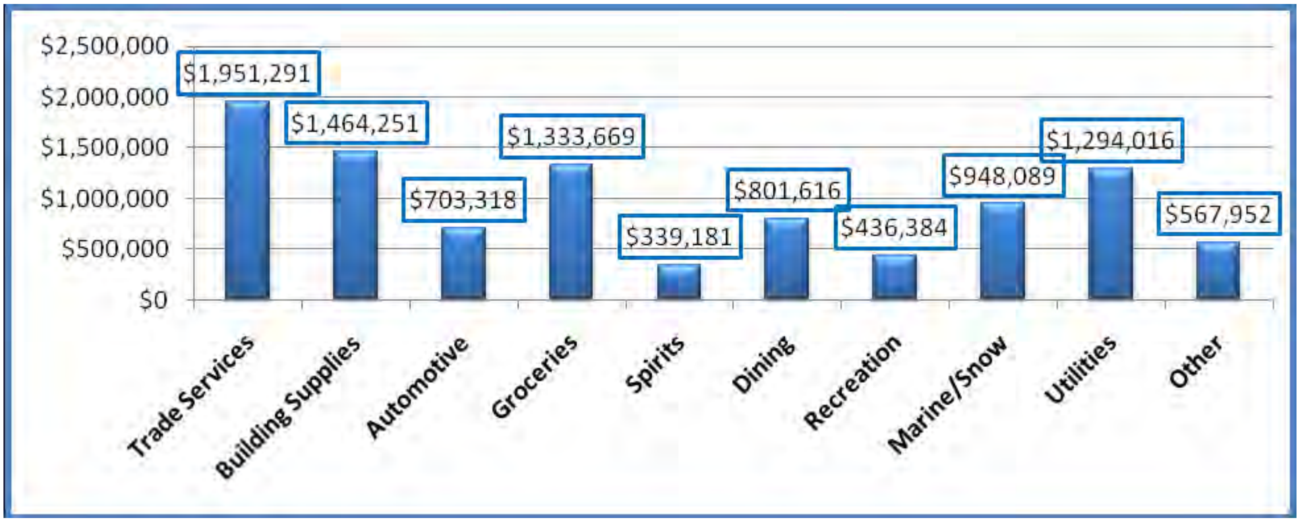
Cranberry Operation Discharges

Using the above bay volumes, an analysis of the relative magnitudes of a range of cranberry discharges by LCO bay was generalized based on the approximate surface area of cranberry production acres and the number of one-foot flooding and discharge events (1-5) per discharge location. For this purpose, the following cranberry operation acres were utilized: (1) 79 acres for the Musky Bay; (2) 97 acres for Stuckey Bay; and (3) approximately 7.5 acres for the east bay. Over the range of flooding events, cranberry discharges account for a percentage of bay volumes ranging from ~5-25% for Musky and Stuckey Bays and a much lower percentage of the total volume for the east bay (e.g. 0.01% - 0.05%).

Lac Courte Oreilles Economic Survey and Assessment.

Lac Courte Oreilles (LCO) is a popular and regionally recognized Hayward Area destination receiving an estimated 84,000 visitor days per year from full-time LCO residents + seasonal LCO residents (second home property owners) + their LCO guests - estimated from mail-in surveys sent to 650 LCO residents. LCO Residents and their guests purchase a wide variety of goods and services (see Figure 2) with estimated LCO resident annual expenditures, varying from about $2 million dollars for trade services (plumbing, electricians, carpenters etc), $1.5 million for building supplies, $1.3 million for groceries and utilities, $948 thousand dollars for marine/snowmobile, $801 thousand for dining out, and $703 thousand for automotive. Survey responses were summed by category from the 219 respondents and then extrapolated to 650 LCO residents. In total, estimated LCO resident total 2009 expenditures were ~$9.8 million. Using a range of multipliers, the total effects of these expenditures in the LCO region was approximated to be about $ 10.8 million to $14.8 million annually. These values represent about 9% of total Sawyer County travel and tourism revenue noted in 2008. Travel and tourism, referred to as one of the three pillars of Wisconsin industry along with agriculture and manufacturing, was estimated by the Wisconsin Department of Tourism to be about $12 billion in 2009 and responsible for about 300,000 jobs (Davidson-Peterson Associates, 2010).

Figure 2. From Lac Courte Oreilles Economic Survey and Assessment, Wilson (2010).



Residential Development

Recreational real-estate development is a major trend for northwestern Wisconsin with LCO lakeshore and secondary new home development expanding from the 1960's to present from about 206 to over 650 residences. The number of resorts has dropped markedly from 18 to 3 with the trend for resorts to sub-divide into private, single family residences. Present LCO shoreland zoning, "category 1" (least restrictive) classification, requires new residential developments to have a minimum lot width of 100 feet and a minimum structure setback of 75 feet. New development (post 1998) requires a 35-foot shoreline buffer zone. COLA has actively promoted shoreline buffer restoration or protection for all properties. Much remains to be done to establish shoreline buffers around the lake.

Sawyer County's Comprehensive Plan (Northwest Regional Development Commission, 2010) indicates urban growth rate projections of about 27 percent by the year 2035, with occupied housing units projected to increase by 46.5 percent. "Sawyer County is projected to grow the second most between 2000 and 2035 compared to the other nine counties in the northwest region. LCO is located in Bass Lake and Sand Lake Townships." By the year 2030, Bass Lake is projected to grow about 34% in population and about 55% in the number of households (about 297 additional households) while Sand Lake has a slightly lower growth projection rate of 13% with a 30% increase (about 50 additional households).

Sawyer County Ordinances

Sawyer County has updated their ordinances for shoreline buffer areas and development with Classification 1 covering LCO with many excellent provisions including a cap on impervious surfaces. It is proposed that Sawyer County consider adoption of additional new development rules to better address new development stormwater volume control practices. For example, the first 1.25 inches of runoff from impervious areas would be treated to the greatest extent practicable using infiltration, reuse, and filtration practices. This would remove about 90%+ of the phosphorus and sediment loads from the site depending upon the site disturbance areas that trigger ordinance provisions. It is suggested that COLA work with Sawyer County to review potential upgrades to the County Codes to include new development volume control standards.

Table 2. Residential shoreline development on Lac Courte Oreilles (from Pratt and Neuswanger, 2006).

Year	Residences	Resorts
1967	206	18
1998	542	3
2005	651	3

Lac Courte Oreilles Watershed Characteristics

The watershed areas and characteristics were summarized from the WDNR interactive Geographic Information System website (www.dnr.wisconsin.gov) using the Surface Map function linked to the Department of Agricultural & Biological Engineering, Purdue University Watershed Delineation Program (Engel, 2010). Summary land uses, soils and other information were extracted and summarized below. In total, the watershed covers a surface area of 68,990 acres to the LCO outlet with the majority of land cover in forest 36,517 acres (53%) and water covering about 21,557 acres (31%).

Grass and pasture were tabulated to cover over 5,300 acres with High Density and Low Density residential covering about 2, 900 acres and agriculture about 2,704 acres (Table 3). Forest plus water categories cover about 84% of the watershed with agriculture, commercial, industrial and residential less than 9%. The coverage of agricultural fields and grass lands can be observed on the west sides of Round Lake and LCO.

Figure 3. Google Map Watershed Overview with the City of Hayward in upper left quadrant.

Table 3. Summary land uses in the Lac Courte Oreilles Watershed.

LCO Land Uses	Acres	Percent
Forest	36,517	52.9%
Water	21,557	31.2%
Grass/Pasture	5,307	7.7%
Agriculture	2,704	3.9%
Low Density Residential	2,099	3.0%
High Density Residential	751	1.1%
Commercial	52	0.1%
Industrial	4	0.0%
Total (acres)	68,990	

Figure 4. Highlighted View of LCO Watershed.

Land areas draining into Lac Courte Oreilles cover a total of about 68,990 acres with the largest tributary areas Osprey Creek (from Round and Osprey Lakes) with about 18,661 acres, Whitefish Creek (drainage from Sand and Whitefish Lakes) covering about 17, 855 acres, Grindstone Creek covering about 14, 656 acres, Spring Creek covering 4,799 acres and West LCO Watershed covering about 3,179 acres. Direct drainage and miscellaneous areas accounted for about 4,000 acres (see Tables 3 and 4).

Table 4. LCO Subwatersheds

Subwatershed	**Acres**	**%**
Osprey Creek	18,661	27.0%
Whitefish Creek	17,855	25.9%
Grindstone Ck	14,656	21.2%
Ghost Creek	4,799	7.0%
Direct Drainage	3,987	5.8%
West LCO	3,179	4.6%
Ring Creek	281	0.4%
Unnamed Creek	234	0.3%
Total acres to LCO Outlet	68,990	
Little LCO	1,487	2.1%

Watershed Soils

The U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS) has grouped soils into categories (A, B, C, D) based on their hydrologic characteristics and runoff potential under similar storm and vegetation conditions. The four hydrologic soil groups are defined below:

Hydrologic Soil Group A (Low runoff potential): The soils have a high infiltration rate even when thoroughly wetted. They chiefly consist of deep, well drained to excessively drained sands or gravels.
Hydrologic Soil Group B: The soils have a moderate infiltration rate when thoroughly wetted. They mainly are moderately deep to deep, moderately well drained to well drained soils that have moderately fine to moderately coarse textures.
Hydrologic Soil Group C: The soils have a slow infiltration rate when thoroughly wetted. They chiefly have a layer that impedes downward movement of water or have moderately fine to fine texture.
Hydrologic Soil Group D (High runoff potential): The soils have a very slow infiltration rate when thoroughly wetted. They chiefly consist of clay soils that have high swelling potential, soils that have a permanent high water table, soils that have a clay layer at or near the surface, and shallow soils over bedrock.

Hydraulic conductivity rates vary greatly by soil type and texture varying from sands infiltrating at rates of 10 + inches/hour, loams less than 0.8 inches per hour and clays usually infiltrating less than 0.3 inches per hour. Incorporating infiltration characteristic will be important for future watershed development using Low Impact Development (LID) techniques that treat runoff on site for typical storms (up to the one year 24 hour storm) as well as on-site sewage treatment systems (septic tanks).

Hydrologic Soil Group soils A and B cover about 64% of the watershed with less infiltrating C and D soils common in about 1/3 of the watershed (Figure 3). There is a higher prevalence of D and C soils groups in Spring, Osprey, Grindstone and Whitefish drainage areas that result in higher runoff values (Table 5). New development and road projects with impervious surfaces (roofs,driveways, roads) will also tend to generate greater runoff from A and B soils would have otherwise infiltrated. Hence, future development should consider preserving as much A and B soils for infiltration as is possible. Runoff from D soils is high so that adding impervious surfaces does not greatly increase runoff by comparison with A soils. A and B soils were much more prevalent in the Ring and West drainage areas (e.g. ~90%) and likely translate into greater infiltration of runoff volumes. New developments should observe minimal soil disturbance practices during construction and apply better site designs that preserve forest and stream buffer areas as much as possible.

Figure 5. Prevalence of HSG Soil Types in LCO Watershed.

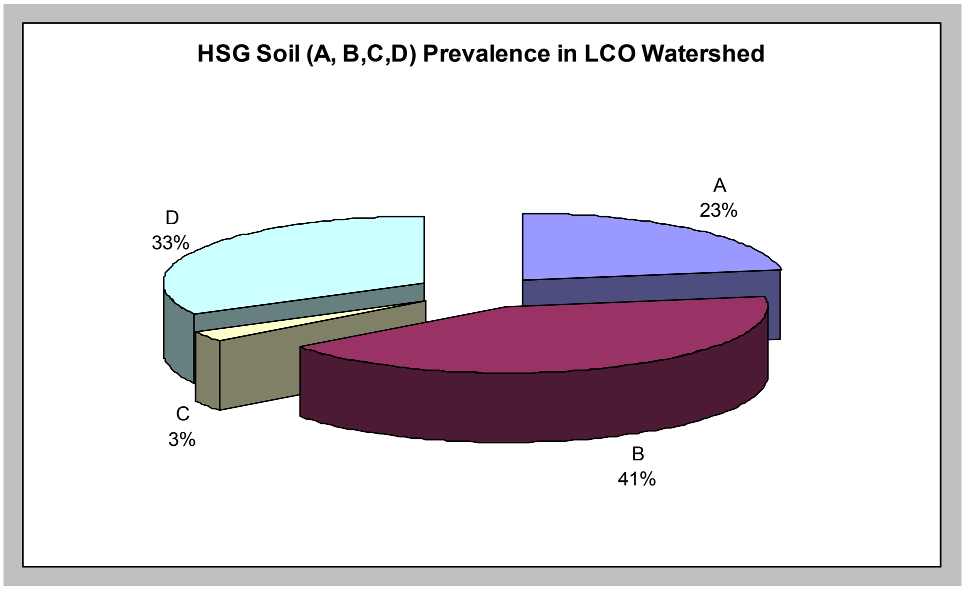


Table 5. Hydrologic Soil Group Occurrence by LCO drainage area.

	Ghost Creek	Osprey Creek	Grindstone Creek	Whitefish Creek	Ring Creek	West	LLCO
D soils %	23.6%	25.8%	34.8%	32.7%	16.0%	10.6%	1.1%
C soils %	0%	0%	0%	5%	0%	0%	16.4%
B soils %	7%	53%	22%	45%	76%	80%	82.6%
A soils %	70%	21%	43%	17%	8%	10%	

Hydrologic Budget: Climatological Summary. Precipitation

The long-term precipitation average (1971-2000) for Couderay, WI used for water budget purposes was 34.5 inches with most (63%) of the rainfall occurring during the growing season of May through September (Table 6). Winter snow fall has typically been about 55 inches with considerable variability as regional values have varied from about 46 inches to 76 inches. Calendar year 2009 was a dry year in Wisconsin, centering on Sawyer County with about 6-9 inches below normal rainfall (Figure 6).

The intensity of rainfall events can have a significant effect on the nature of runoff to streams and lakes. Hence, data for northern Wisconsin was summarized in Table 7 shows that most rainfall days with events exceeding 0.01 inch/day are on the order of 90 per year, with 74 event days exceeding 0.1 inch/day, 24 event days exceeding 0.5 inch/day and about 9 event days exceeding 1.0 inch/day (Table 7). Until the new Atlas 14 is completed for Wisconsin, rainfall frequency data from the old TP-40 will serve as temporary benchmarks and are plotted in Figure 7. Storm frequency range from 1 Year ~ 2.3 inches, 2 Year ~2.75 inches, 3

Year ~ 3.2 inches, 10 Year ~ 4 inches, 50 Year ~ 5 inches and the 100 year storm ~ 5.5 inches.

Figure 6. 2009 Wisconsin Precipitation Patterns.

