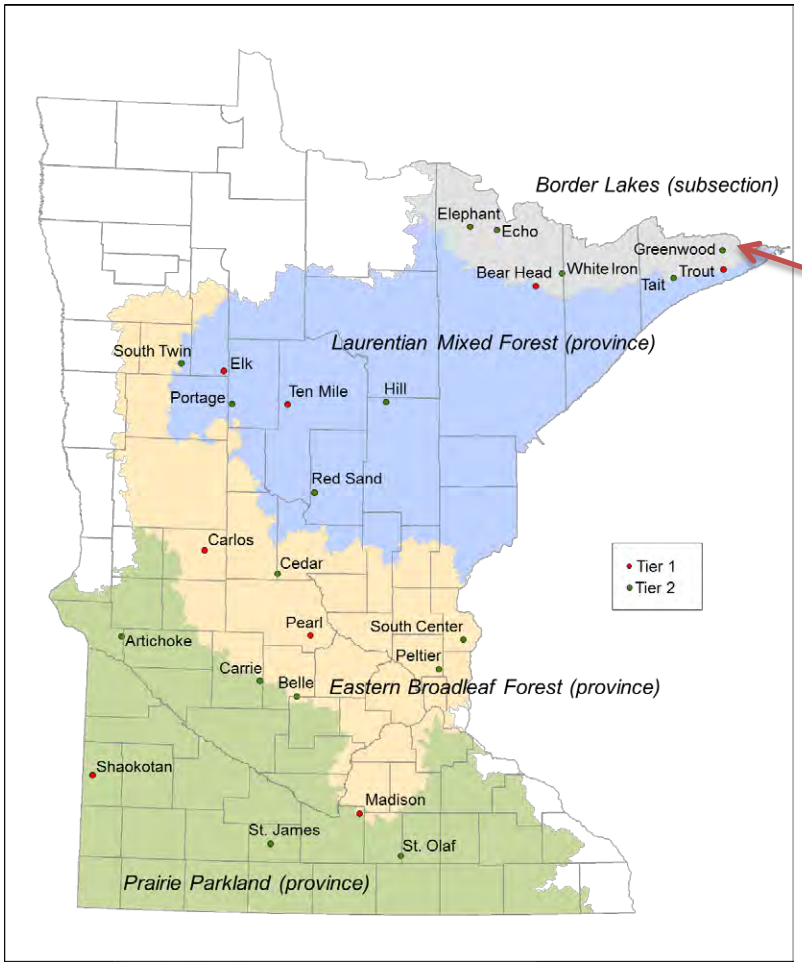
Sentinel Lake Assessment Report
Greenwood Lake (16-0077)
Cook County, Minnesota





Minnesota Pollution Control Agency
Water Monitoring Section
Water Quality Monitoring Unit
&
Minnesota Department of Natural Resources
Section of Fisheries

September 2015

Minnesota Pollution Control Agency

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DEPARTMENT OF NATURAL RESOURCES

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Executive Summary

The Minnesota Pollution Control Agency (MPCA) is working in partnership with the Minnesota Department of Natural Resources (MDNR) on the Sustaining Lakes in a Changing Environment (SLICE) Sentinel Lakes Program. The focus of this interdisciplinary effort is to improve understanding of how major drivers of change such as development, agriculture, climate change, and invasive species can affect lake habitats and fish populations, and to develop a long-term strategy to collect the necessary information to detect undesirable changes in Minnesota Lakes (Valley 2009). To increase our ability to predict the consequences of land cover and climate change on lake habitats, SLICE utilizes intensive lake monitoring strategies on a wide range of representative Minnesota lakes. This includes analyzing relevant land cover and land use, identifying climate stressors, and monitoring the effects on the lake's habitat and biological communities.

The Sentinel Lakes Program initially selected 24 lakes for long-term intensive lake monitoring (Figure 1). The "Deep" lakes typically stratify during the summer months. "Shallow" lakes are defined as mixing continuously throughout the summer. "Cold Water" lakes are defined as lakes that either harbor Cisco, Lake Whitefish, or Lake Trout and were the focus of research funded by the Environmental and Natural Resources Trust Fund (ENRTF). "Super Sentinel" lakes also harbor cold-water fish populations and research on these lakes is currently funded by the ENRTF. In the three super sentinel lakes (Trout, Elk, and Carlos) lake and watershed models have been built by the U.S. Geological Survey (USGS) to forecast various outcomes of climate change on coldwater habitat. Information from this work will likely be beneficial for future analysis of Greenwood. Because of financial and manpower limitations, the Sentinel Lakes were prioritized as Tier 1 and Tier 2 (Figure 1) in 2012, whereby Tier 1 lakes would receive frequent, often annual or biennial, monitoring while Tier 2 lakes would be monitored less frequently.