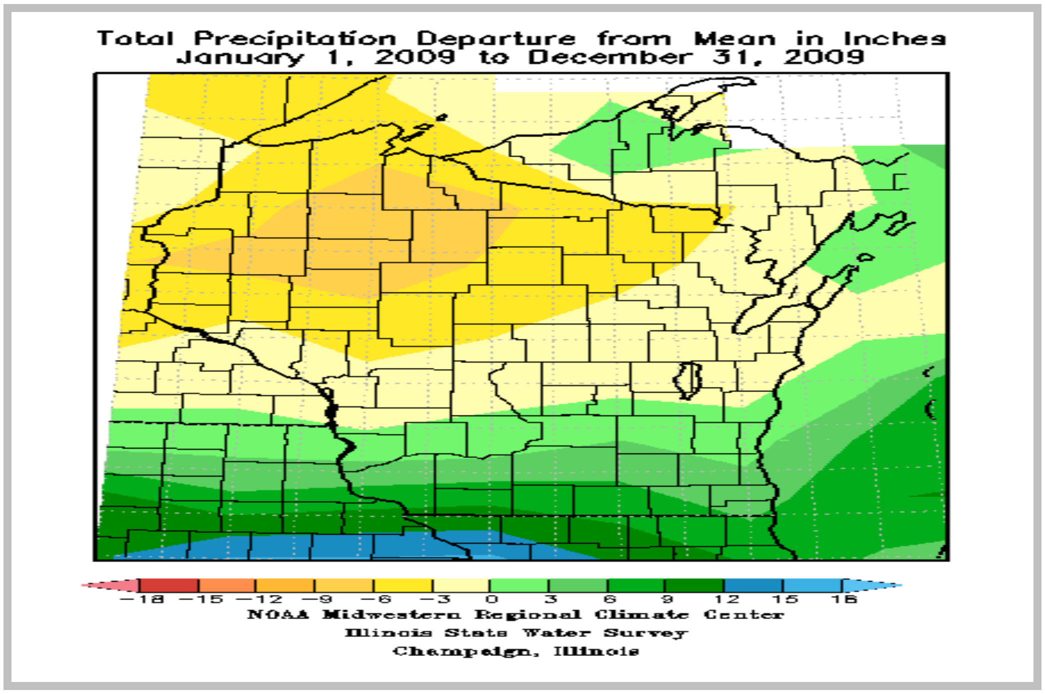


**Table 6 . Precipitation Summary Station: 471847 COUDERAY 7 W, WI
1971 - 2000 NCDC Normals**

Element	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Precip (in)	1.07	0.96	1.87	2.63	3.27	4.48	4.76	4.72	4.37	3.29	2.08	1.02	34.52

Figure 7. TP 40 Storm Frequency Data (Data being recalculated by National Oceanic and Atmospheric Administration (NOAA) under contract with the WDNR.)

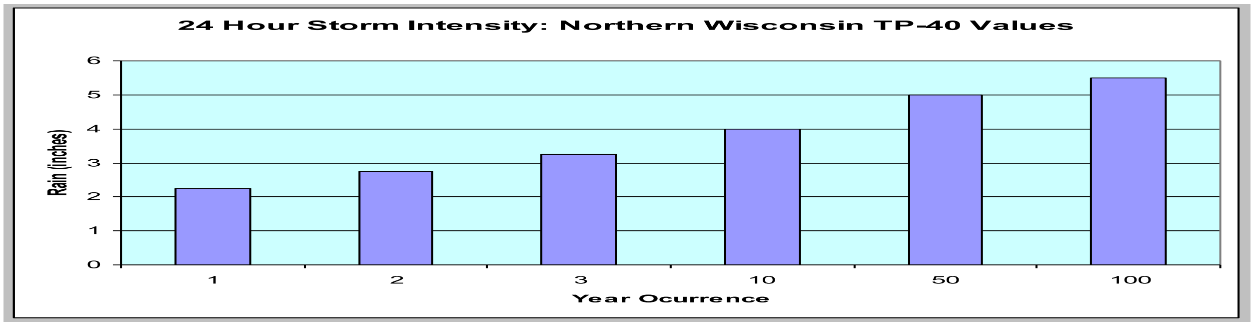


Table 7. Precipitation Climatology Derived from 1971-2000 Averages

Month	# Days Total ≥ 0.01"	# Days Total ≥ 0.10"	# Days Total ≥ 0.50"	# Days Total ≥ 1.00"
JAN	5.0	3.2	0.4	0.1
FEB	3.8	2.9	0.5	0.1
MAR	6.0	4.6	1.0	0.4
APR	7.8	6.8	1.7	0.5
MAY	8.8	7.3	2.5	0.7
JUN	10.1	8.8	3.4	0.9
JUL	8.9	7.9	3.2	1.5
AUG	9.4	8.0	3.4	1.5
SEP	9.2	8.1	2.7	1.1
OCT	7.4	6.5	2.0	1.0
NOV	6.0	4.9	1.3	0.5
DEC	4.7	3.4	0.5	0.0
Annual	88.6	74.1	23.5	8.6
Winter	13.5	9.6	1.4	0.2
Spring	22.7	18.8	5.2	1.5
Summer	28.4	24.6	10.0	3.9
Fall	22.5	19.5	6.0	2.6

Annual/seasonal totals may differ from the sum of the monthly totals due to rounding.

Recent weather assessments prepared for Iowa "Climate Change Impacts on Iowa 2010 (Iowa Climate Change Commission, 2011) include main findings that changes to its economy and human welfare are well underway. The report identifies changes to Iowa's climate, agriculture, environment, public health, and infrastructure. The state's increased rainfall and humidity have allowed unwanted pests and pathogens to spread, leading to an increase in pesticide use. Increased flooding in 2008 cost the state and federal government $3.5 Billion in lost crops, displaced homes and damaged businesses. The report included a general graphic for the Wisconsin, Iowa and Minnesota area of the upper Midwest showing a 31% increase in heavy precipitation (top 1% of precipitation events).

The long–term rainfall record (1891 – 2009) for Northwest Wisconsin was plotted by NOAA and summarized in Figure 8. Recent dry and wet periods since 1990 are evident with three below normal dry years noted since 2000. The recent succession of dry years resulted in very dry conditions noted during the 2009 monitoring season with many dry wetlands and below normal lake levels noted in the LCO watershed. 2009 LCO lake levels were down about 6-9 inches from average summer conditions according (Pulford, personal comm.)

By comparison, the 2010 precipitation through October for the nearest regional weather center (Eau Claire) totaled 29.59 inches through early November, 2010 which is about 2.7 inches above normal. Daily precipitation at the US Geological Survey (USGS) Chippewa River site near Winter during 2010 was limited until mid-June when there were several >0.5 inch storms followed by another dry period extending into the severe storms of September (Figure 9) with ~two one-in-a-year events back to back.

Figure 8. Long-term annual precipitation record.

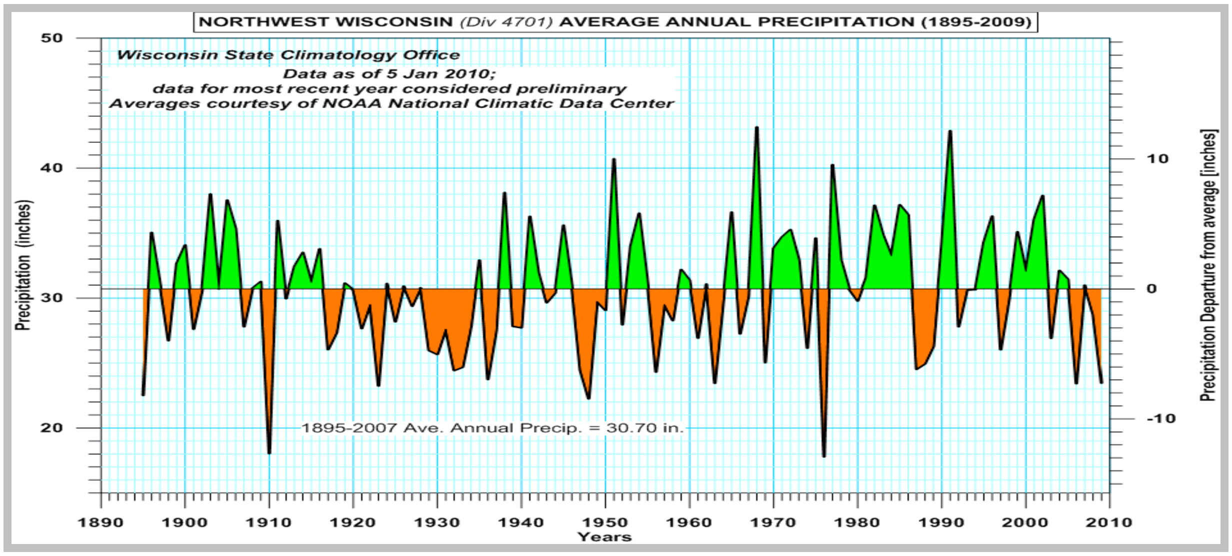


Figure 9. 2009-2010 Chippewa River near Winter Precipitation Plot.

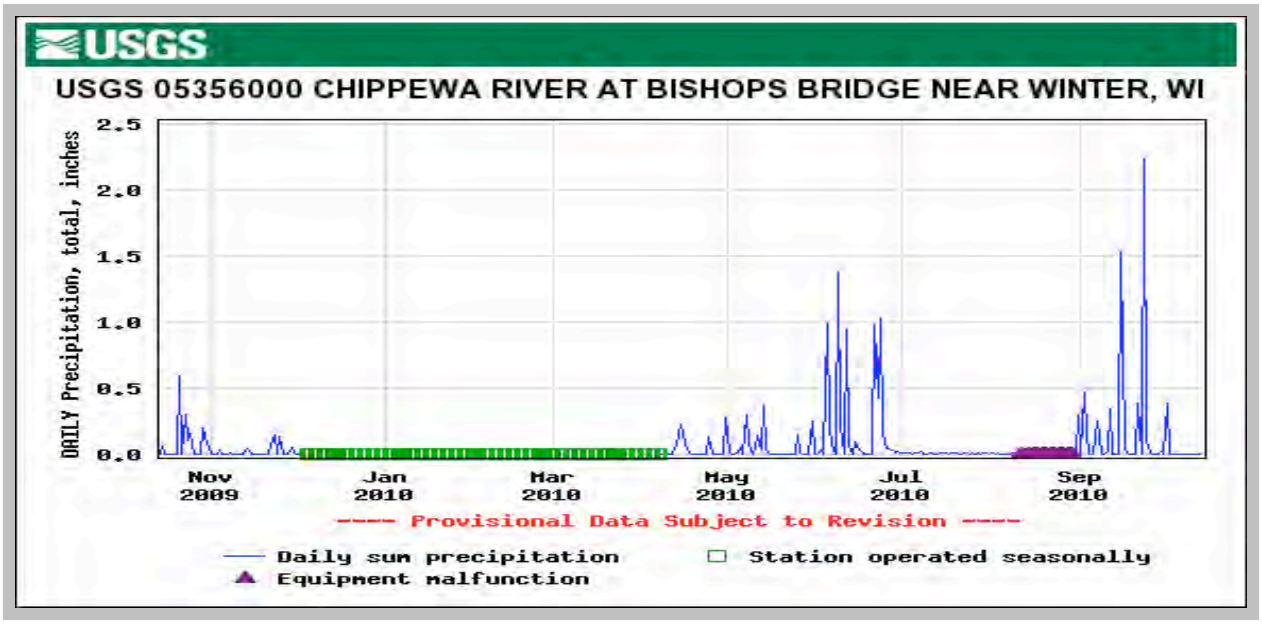
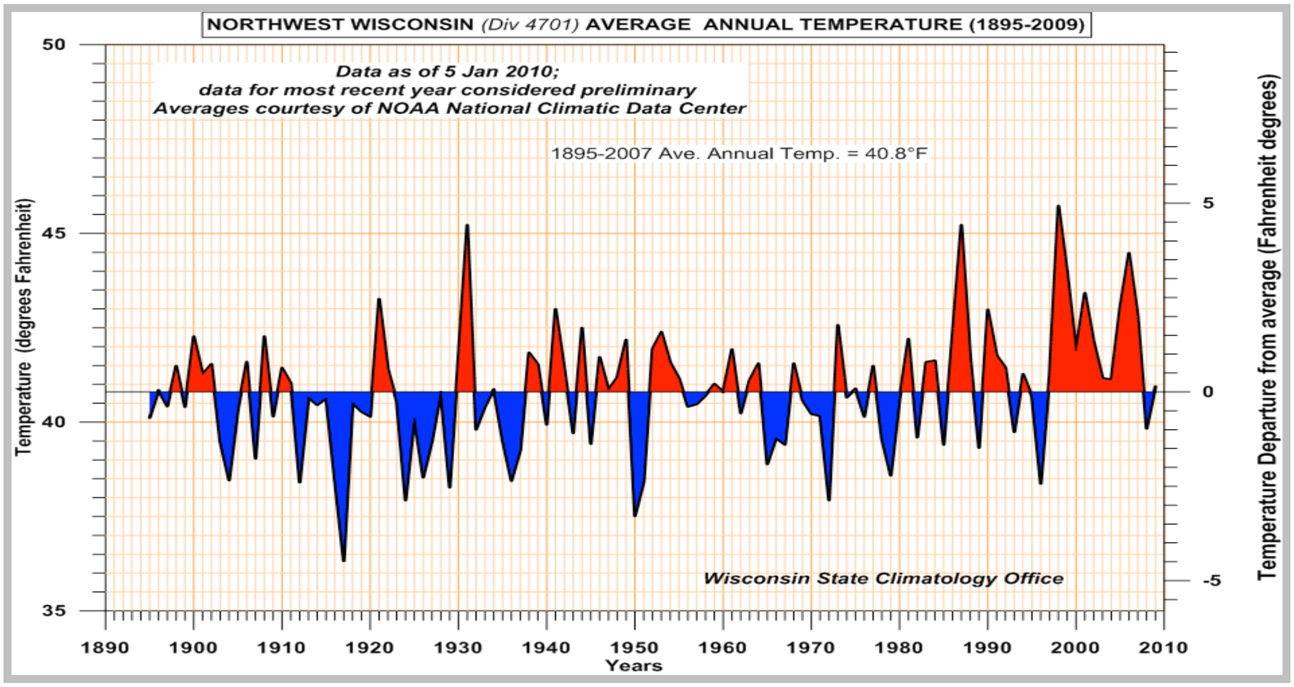


Figure 10. Long-term average annual temperatures for Northwest Wisconsin.



Temperatures

The annual mean long-term temperature for the Northwest Wisconsin NOAA region is 40.8 degrees F with recent years showing substantial increases from the long-term average (Figure 10). Typical averages are about 23 degrees F in the winter and 75 degrees in the summer with about 7 days with temperatures exceeding 90 DF. The LCO watershed is in an 'epicenter' of summer and winter warming patterns noted from 1950-2006 with a peak warming of 2-2.5°F across northwest Wisconsin (WICCI, 2009). Wisconsin is becoming "less cold", with the greatest warming during winter-spring and nighttime temperatures increasing more than daytime temperatures.

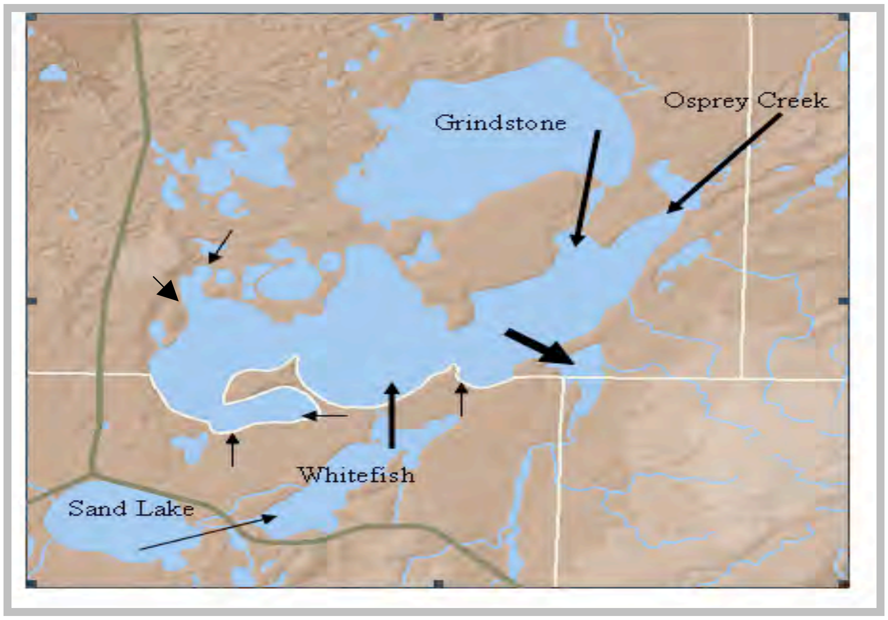
Evaporation

Evaporation rates plotted for Wisconsin by NOAA were estimated for the LCO region of Sawyer County to be about 30.5 inches per year. Of this, NOAA estimates approximately 7 inches of evaporation occurs over the November-April (ice season) or about 1.2 inches per month.

Surface Water Hydrology

The LCO watershed does not have continuous surface water gauging stations and in general, there are relatively few continuous flow gauging stations in Northwestern Wisconsin. Data from the nearest continuous gauges located on the Chippewa River at Winter, WI (790 square mile watershed) and at the Namekagon River at Leonards, WI (126 square mile watershed) were assessed using available data for both sites. The Chippewa River at Winter is downstream of the 15,300 acre Lake Chippewa and the dam operated by Xcel Energy. The Lac Courte Oreilles (LCO) Band of Chippewa operates an electrical power generation facility at the dam power generation and as such, the Chippewa River at Winter is subject to flow regulation. The Chippewa River at Winter is the nearest continuous flow gauging station to LCO with a data record from 1912 to present. The Namekagon River site at Leonards, WI with ~10 years of records (1996-2001 and 2005 to present) is cooperatively operated by the USGS and the National Park Service, St. Croix National Scenic Riverway. The drainage area for the Namekagon River at Leonard is comparable to that of the LCO (e.g. 126 square miles versus 108 square miles, respectively).

Figure 11. Lac Courte Oreilles Surface Flow Network



Available annual flows from 1970-2009 for the Namekagon River at Leonards, WI and the Chippewa River at Winter were normalized to flows for the LCO based on yearly flows prorated by area and plotted in Figure 12. Derived LCO flows estimated from Namekagon River flows over a 10 year period of record, were slightly greater (about 7%) than those calculated from Chippewa River flows at Winter. While these values are approximations for the LCO system, they are the only available data. As such, the lack of gauged stations in the area and specifically for the LCO outlet are critical data gaps. The estimated flows give a useful range for comparison and overview modeling purposes and are the best available data.

Long-term USGS flow data for the Chippewa River at Winter, WI was obtained and reduced to average annual runoff plotted in Figure 13, for the 1970-2009 time period with 90th percentile, 50th percentile and 10th percentiles also noted. Recent years show a marked pattern of lower than normal runoff with a long-term downward trend line for 1970 to 2010 (linear regression line superimposed), with ~ 3 + inches decline over 39 years or a decline of 0.08 inches runoff per year. Flows for 2005 -2009 hoover around the 10th percentile with 2009 values at the 3rd percentile (or about 5.9 inches of runoff per year). Chippewa River flows (at Winter) remained at very low flow until the 2010 mid-summer storms (e.g. July, 2010) that began the recharge of wetlands and stream flows (Figure 14).

Figure 12. Estimated LCO Outlet Annual Volumes (cfs) 1970-2009 based on Chippewa River near Winter and Namekagon River at Leonard flows.

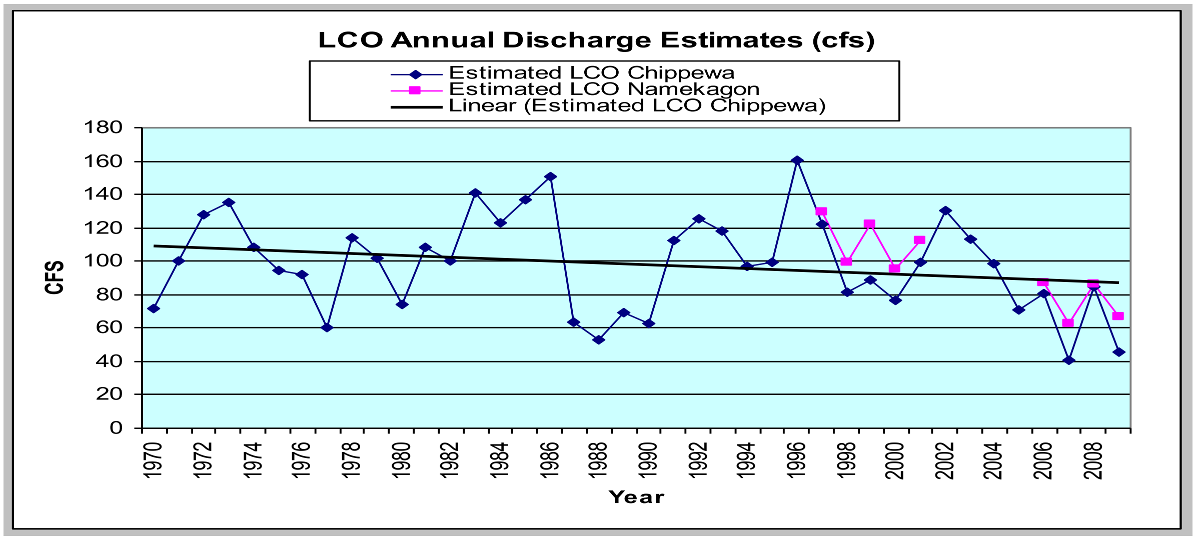


Table 8. Chippewa River (near Winter) statistical summary of annual flows (1970-2009) expressed in cubic feet per second (cfs) and inches per year of runoff.

Percentile	**Annual Mean CFS**	**Runoff Inches**
90 %	991	17.0
75%	883	15.2
50%	728	12.5
25%	557	9.6
10%	456	7.8
3%	341	5.9

Figure 13. Long-term Flows. USGS gauging station: Chippewa River at Winter (inches of runoff per year).

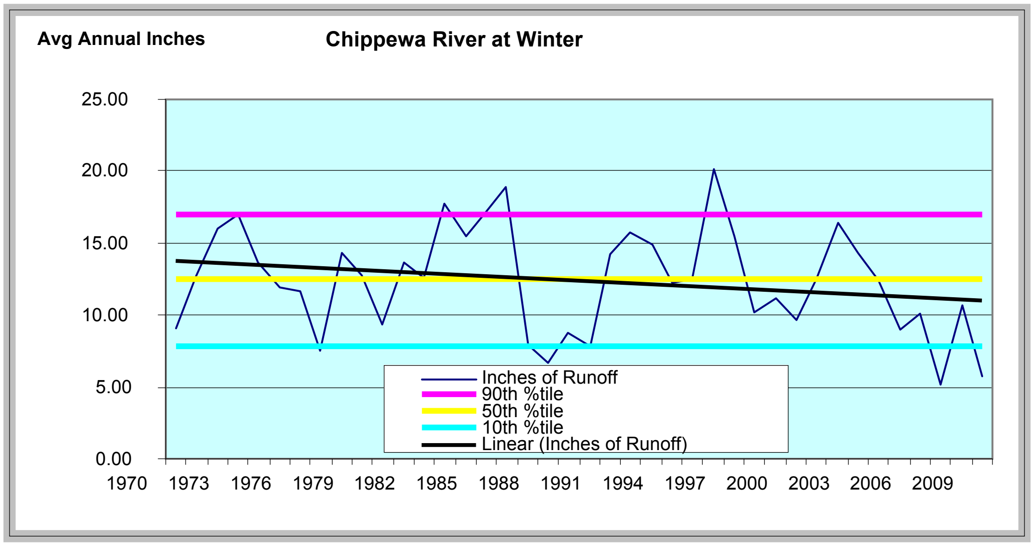
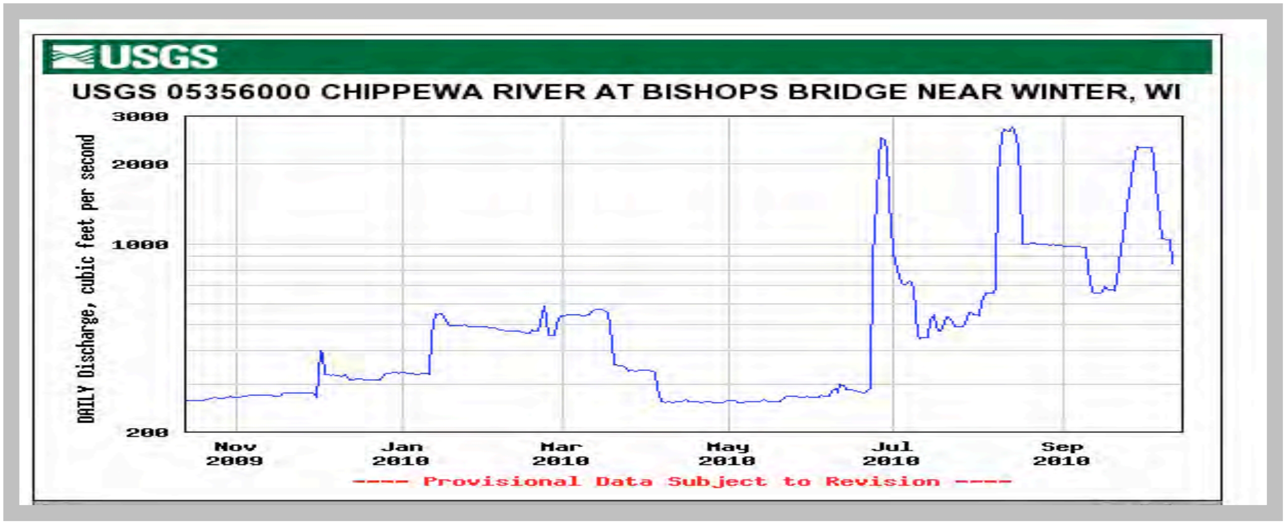


Figure 14. 2010 USGS Flow Gauging of Chippewa River flows.



LCO Outlet Volumes

LCO outlet volumes were estimated from Chippewa River flows at Winter, WI based on prorating of water yields. Annual flows were estimated to range from high flow years (90th percentile) of 137 cfs (122.7 Hm3 or million cubic meters), to average flows (50th percentile) of 101 cfs (or 90.2 Hm3) to 47 cfs (or 42.3 Hm3) for 2009 in Table 9. The highest projected flows through the system were likely realized in WY1996 with an annual average flow of ~160 cfs. Estimated annual runoff variability over the past decade was substantial and varied by a factor of ~ 3 from the very dry years such as 2009 to the wet years similar to 1996 and 2002.

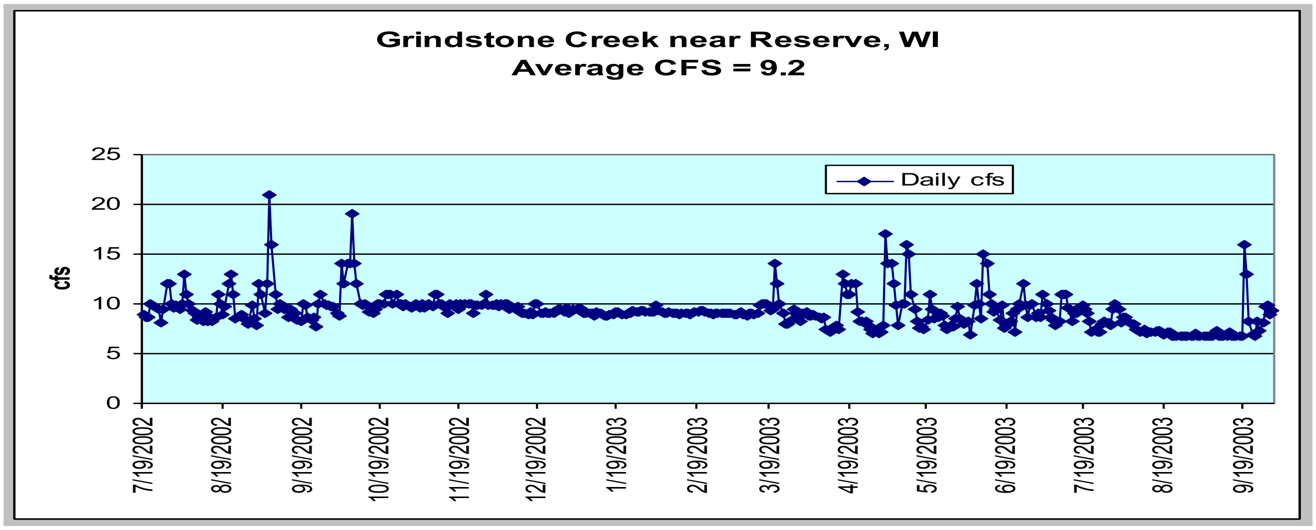
Over the 1970 to 2009 time period, there has been observed a general decline of average annual flows of about 20 cfs or about 18%. Reduced flows have been more pronounced from 2005 to 2009 resulting in lower annual water and phosphorus loads to LCO. Lower flows and phosphorus loading to LCO will influence in-lake responses (e.g. increased transparencies and reduced phosphorus and chlorophyll-a concentrations). The return of wet years produce greater phosphorus loads, chlorophyll-a concentrations and somewhat reduced transparencies.

Previous studies of LCO included "Lac Courte Oreilles Management Plan. Phase I: Water Quality Study of Lac Courte Oreilles; Phase II: Hydrologic and Phosphorus Budgets" (Barr, 1998) was accomplished during the highest flows estimated for the LCO system during the past 40 years (e.g. about 160 cfs at the LCO Outlet) and since then, flows through the system have been declining.

Table 9. Estimated annual average flows in cubic feet per second and million cubic meters (Hm3) at LCO outlet

Percentile Flow	CFS	Hm3
90 %	137	122.7
75%	121	108.4
50%	101	90.2
25%	77	69.0
10%	63	56.5
3%	47	42.3

Figure 15. Grindstone Creek near Reserve, WI continuous flows (2002 – 2003).



In the relatively wet water year (October 1 to September 30) WY 2002, the USGS monitored Grindstone Creek which was found to contribute 9.2 cfs annual average flow to the LCO system. This represented about 7% of the total LCO outlet volume from the Grindstone Creek's 4 square mile watershed. This translates into about 1.3 cfs per square mile which was quite similar to the 1.2 cfs per square mile noted for the Chippewa River near Winter, WI for the same period. Grindstone Creek watershed, with substantial D (clay) soil coverage, exhibits relatively flashy (rapid increases and decreases) runoff responses contrasted by relatively stable flow periods over the winter (base flows from groundwater contributions (Figure 15).

Figure 16. Estimated Long-Term LCO Outlet Volumes (Average cubic feet per second (CFS) per year).

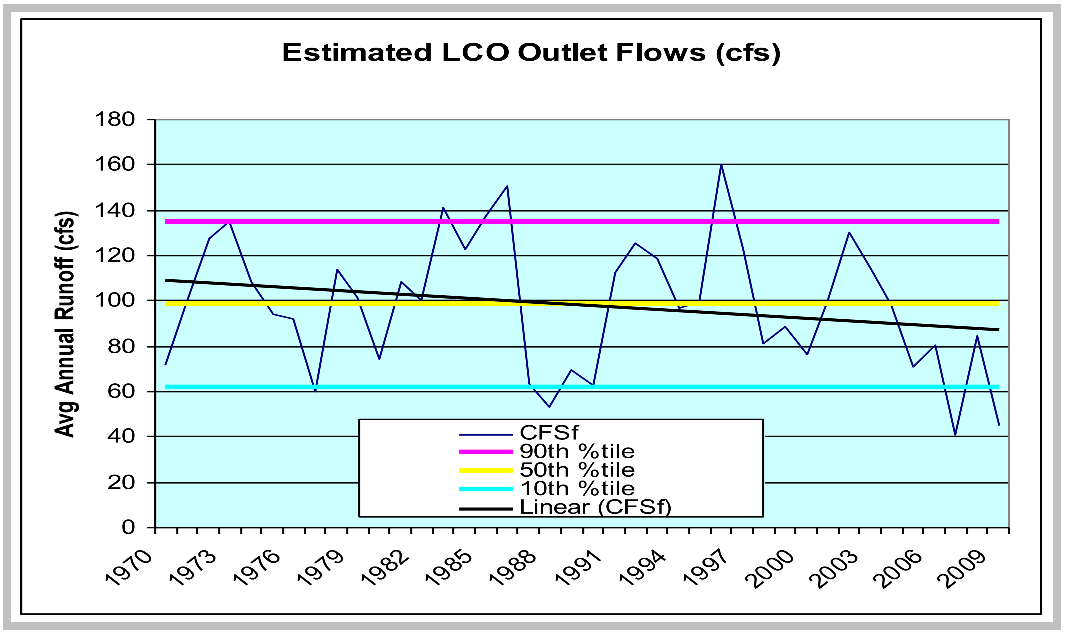


Table 10. Estimated LCO Flows by Subwatershed.

Subwatershed	Estimated Lac Courte Oreilles Flows by Drainage Area 2009 cfs	10th cfs	25th cfs	50th cfs	75th cfs	90th cfs
Osprey Creek	12.6	16.8	20.6	26.9	32.3	36.6
Whitefish Creek	12.1	16.1	19.7	25.7	30.9	35.0
Grindstone Creek	9.9	13.2	16.1	21.1	25.4	28.7
Spring Creek	3.2	4.3	5.3	6.9	8.3	9.4
Direct Drainage	2.7	3.6	4.4	5.7	6.9	7.8
West LCO	2.1	2.9	3.5	4.6	5.5	6.2
Ring Creek	0.2	0.3	0.3	0.4	0.5	0.6
Unnamed Creek	0.2	0.2	0.3	0.3	0.4	0.5
Total acres	46.6	62.2	76.0	99.4	119.4	135.2

Flows for estimation of water balances within the LCO flow network were developed from average runoff values for the entire system prorated by drainage areas as defined in Table 10, above. Estimated annual average outlet volumes for the LCO system are depicted in Figure 16, with percentile levels superimposed (10th percentile flows = low flows).

Lake Data Analysis

Lake Mixis The vertical mixing of lake water layers due to wind is related to the intensity of summer thermal stratification, duration of storms, length of fetch & orientation to predominant winds, shoreline height/protection, mean and maximum depths and other factors. As storm intensities increase coupled with lengthening of growing seasons and warmer temperatures related to a variable climate, the mixing status will be an important factor in future lake conditions relating to sedimentation, internal loading of phosphorus and oxygen dynamics.

Heiskary and Wilson (1995) summarized previous studies and have related mixing status to average lake total phosphorus, chlorophyll-a and related Secchi transparency. In their effort, they defined three classes of lake mixis: polymictic (shallow lakes that frequently mix top to bottom), intermictic (somewhat deeper lakes that mix occasionally mix top to bottom) and dimictic lakes (maximum depths greater than 35 feet that mix top to bottom in the spring and fall). In general, their analysis suggested that (1) most dimictic lakes tended to have maximum depths greater than 10 m (33 feet), and surface area: maximum depth ratios less than 20:1; and (2) polymictic lakes had maximum depths less than 8 m (~26 feet) and surface area: maximum depth ratios greater than 30:1. Whitefish Lake, noted to have a classic dimictic thermal pattern with the coldest bottom waters, has a maximum depth of 105 feet and a surface area: maximum depth ratio of 11. All of the deeper LCO bays had surface area : maximum depth ratios exceeding 20:1.

Using their classification and monitored temperature – dissolved oxygen profiles, lake mixis types were assigned to each of the primary lakes and bays within the LCO watershed (Table 11). The shallower areas (Musky Bay, Stuckey Bay, and Northeast Bay) were classified as polymictic while the deep main bays (West, Central and East) were classified as weak dimictic meaning that these bays showed evidence of mixing over the course of the growing season. Intermictic mixing patterns were identified in Sand Lake – meaning the lake mixes occasionally from top to bottom in response to storm events. The weakly dimictic bays, based on measurements of 2000, 2002, 2007 and 2009, periodically exhibited weak clinograde temperature and dissolved oxygen patterns with bottom waters frequently warming to 50 to 55 degrees F (from 32 degrees F in the spring).

In contrast, the deep Whitefish Lake (max depth of 105 feet) had the coldest hypolimnetic water (~ 40 degrees F on July 18, 2007) and the most defined thermocline – e.g. most distinct decline of temperature with depth and a well defined hypolimnion. All of the dimictic bays and lakes tended to exhibit oxygen concentrations less than 5.0 mg/L (the oxygen concentration crucial for sports fisheries maintenance) below 9-11 m (or greater than 30 to 36 feet) during peak growing season conditions. This data indicates a relatively high volumetric oxygen depletion rates in these lakes such that the bottom waters have less that 5 mg/L within 60 to 90 days from the onset of spring thermal stratification. Example temperature and dissolved oxygen profile graphs are included in Appendix C.

Table 11. Lake Mixing Patterns (strong thermal, weak and well-mixed).

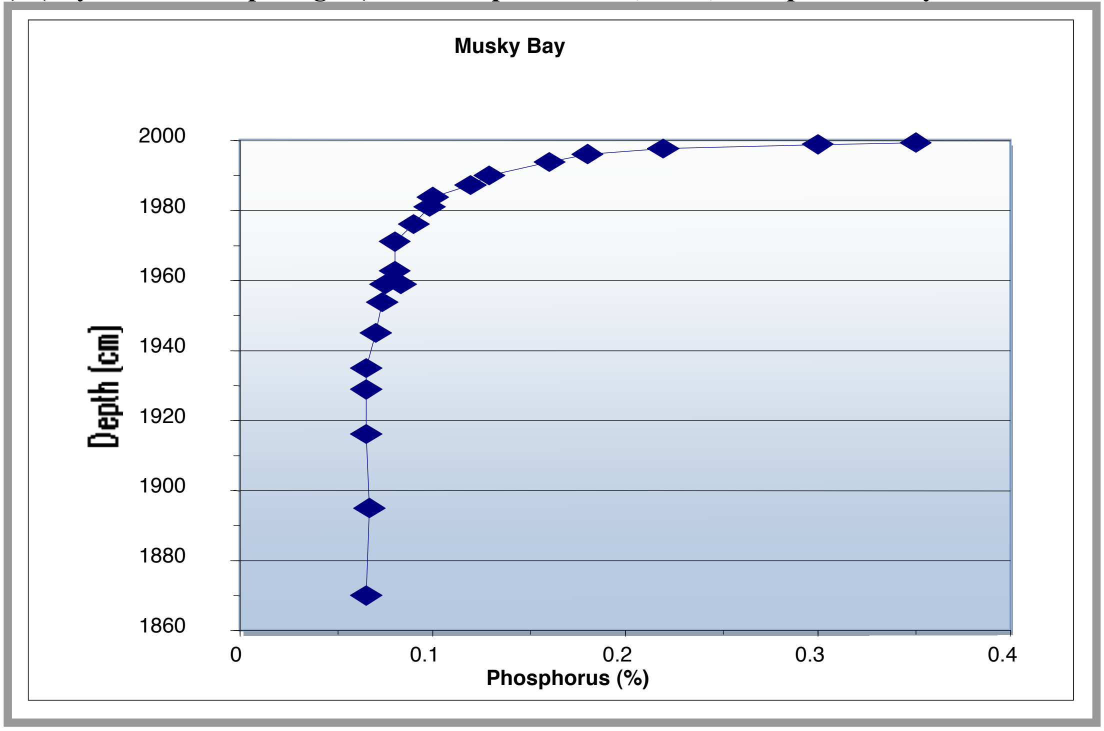
Lake / Bay	Max	Mean	Surface Area to Max Depth	Mixis Type	Depth
	Depth feet	Depth feet	(ha/m)	P, I, D	DO < 5

LCO Musky Deep	16	6	22	Polymictic	~2m peak
Stuckey	24	15	5	Polymictic	
West	67	35	21	Dimictic - weak	~10 m
Central	63	31	38	Dimictic - weak	~10m
East Deep	92	42	26	Dimictic - weak	~10m
NE Bay	25	14	5	Polymictic	
Little LCO	46	15.3	21		
Grindstone	60	30*	78	Dimictic - weak	~11m
Sand	50	21*	28	Intermictic	~7m
Whitefish	105	45*	11	Dimictic	~11m

* From Barr, 1998

In 1999, the USGS collected sediment cores in Musky Bay, Stuckey Bay, LCO central and LCO northeast bay to examine historical water quality patterns (Fitzgerald et al, 2003). All of the sites sediments were described as dark organic-rich muck or black muck indicating enriched sediments from oxic and anoxic littoral and profundal zones. Iron and phosphorus at the Musky Bay site were further examined. Sediment characteristics since ~1980 indicate two very distinct patterns: (1) sediment phosphorus content has increased exponentially while (2) iron values have declined in nearly dramatic fashion (Figures 17a, 17b). The report noted that "a "rotten egg" odor was detected throughout the entire core, implying sulfate reduction as a major organic matter decomposition pathway. With sulfide in excess, all iron would precipitate as monosulfides and pyrite" thereby stripping iron from the sediments. Accordingly, since ~1980 the iron to phosphorus molar ratios were noted to decline from ~7: 1 to ~ 1 : 1 as the iron has been removed by pyrite reactions leaving very low values for combining with phosphorus compounds in oxygenated conditions. Concentration ratios less than ~3:1 indicate lower control by iron of labile sediment P and thus a greater likelihood of internal P release. Sulfur data may also warrant further review for methyl mercury considerations.

Figure 17 a. Musky bay total phosphorus content (%) by depth/age dating ; 17 b. Iron content (%) by sediment depth/age. (From Fitzpatrick etal, 2003, data provided by Paul Garrison).



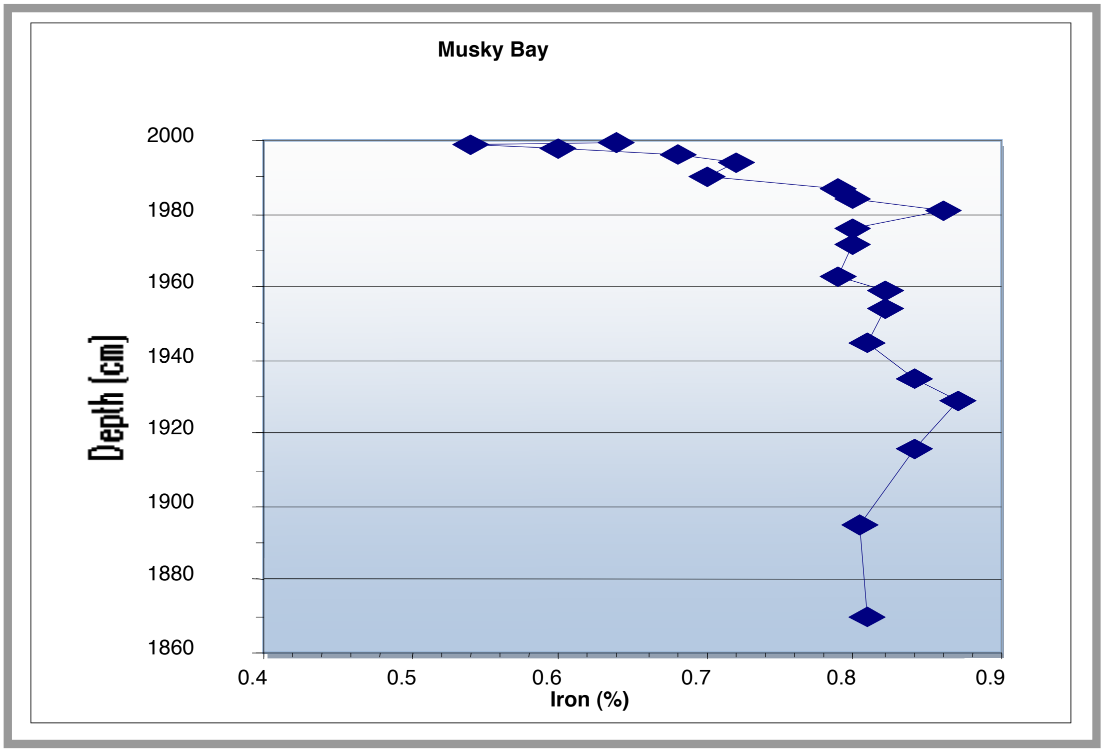
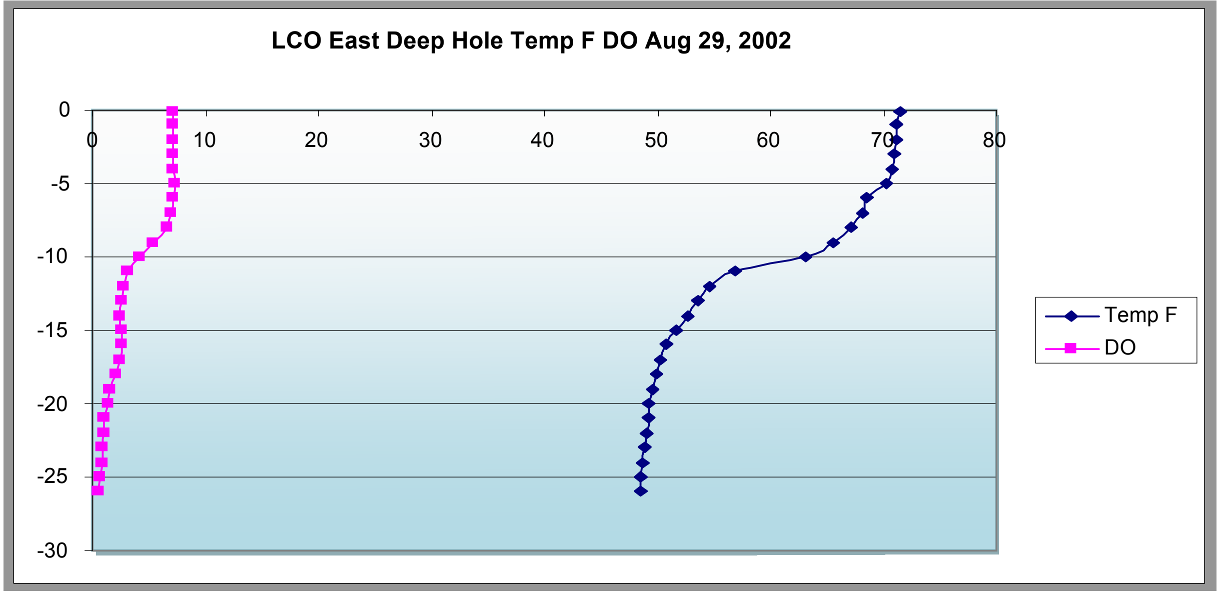


Figure 18. LCO east bay, representative late summer temperature and dissolved oxygen profile by depth (m).



New WDNR Phosphorus Rules: Stratified Lake Definition

Under the new WDNR rules (NR 102.06(g), LCO would be considered a stratified two-story lake with a stratified coefficient (e.g. Maximum Depth (m) – 0.1/(Log10 Lake Areas(ha)) or ((92 ft*.305)-0.1).(Log10 5039acres*0.405) = 8.4. This value exceeds the rule value of 3.8 and hence is considered a stratified two story lake (Figure 18).

Lac Courte Oreilles Data

Growing Season Average Total Phosphorus, Chlorophyll-a and Secchi Transparency

Lake monitoring stations were established at five LCO sites (e.g. northeast, east, central, west and Musky Bays) by the LCOCD. Other sites have been monitored over time and include Stuckey, Chicago, and Grindstone Bays but that data is not included in this assessment. Laboratory analyses were contracted by the LCOCD following U.S. Environmental Protection Agency (EPA) approved methods (via the EPA approval of the LCOCD monitoring plan). Surface water lake samples were analyzed for total phosphorus and chlorophyll-a. Temperature and dissolved oxygen profiles and Secchi transparency measurements were obtained. In recent years, there were generally 2 to 9 samples per summer per lake bay and hence, trend analyses were not conducted. Data per bay was pooled and averaged for the 1996 and 2004-2008 timeframes (Figures 19 and 20).

Routine WDNR Fisheries measurement of total phosphorus data from LCO's east bay (deep site) measured from 1987 to 1998 are plotted in Figure 21, where an increasing pattern is evident. Over this time period, concentrations have nearly doubled from ~6-10 ppb to ~10-17 ppb. Recent data indicates that the east bay has remained about 9-12 ppb.

Increases in eutrophication have been noted by LCO residents. The majority (59%) of respondents to the LCO Economic Survey stated that the water quality was worse today compared to the date of purchase (average length of ownership was about 32 years). Some write-in comments included: less clarity, more aquatic plants, no frogs, more algae, wildlife all but gone, more weeds, no clams, swimmer's itch, slime, and water not as clear. 3% of respondents believed the water quality had improved in their LCO section. Water quality degradation was perceived in all LCO sections. Economic Survey respondents overwhelmingly participate in primary contact water-related recreational activities (boating, swimming, fishing, canoeing/kayaking, and sailing).

Figure 19. Average summer total phosphorus by LCO Bay.

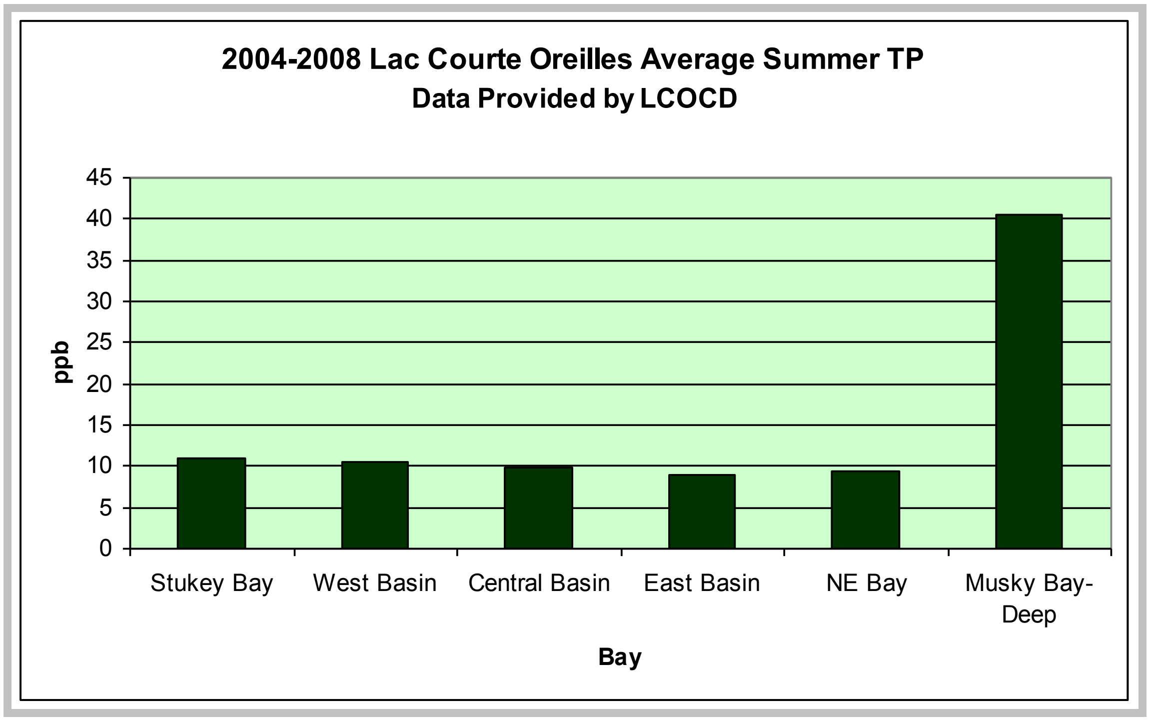


Figure 20. Average summer chlorophyll-a by LCO Bay (2004-2008).

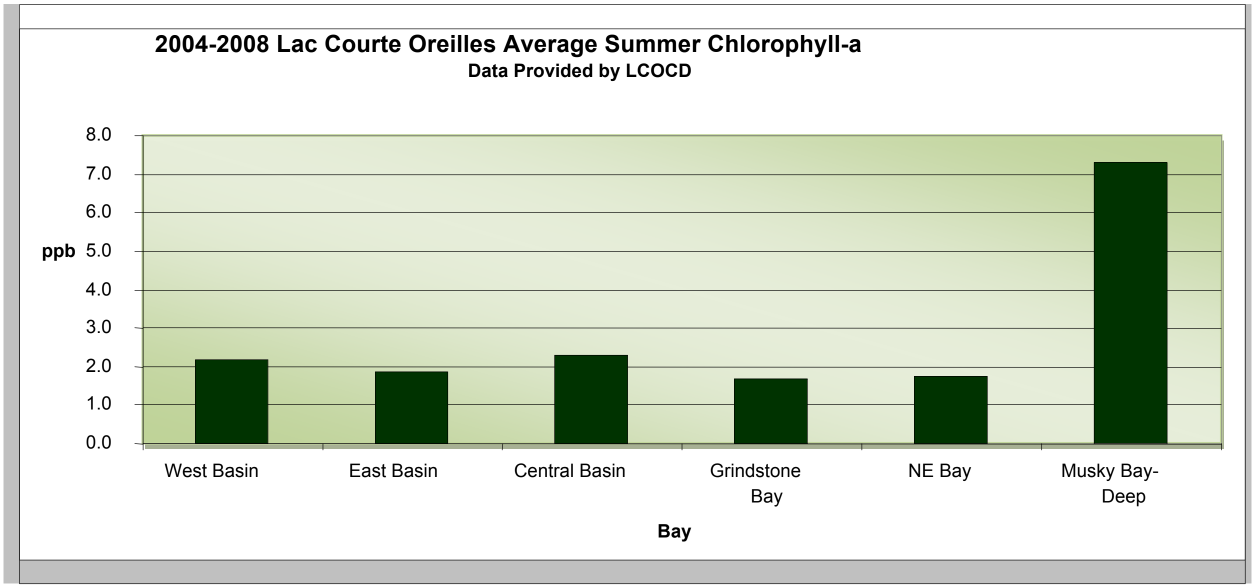


Figure 21. Historical WDNR TP Data for East Bay Deep Site (WDNR Site 583046) (1987-1998).

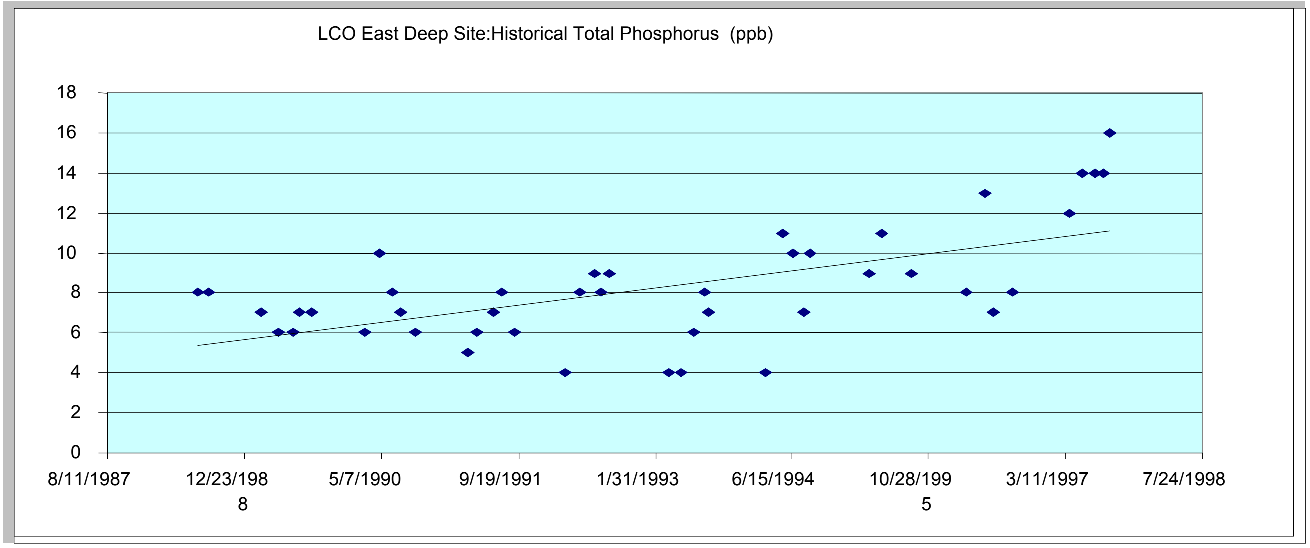


Table 12. 2004-2008 Summer Averages by LCO Bay (1996-2008 Data Provided by LCOCD).

LCO Bay	TP 2004-2008	Chl-a 2004-2008	Secchi 2004-2008	Secchi 2009	Secchi 2010	Secchi 1996
Musky Bay-Deep	41.0	7.3	7.2	5.7	6.7	9.9
West Basin	10.6	2.2	15.6	15.9	16.2	13.4
Central Basin	9.8	2.3	16.9	18.3	16.8	14.2
East Basin	9.1	1.9	18.4	18.9	18.0	17.3
NE Bay	9.5	1.8	16.0	16.8	14.2	12.9
Little LCO	12	2.1	14.4	-	-	-

It should be noted that all of the LCO bays had relatively similar total phosphorus concentrations up until the 1940's when cottages and cranberry farming increased concentrations into Musky Bay (Fitzpatrick etal, 2003). Today, all bays but Musky Bay have similar P concentrations and this report makes that distinction repeatedly. As such, future goal setting should consider all of the lake as one interconnected flowage rather than different lakes embedded in separate watershed drainages. There should be one lake-wide P management goal.

LCO bay average summer total phosphorus and chlorophyll-a for 2004-2008 transition from the highest system values noted in Musky Bay and decline substantially in the west bay to the central and east bays (Table 12). For comparison purposes, except for Musky Bay, average summer total phosphorus values are comparable to the 10th percentile Northern Lakes and

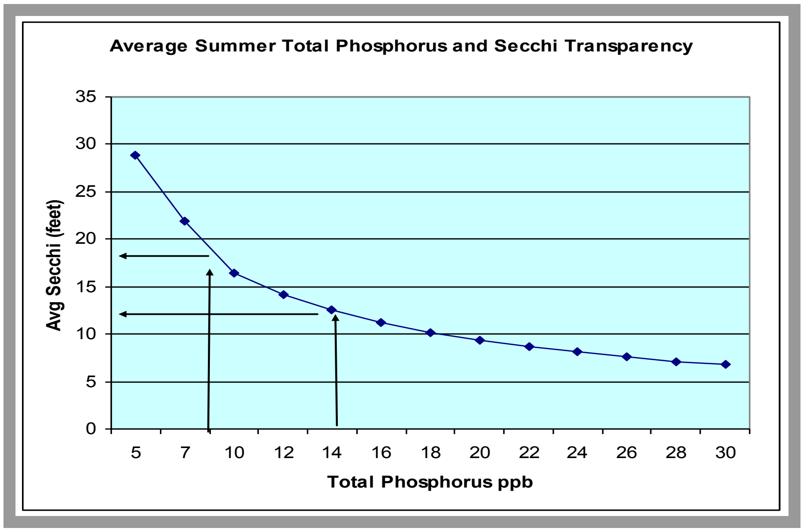
Forest ecoregion levels monitored in lake mixing types (Table 13). Musky Bay total phosphorus values are closer to the 80th percentile values for polymictic lakes. Hence, except for Musky Bay, LCO lake conditions represent excellent water quality from an ecoregion perspective. Severe infestations of Curly leaf pondweed has been associated with increased P loss as the plants die in late June, decompose and release P (0.25 + pound P/acre per year noted in Half Moon Lake (James, Barko & Sorge, (2003)).

Table 13. Average Summer Total Phosphorus Concentrations by mixing type (from Heiskary and Wilson, 1995).

	Northern Lakes and Forests		
Mixing Status:	**D**	**I**	**P**
Percentile value for [TP]	ppb		
90 %	**37**	**53**	**57**
75 %	**29**	**35**	**39**
50 %	**20**	**26**	**29**
25 %	**13**	**19**	**19**
10 %	**9**	**13**	**12**
# of obs.	257	87	199

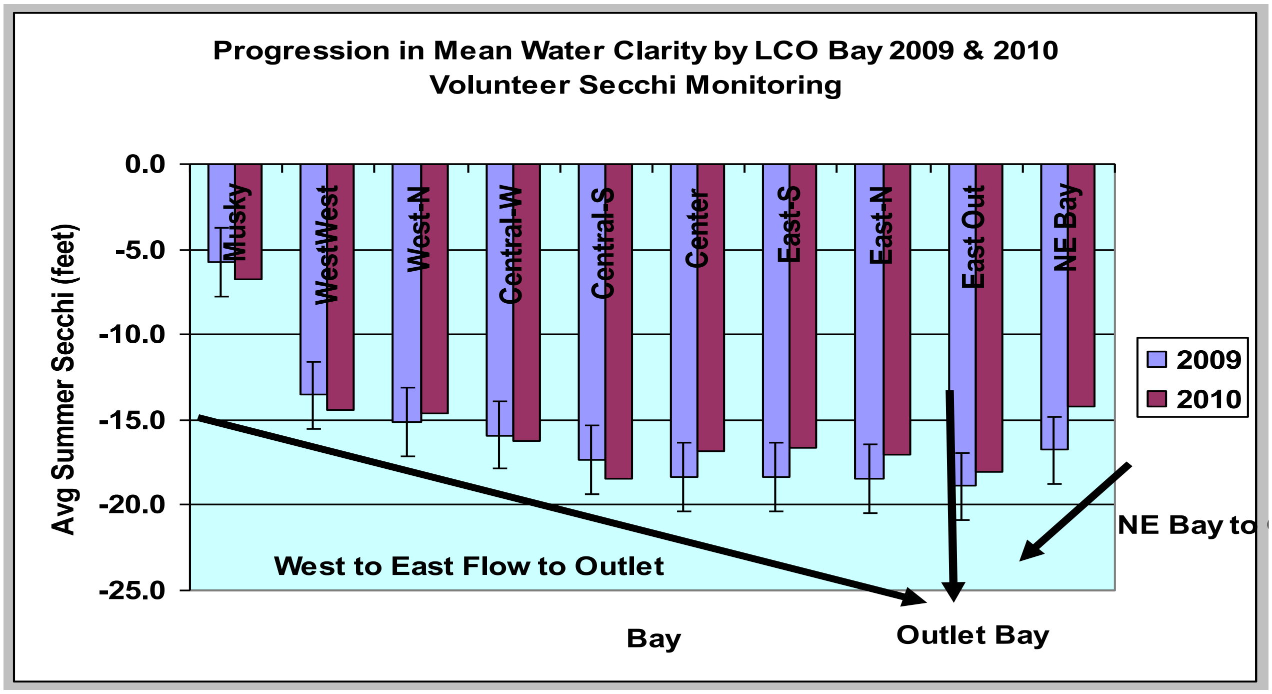
At lower total phosphorus values noted in Figure 22, transparency values will be responsive to subtle changes. Increasing phosphorus values from 9 ppb to 15 ppb can be expected to reduce transparencies from about 18 feet to ~12 feet. Average summer Secchi values are fairly consistent for 2004-2008, 2009 and 2010. These summers were generally representative of low flow conditions in contrast to the high flow conditions of the Barr study of 1996 (Barr, 1998).

Figure 22. Average summer transparency in feet as a function of total phosphorus



The progression of average summer Secchi values per bay are plotted in Figure 23, ranging from the lowest system values noted in Musky Bay to the highest readings noted in the east bay. Similar patterns were noted in both 2009 (N=9) and 2010 (N=5).

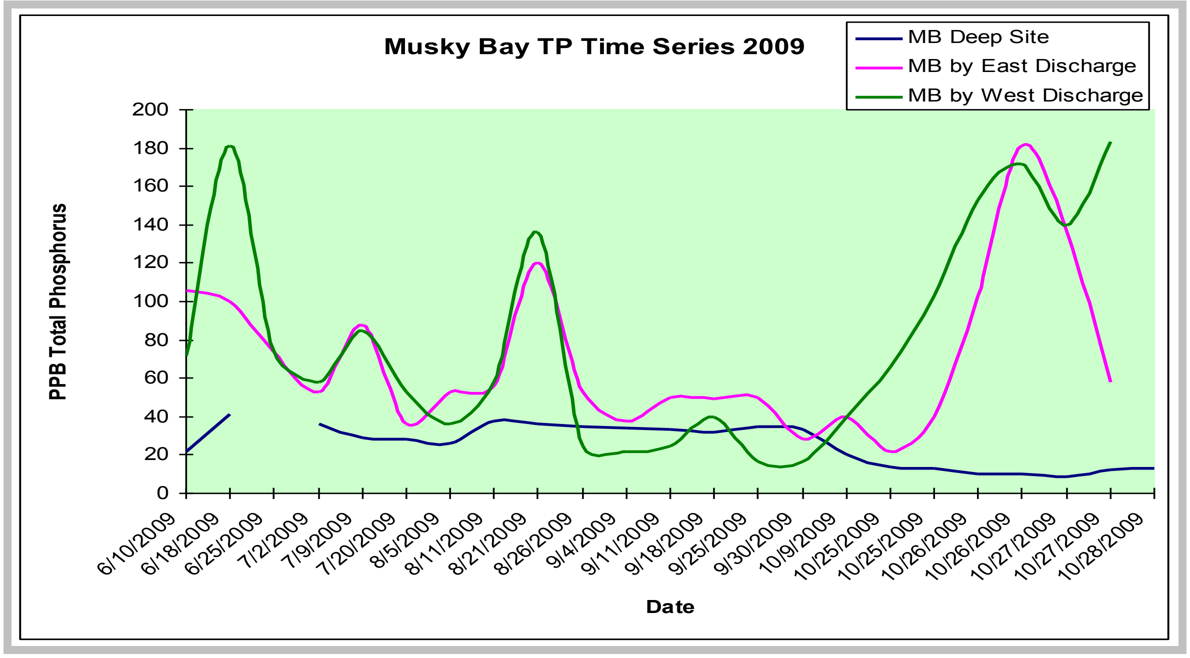
Figure 23. Average summer Secchi Transparency by LCO Bay for 2009 and 2010.



Musky Bay

The water quality of Musky Bay has been documented in other documents (LCOCD (2004, 2004b), Tyrolt (2003, 2004, 2009), Wilson (2007) and Wilson and Tyrolt (2009)). This bay has received the discharges from two cranberry dischareges (Musky Bay East and West) along with general runoff. The LCOCD has monitored the discharge total phosphorus concentrations of the East and West Musky Bay discharge flow-paths along with the main Musky Bay concentrations over the past few years with 2009 concentrations depicted in Figure 24. East and West Musky Bay cranberry discharge total phosphorus concentrations varied from ~20 to 180 ppb while the deep Musky Bay concentrations varied from ~10 – 40 ppb in 2009. Noted by samplers at the time were distinct flows out of Musky Bay into LCO west bay by the LCOCD (LCOCD, 2009). This data suggests that the noted turbid cranberry discharge flows in June, August (storm runoff) and October, 2009 were flowing through Musky Bay and into LCO west bay perhaps due to gradients caused by temperature, lack of flow impeding macrophytes (after Curly leaf pondweed treatments) or other mechanisms as evidenced by the time series of total phosphorus concentrations noted in Figure 24. Seasonal die-back of Curly leaf pondweed can also cause P enrichment as plants decompose (~0.25 pounds+ P/acre/year noted in Half Moon Lake). Hence, the quality of discharges into Musky Bay can directly affect quality of the west bay.

Figure 24. 2009 Musky Bay Time Series Total Phosphorus Concentrations (data provided by LCOCD).



Variable Climate

Future management actions should consider the effects of variable climate upon lake dynamics and the more intensive agricultural and urban land uses. Variable climate patterns that have been noted include:

- Wisconsin is becoming "less cold", with the greatest warming during winter-spring and nighttime temperatures increasing more than daytime temperatures. The LCO watershed was an 'epicenter' of summer and winter warming patterns noted from 1950-2006 with a peak warming of 2-2.5°F noted across northwest Wisconsin (WICCI, 2010).
- Long-term (1970-2009) pattern of decreasing annual mean flows for Chippewa River at Winter with a decrease runoff of about 3+ inches runoff over 39 years.
- Dry periods have cumulative impacts reducing lake levels and shallow groundwater levels. Seepage lakes in the LCO watershed, as noted for Sparkling Lake, WI by Lenters (2008), may exhibit large lake level changes.
- Increased climate variability including dry/wet cycles and increased fluctuations in upland wetland and lake levels. This may mean more drying and rewetting (changing redox) of wetlands due to variable runoff that has been associated with increased loss of phosphorus (Zak etal, 2010; Walker 1995) and increased methyl mercury formation potential (Selch etal, 2007). Increased P losses from wetlands due to variable water levels particularly during wet summer conditions with peak temperatures, is becoming an increasingly common occurrence. For example, the Pelican River Watershed District has monitored increasing P loss rates (hundreds of pounds P) during the peak summer wet periods in Rice Lake above Detroit Lakes, MN (Pelican River Watershed District, 2008). Monitoring wetland P surges were not included in this assessment, but could become significant in the future. Maintaining **vulnerable wetlands, streams and system** storage is recommended to be a primary lake management activity via protective buffers, acquisition of permanent easements and ditching/draining/pumping activities.

- Extended dry periods as observed in 2005-2009, may also lead to greater fire danger periods, hence forest management may include measures such as under canopy biomass removal (especially old storm damage) and education and strict enforcement of 'no burning' periods.
- Increasing number of extreme events such as tornados and intense summer thunder storms are accompanying increasing summer dew points. The WDNR is participating in a 11 Midwest State cooperative effort with the National Oceanic and Atmospheric Administration (NOAA) to update precipitation event intensity and duration data. Updated NOAA data should be distributed in early 2012. The previous reference document, TP-40, is quite outdated (data through the late ~1950's) and hence, storm intensity and duration values are expected to change.
- Recent regional storms particularly the derechos or super cell convective/wind storms cause massive forest damage or blow-downs as seen in northern Minnesota, increasing numbers of tornados, and large convective storm systems bringing prolonged periods of heavy rainfall. These intense storms cause damage to forests, increased erosion and runoff causing shock loadings of sediments, organic materials and nutrients to area streams and lakes. This would emphasize the importance of increased urban stormwater control measures, increasing emphasis on buffer strips around lakes and stream corridors, maintaining important upland storage within the flow networks and to avoid channelization (ditching) of wetlands and shallow lake systems.
- Longer growing seasons.
- Longer ice-free time periods. For Lake Mendota, ice cover has shortened from about 4 months to about 3 months per winter season over the 150-year period.
- More winter thaws.
- Increased evaporation of about 8 inches per year is projected over the next several decades (Stefan, Fang and Hondzo (1998). This effect may be partially offset by increased precipitation (WICCI, 2010), however, larger lake and wetland water level fluctuations may become more common. Water level management will become a more important issue as it relates to navigation between the lakes, internal lake dynamics and groundwater levels.
- Potential upland lake enrichment of Grindstone, Sand and Whitefish Lakes from shock loads, and increased internal recycling of phosphorus.

Predictive Modeling

Standard assessment predictive models are typically used for quantifying the effects of nutrient and water budgets on in-lake response variables such as total phosphorus, chlorophyll-a and Secchi transparency. These models are used to relate the flow of water and nutrients from a lake's watershed to observed conditions in the lake. Alternatively, they may be used for estimating changes in the quality of the lake as a result of altering nutrient inputs to the lake (e.g. changing land uses or stream quality). To analyze the lake water quality of the LCO system, the US Army Corps of Engineers' model BATHTUB (Walker, 1996) was employed. BATHTUB is a series of empirical eutrophication models that perform water and nutrient balance calculations and estimates water quality related conditions (e.g. total phosphorus, chlorophyll-a, transparency and numerous diagnostic measures). Stream gauging and sampling has not been accomplished for the LCO system. Hence, regional runoff values were determined from near-by gauging stations coupled with area monitored mean total phosphorus concentrations, which in general, are quite low and typical of the ecoregion. As a result, the runoff modeling uncertainty is relatively high. However, in-lake responses have been extensively monitored from 1996 to 2009 and have a much greater degree of certainty. The modeling includes assumptions regarding budget components that are not directly measured (e.g., direct runoff from shoreline areas, groundwater, unmonitored tributaries, shoreline septic tanks, atmospheric loads).

Because of the relatively high ratio of watershed area to lake surface area, atmospheric fluxes are relatively significant (~30% for 2005-2009) components of the water (precipitation, evaporation) and phosphorus (deposition) budgets. Because they are difficult to measure directly, estimates of precipitation, evaporation, groundwater inflows and outflows, inputs from shoreline septic tank systems, and atmospheric phosphorus deposition introduce uncertainty into the overall water and phosphorus budgets that would be refined with a more intensive inlet and outlet monitoring. The lack of groundwater estimates or measured inflows and outflows precluded including in the modeling. As such, there are areas of uncertainty in the estimated water and phosphorus budgets that can be improved with future studies.

The water and phosphorus budgets were estimated for (1) the relatively dry period of 2005-2009 and (2) the wet year 1996 and related to measured in-lake responses. There was insufficient lake data for use of the model for other years. Future lake water quality ranges were estimated by management scenario. The LCO Economic Survey (Wilson, 2010) estimated the number of permanent, seasonal and visitors at about 84,000 days which translates into about 229 capitas. Based on Sawyer County septic tank compliance, a loss of 22.5 kg/year was estimated (= 229 capitas X 0.5 kg P/capita X (1-soil retention of 80%).

Available historical data from stream sampling sites (Table 14) were incorporated along with average summer lake data for Whitefish and Grindstone Lakes used for defining lake outlet average stream phosphorus concentrations. This data was also compared to MINLEAP and WILMS background concentrations of 10-30 ppb. The relatively few available concentrations suggests that future monitoring should focus on Osprey Creek, Ghost Creek, and cranberry discharges. Future LCO lake monitoring should include 10-12 paired Secchi, total phosphorus and chlorophyll-a growing season measures by bay to allow for more refined quantifications. Estimates of loads from the watershed are of primary importance for evaluating the potential effects of urban development and animal/row crop agricultural. Expressing loads in terms of average inflow concentrations adjusts for differences in hydrologic conditions (e.g., wet, dry, average years).

The LCO system was segmented into four lake segments; east, central, west and Musky Bays (lake map in Appendix A). The model was calibrated to account for the relatively high Secchi transparency ranges (e.g. greater than 4 meters) historically observed in the LCO system. Available information collected by previous studies (Barr, 1998), LCOCD (2004, 2005), Tyrolt (2003, 2004, 2004b, 2009), WDNR, and USGS have been summarized to define ranges of runoff volumes, evaporation, precipitation and flow-weighted mean inflow concentrations to each bay of the flow network. Model inputs are listed in Appendix D.

Table 14. Available Monitored LCO Stream Total Phosphorus Concentrations (ppb or ug P/L) for 1996.

Location	5/20/96	5/28/96	6/4/96	6/19/96	7/3/96	7/18/96	8/2/96	8/26/96	9/16/96	9/24/96	10/8/96	Avg.
INFLOW:												
I-1, Grindstone Creek		12	10	9	11			10	11	10	12	**11**
I-5, Ring Lake Creek		44	24	30		30		23				**30**
I-8, Whitefish Creek		14	27	10	14			10	9	10	10	**13**
I-9, Ghost Creek	45		34	60	48		50	44	42		26	**44**
I-11, Osprey Creek					20	25	13		11		10	**16**
OUTFLOW:												
Lac Courte Oreilles Outlet		13			7		8		8		10	**9**

As noted in the Fisheries section, the lake's littoral substrates are comprised of sand, gravel and rock except where replaced by soft organic muck in Musky and Stuckey Bays. As such, the main lake bays have sufficient organic deposits to fuel loss of oxygen in hypolimnetic layers and release phosphorus from the sediments (called internal loading). Internal loading from the deep main bays does not look to be excessive at this time. However, the more organic debris that is deposited on the sediments, the greater the phosphorus accumulations that will occur and that may be recycled into lake waters. If watershed loading of phosphorus increases, it will fuel more algae that decompose, get deposited along the lake's sediments and hence become a source of internal phosphorus. Increased organic loading coupled with relatively long water residence times (e.g. greater than 3 years) that provides very little flushing or dilution, means that the lake's phosphorus memory is going to be relatively long to external loads including shock loads from severe events. As such, the effects of shock loading may be realized over long time periods.

Future Scenarios

Modeling of future scenarios focused on three main factors:

- Projected loading changes due to variable climate effects. For this purpose an increase of 30% in watershed total phosphorus loads (e.g. flow-weighted mean concentrations coupled with average flows) was used. Increased loading was attributed to these loading components:
    1. Increased P loss from wetlands due to fluctuating dry/wet cycles using a loss rate of 25 -35 mg/m2/year (Zak etal, 2010) from LCO wetlands covering about 10% of the watershed (Fitzpatrick etal, 2003) or about 690 acres (279 ha). Wetland P loss was estimated to be about 70 - 100 kg P/year.
    2. Increased annual P loads due to increased precipitation by 15% (based on annual precipitation changes projected by WICCI (2010)). Using the simple method for runoff estimation, this would correspond to increased runoff of about 15 percent using the same phosphorus concentration.

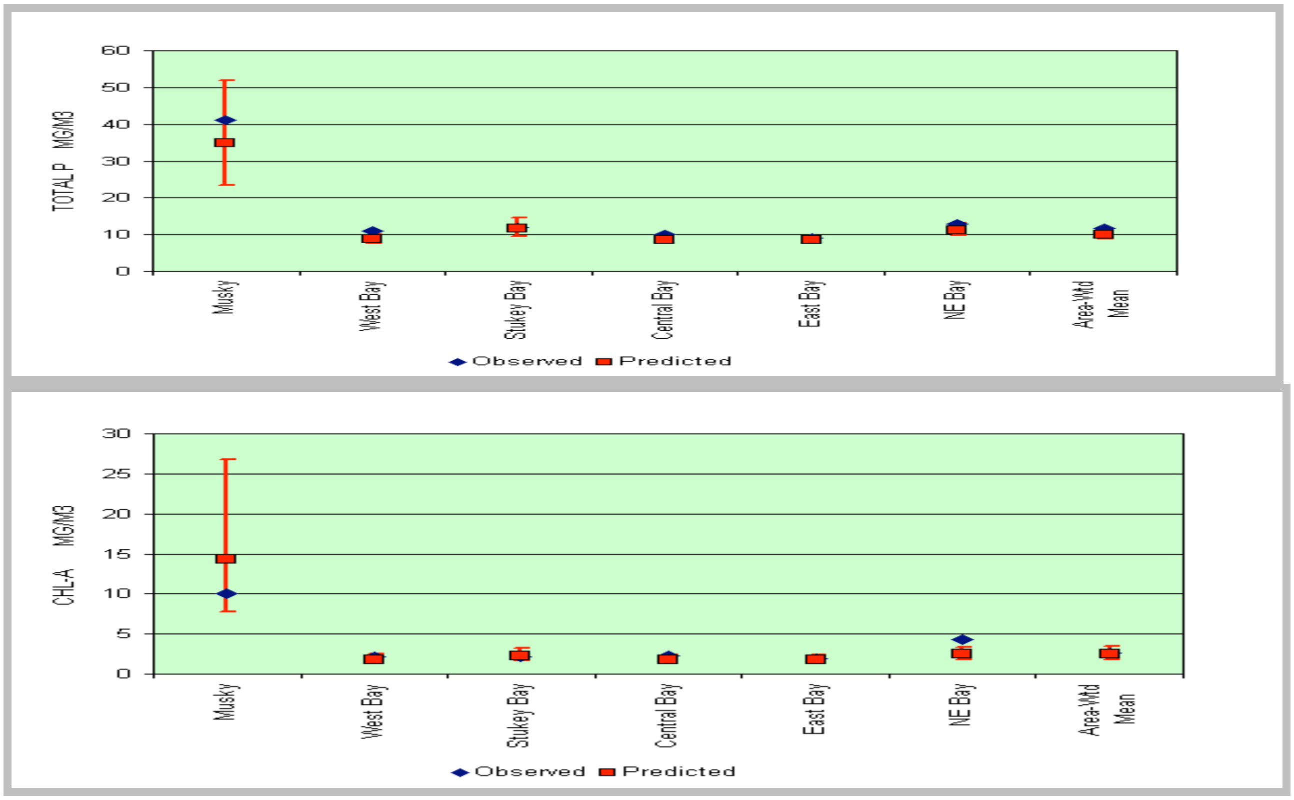
3. Increased the loads to LCO by 10% to reflect increasing occurrence of large intense storms, peak snowpack melts and other shock loading events. A worst case loading event might occur during snowpack melt with intense spring storms after forest fires.

- Increased internal loading. Effects on internal loading from the combination of longer growing season, warmer hypolimnetic temperatures, more intense storm induced mixing events, and watershed organic & P loads. For this purpose, a sediment release rate of 1.0 mg/m2/day was employed.
- A sensitivity analysis of impacts by bay resulting from a range of P increases was accomplished.

Modeling Results

Lake modeling of 2005-2009 - dry conditions was accomplished using watershed runoff and lake outlet volumes calculated as defined in this report. The model estimated average Secchi within 7% in all bays except for Musky Bay which has different macrophyte-algal interactions. 1996 wet year conditions were then estimated as a using a much smaller verification dataset with predicted water quality within +/- 25% of observed values generally observed.

Figure 25. Dry year (2005-2009) average observed and predicted (a) total phosphorus by LCO bay (b.) chlorophyll-a and (c) Secchi transparency.



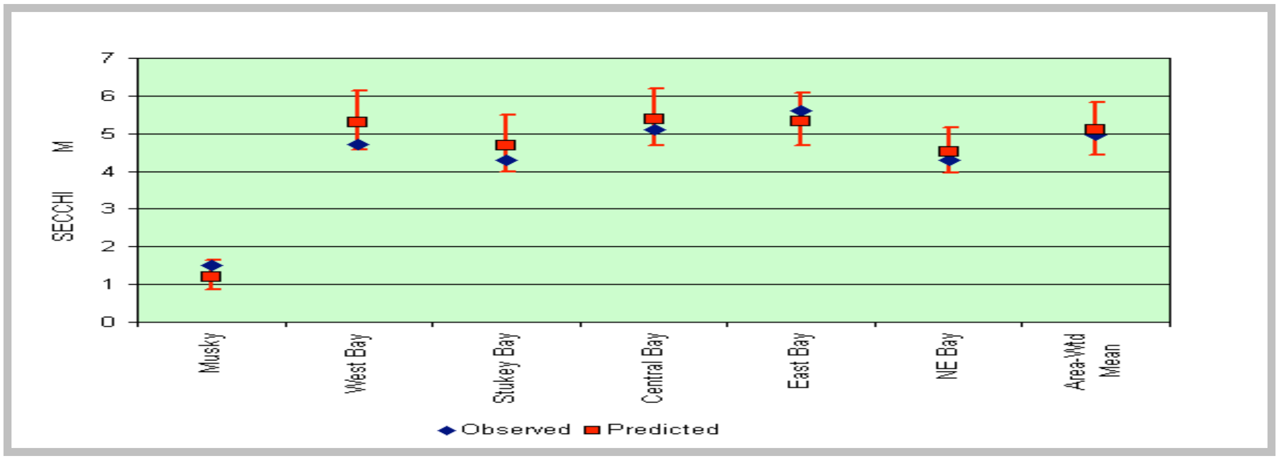


Table 15. Summary of Dry Years (2005-2009) BATHTUB Predicted vs. Observed LCO Water Quality Parameters

	Predicted Average Summer				Observed Average Summer			
2005-2009 Averages	Total P	Chl-a	Secchi m	**Secchi ft**	Total P	Chl-a	Secchi m	**Secchi ft**
Entire LCO average	10	2.6	4.9	**16.1**	12	2.6	5.0	**16.4**
Musky Bay	35	14	1.2	**3.9**	41	10	1.5	**4.9**
West Bay	9	1.9	5.1	**16.7**	11	2.2	4.8	**15.7**
Stuckey Bay	12	2.9	4.1	**13.4**	12	2.1	4.3	**14.1**
Central Bay	9	1.9	5.2	**17.1**	10	2.3	5.1	**16.7**
East Bay	9	1.9	5.2	**17.1**	9	1.9	5.6	**18.4**
NE Bay	11	2.8	4.2	**13.8**	13	4.3	4.3	**14.1**

Table 16. Summary of Wet Year (1996) BATHTUB Predicted vs. Observed LCO Water Quality (Secchi)

1996 Conditions	Predicted Average Summer				1996	Observed
1996 Wet Year	Total P	Chl-a	Secchi m	**Predicted Secchi ft**	**Observed Secchi Ft**	
Entire LCO average	**10**	2.7	4.8	**15.7**	**14.6**	
Musky Bay	**32**	13	1.3	**4.3**	**9.9**	Clear Water
West Bay	**9**	2	5.1	**16.7**	**13.4**	
Stuckey Bay	**15**	4.1	3.5	**11.5**		Obs TP=18
Central Bay	**9**	2	5.1	**16.7**	**14.2**	
East Bay	**9**	2	5.1	**16.7**	**17.3**	
NE Bay	**12**	3	4.1	**13.4**	**12.9**	

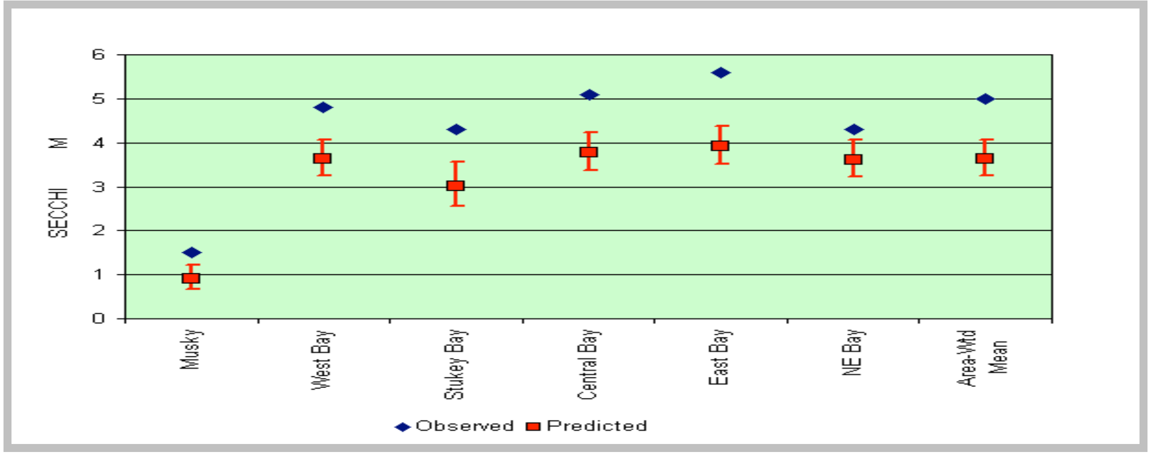
Table 17. Predictions with long-term average flows and 30% increase in stream P loading.

Average Year Flows	Predicted Average Summer				2005-2009 Observed	**% change**
	Total P	Chl-a	Secchi m	Predicted Secchi ft	Secchi ft	
Entire LCO average	13	3.4	4.1	13.4	16.4	**-18%**
Musky Bay	33	13	1.2	3.9	4.9	**-20%**
West Bay	10	2.4	4.5	14.8	15.7	**-6%**
Stuckey Bay	14	4	3.5	11.5	14.1	**-19%**
Central Bay	11	2.6	4.4	14.4	16.7	**-14%**
East Bay	12	3	4.1	13.4	18.4	**-27%**
NE Bay	17	5.2	3.1	10.2	14.1	**-28%**

Table 18. Variable Climate Effecting Internal P Loading (1mg/m2-day over lake surface area).

	Predicted Average Summer				Observed	**% change**
	Total P	Chl-a	Secchi m	Secchi ft	Secchi ft	**Secchi**
Dry Year Internal P						
Entire LCO average	15	4.6	3.6	11.8	16.4	**-28%**
Musky Bay	50	24.7	0.9	3.0	4.9	**-40%**
West Bay	14	3.7	3.6	11.8	15.7	**-25%**
Stuckey Bay	18	5.3	3	9.8	14.1	**-30%**
Central Bay	13	3.5	3.8	12.5	16.7	**-26%**
East Bay	13	3.2	3.9	12.8	18.4	**-30%**
NE Bay	14	3.8	3.6	11.8	14.1	**-16%**

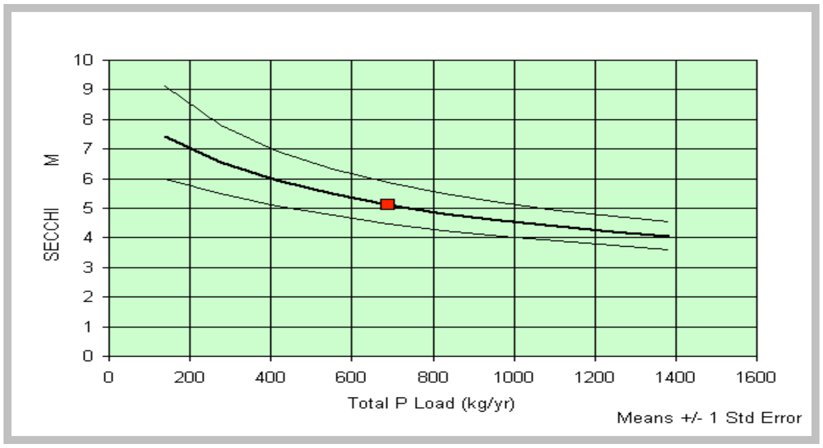
Figure 26. Variable Climate Affecting Internal Loading (1 mg/m2-day over lake surface area) and Predicted Bay Average Summer Transparencies.



Modeling Conclusions

1. The USACE model BATHTUB was employed to simulate recent water quality patterns with estimated flows and monitored stream concentrations through the LCO system.
2. The model reasonably estimated recent dry conditions (2005-2009) with predicted Secchi generally within 7% of observed values. Wet year (1996) with ~9^{5th} percentile high flow was also modeled and predicted in-lake responses were reasonable, given available data.
3. Future conditions. Modeling indicates that increasing stream phosphorus flow-weighted mean concentrations by 30% would result in observable declines in average summer Secchi transparency to long-term residents on the order of 20% to 30%. Higher declines in Secchi transparency were estimated for deep bays due to the sensitivity of the phosphorus:Secchi.
4. Increased income of phosphorus/organic materials was predicted to increase in-lake productivity (e.g. chlorophyll-a). At some point, these external increases lead to increases of internal phosphorus recycled from the lake sediments. It is anticipated that lake mixis coupled with warmer tempeatures and longer summer stratification periods will tend to increase internal loading sources (both oxic and anoxic release rates). For illustration, a value of 1 mg/m2-day internal loading rate was predicted to decrease LCO area-weighted average summer Secchi values bay about 28% .
5. Long-term WDNR monitored phosphorus data for the East bay generally confirms the range of water quality estimated by the modeling. Historical data suggests that the east bay's total phosphorus concentrations increased from 6 ppb to over 15 ppb during the 1980's and 1990's.
6. **Sensitivity Analysis**: Based on sensitivity analyses of the 2005-2009 model, LCO bays will be extremely sensitive to nutrient inputs such that relatively small increases (e.g range of 50 to 300 kg P/Year (or about 110 to 660 pounds)) by bay, will likely cause observable losses in average summer transparency (e.g. 0.5 to 2 meters or 1.5 to 7 feet loss in average transparency ranges) in the west (Figure 25), central and east LCO bays. From a lakeshore owner's perspective, about 50% of LCO Economic Survey respondents indicated that this range of transparency losses would negatively affect their continuing ownership of LCO related properties.

Figure 27. BATHTUB Load Response for West Basin, Mean Secchi as function of P load.

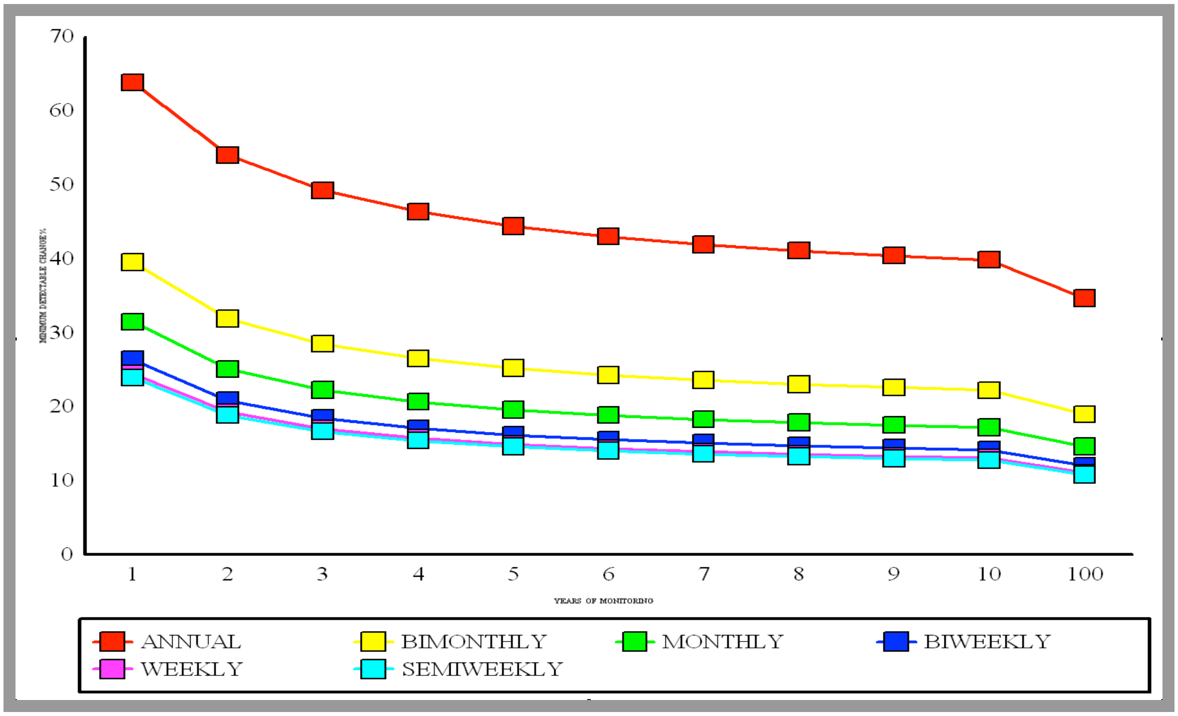


Cumulative impacts of variable climate may be expected to increase P loading to LCO. Subtle increases in forest runoff may be expected with variable climate and infestations, fires and shock loadings resulting from intense storms. Values for these changes were estimated to range up to 30%. Coupled with longer growing seasons and warmer temperatures, this increase can be expected to influence lake internal P loading. Very small changes in internal loading rates will tend to reduce transparencies with modeling indicating a potential for loss of 4-6 foot of average summer transparencies.

Trend Detection.

Future water quality trend detection should be primarily based on total phosphorus and Secchi transparency measures. Increasing the monitoring effort to semi-weekly or weekly measurements intervals over 3-5 years allows detection of 15% to 25% changes in summer average Secchi in each of the LCO bays. Statistics for total phosphorus were calculated using LRSD software (Walker, 1990) with an assumed 100 day summer monitoring period and standard total phosphorus statistics. If monitoring frequency is reduced to once a month, the minimum statistically detectable change increases to about 40% to 50% (Figure 24). Chlorophyll-a measures can exhibit much greater variability, and hence, it is recommended to base future trend detection on Secchi and total phosphorus measurements.

Figure 28. Detecting minimum average summer total phosphorus changes as a function of number of years and monitoring frequency as estimated by LRSD (Walker, 1990).



Conclusions

1. LCO is a designated Outstanding Resource Water located in Sawyer County, classified as an oligotrophic lake (Garrison and Fitzgerald, 2005). It is Wisconsin's eighth largest natural lake (Pratt, 1977) covering 5,039 acres that represents about 9% of Sawyer County's lake acreage.
2. LCO with its four main bays and Little Lac Courte Oreilles, are regionally exceptional lakes in terms of their size, water quality, including LCO's historical two story fishery and general habitat. This is due in large part to the number of upstream wetlands and lakes (Sand, Whitefish, Round and Grindstone) that act as sediment and nutrient traps.
3. Most water flows into and out of LCO through the east bay - except for bay-to-bay wind mixing. With much less water runoff reaching other bays, the central and west bays have much longer water residence times (e.g. estimated 5 and >20 years, respectively versus the east bay's estimated residence time of ~ 2 years during dry year of 2009).
4. Variable climate has been noted over the past two decades including swings from wet years (1996 and 2002) to drought conditions (2005-2009), intense storms, reduced stream flows and longer growing seasons. Over the past 40 years, there has been a declining regional runoff pattern (about 18% less) for the Chippewa River at Winter, WI. This has resulted in greater water level fluctuations of wetlands, streams and lakes.
5. Key challenges include maintaining forests & waters (that make up about 2/3's of the watershed) in an increasingly variable climate with droughts, fires, wet periods, intense storms (damage, erosion and shock loads to lakes and streams) and longer growing seasons and ice-free periods.
    a. LCO has certain characteristics of depth, fetch and orientation that when coupled with longer growing seasons and increased organic loading may result in increased internal loading potential. Minor increases in loading can be rapidly translated into reduced summer transparencies.
    b. Exotic infestations – some exacerbated by variable climate- will have significant effects on lake and forest resources. Curly leaf pondweed infestations die-back in early summer and provide enrichment of the lake sediments with organic material and P loss that will stimulate algal growth.
    c. Variable climate factors appear to have more lake-degrading potential than improvement potential by this assessment. The longer growing seasons and warmer temperatures will result in higher lake temperatures, extreme storm mixing events and dry/wet cycles can be translated into greater watershed P losses. These forces, if not offset by protective actions, will likely result in increased lake P concentrations.
6. The cumulative effects of the pounds of phosphorus reaching LCO is significant as each part per billion increase in LCO average summer total phosphorus can result in a loss of about one foot of average summer water clarity, particularly in the east and central LCO bays.
7. Most LCO Economic Survey respondents (52%) chose their property location because of the water-related recreational opportunities with 57% desiring to maintain long-term family ownership of their property. Additionally, 11% of survey respondents indicated that they were planning on permanent LCO residency at some point in the future. These latter two findings have positive implications for providing long-term ownership stability to the region.
8. The long-term WDNR phosphorus data for the east bay shows a substantial increase that occurred from the late 1980's through the late 1990's. Reinforcing this pattern, 59% of LCO Economic Survey respondents stated the water quality was worse today (than when

purchased with an average resident tenure of 32 years) as evidenced by their observations including: “less clarity, more aquatic plants, no frogs, more algae, wildlife all but gone, more weeds, no clams, swimmer’s itch, slime, and water not as clear.”

9. The USACE model BATHTUB was employed to simulate recent water quality patterns with estimated flows and monitored stream concentrations through the LCO system.
    a. The model reasonably estimated recent dry conditions (2005-2009) with predicted Secchi generally within 7% of observed values. Wet year (1996) with ~95th percentile high flow was also modeled and predicted in-lake responses were reasonable, given available data.
    b. Future conditions. Modeling indicates that increasing stream phosphorus flow-weighted mean concentrations by 30% would result in observable declines in average summer Secchi transparency to long-term residents on the order of 20% to 30%. Higher declines in Secchi transparency were estimated for deep bays due to the sensitivity of the phosphorus:Secchi relationship. This range of potential future changes in water quality are relevant as related to lake shore owners maintaining property ownership.
        i. From the LCO Economic Survey, the future water quality appears to strongly influence future intent to maintain property ownership. Progressively larger losses in summer water clarity resulted in greater percentages of survey respondents not desiring to continue ownership. Loss of 2 – 3 feet average summer clarity resulted in 20% “not staying”, 4 – 6 feet loss resulted in 48% of responses “not staying” and loss of 7-10 feet clarity resulted in 59% ‘not staying’. These findings are noteworthy considering the widespread desire to maintain long-term family ownership of LCO properties noted in the same survey.
10. From the LCO Economic Survey, LCO is a popular and regionally recognized Hayward Area destination receiving an estimated 84,000 visitor days per year from full-time LCO residents + seasonal LCO residents (second home property owners) + their LCO guests - estimated from mail-in surveys sent to 650 LCO residents.
    a. LCO residents and their guests purchase a wide variety of goods and services with estimated LCO resident annual expenditures, varying from about $2 million dollars for trade services (plumbing, electricians, carpenters etc), $1.5 million for building supplies, $1.3 million for groceries and utilities, $948 thousand dollars for marine/snowmobile, $801 thousand for dining out, and $703 thousand for automotive. Survey responses were summed by category from the 219 respondents and then extrapolated to 650 LCO residents.
    b. In total, estimated LCO resident total 2009 expenditures were ~$9.8 million. Using a range of multipliers, the total effects of these expenditures in the LCO region was approximated to be about $ 10.8 million to $14.8 million annually.
    c. These values represent about 9% of total Sawyer County travel and tourism revenue noted in 2008. Statewide travel and tourism, referred to as one of the three pillars of Wisconsin industry along with agriculture and manufacturing, was estimated by the Wisconsin Department of Tourism to be about $12 billion in 2009 and responsible for about 300,000 jobs (Davidson-Peterson Associates, 2010).

Recommendations

1. The ‘Northwood Charm’ is a significant, in a business sense, ‘product’, of the region. Competing for and sustaining future travel and tourism will be dependent upon maintaining the quality of the product, otherwise discretionary travel dollars will be spent elsewhere.
2. LCO has been a two story fishery and should be managed to maintain average summer total phosphorus at present levels or lower. This will mean antidegradation or protection efforts will be needed to maintain 9 -12 ppb total phosphorus.
3. An interim or short-term (e.g. 5 year) goal for Musky Bay of 20 ppb should be established. The long-term recommended total phosphorus goal for Musky Bay is 10 ug P/L. Adaptive management of the watershed coupled with monitoring should be pursued in this regard.
4. Information Gaps and LCO Monitoring Recommendations. The hydrology of the LCO system was estimated from near-by gauging stations over the range of low to high flow years. The lake outlet should be gauged to better define water flushing rates and likely groundwater contributions.
    - **a.** Initiate continuous flow gauging along Osprey Creek and the LCO outlet where best flows can be obtained with consideration of backwatering and tied into lake level gauge. This will require a continuous computerized gauging station with development of staff-discharge relationships for the flowage.
5. Lake levels should be monitored using volunteer efforts along with tracking of ice-on, ice-out, and monthly lake level readings June through October.
6. Measure temperature and dissolved oxygen profiles: spring after iceout, early summer, end of June, mid July, mid-August and mid-September in all four LCO Bays.
7. Groundwater elevation data was not reviewed in this report and representative long-term well water levels should be monitored. The magnitude of groundwater contribution to LCO should be better quantified with outlet monitoring and tracking of seasonal flow patterns including the lake levels of seepage lakes such as Durphee Lake.
8. Hence, antidegradation should be a primary focus of future management efforts with a high priority of protecting forest and wetland areas with low runoff P characteristics. Vulnerable wetlands, forests and streams should be more carefully identified along with appropriate BMPs, protective easements and enforcement.
    - a. Some important considerations for improving and protecting the water quality of the lake include implementation of BMP’s in the shoreland area and with a particular emphasis on the direct drainage areas, particularly in the Osprey Creek area. Proper maintenance of buffers areas between lawns and the lakeshore, minimizing use of fertilizers, and minimizing the introduction of new significant sources of P-loading (e.g., stormwater from near-shore development activities in the watershed), will serve to minimize loading to the lake. Future development should minimize compaction and disturbance of soils, emphasize on-site treatment of runoff via low impact development techniques and require shoreland buffers. Continued vigilance for proper functioning of on-site septic tanks in shoreland areas is needed.
9. Work with owners to eliminate cranberry discharges to the lake.
10. Refined Trend Detection. 10-12 paired total phosphorus, chlorophyll-a and Secchi transparency readings with recreation suitability and physical appearance evaluations per LCO bay per growing season. These readings should be taken over the next 3or 4

years to provide statistical foundation data for statistically detecting future 15% to 25% shifts in Secchi and total phosphorus.

    a. Upstream lake groups are also encouraged to partner in monitoring of Sand, Whitefish, Grindstone and Osprey Lakes. This should include water quality and lake level monitoring of the seepage lakes (Durphee, Windingo and Ring).

11. Continued education. Another significant effort should be made to increase public awareness on the condition of these lakes. The LCO Economic Assessment defines the economic impact of the 'Northwood' product. This is well stated by Krysel, et al (2003) "The evidence shows that management of the quality of lakes is important to maintaining the natural and economic assets of this region."

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