Greenwood Lake was added to the Sentinel Lakes network in 2012 to provide an additional deep oligotrophic lake that supported lake trout and is a Tier 2 lake. Greenwood Lake is located in Cook County approximately 30.4 kilometers (19 miles) northeast of Grand Marais, MN, within Superior National Forest. Greenwood Lake is located in a bedrock basin, and surrounded by forested land. Land use within the Greenwood Lake watershed is dominated by forest, open water, and wetlands. There has been little change in general land use since 1992, primarily because most of the watershed is within the public lands of Superior National Forest; however, there has been a significant change in the composition of the forest with a shift from deciduous forest (1992) to a evergreen, mixed and shrub scrub forest (2011) as a result of forestry activity.

Greenwood Lake is a very dilute lake that is low in nutrients and dissolved minerals, consistent with other lakes in this region. Based on recent water quality data (2013-2014), Greenwood Lake is considered to be oligotrophic with total phosphorus (TP), chlorophyll-*a* (Chl-*a*), and Secchi transparency values of: 7 micrograms per liter (µg/L), 2.0 µg/L, and 5.2 meters (m; 18 feet) respectively. Secchi and Chl-*a* are at expected levels relative to TP. The MINLEAP model predictions compare favorably to observed water quality and indicate the lake exhibits water quality similar to that expected based on its size, depth, watershed area, and location in the state. A subroutine in the model suggests current TP is near background for the lake.

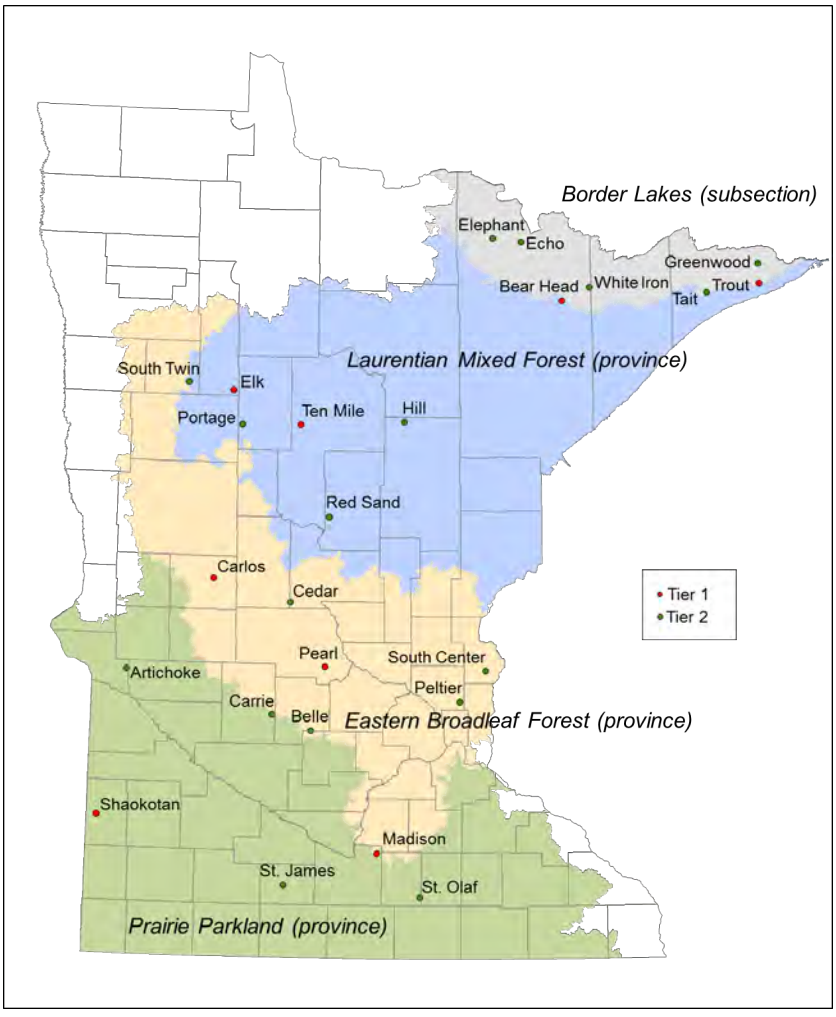
Secchi data are a bit sparse for the lake since there is no active CLMP volunteer. Existing Secchi records and remote-sensed transparency suggest there may be a slight decline in transparency over time. However the data are not sufficient to describe this as a statistically significant trend. Further data collection and future analysis of this data will be needed to detect any trends in this system.

One benchmark measure of coldwater habitat (temperature at 3 mg O_2 - TDO_3; Jacobson et al. 2010) suggests that coldwater resources in Greenwood are excellent for cisco and lake whitefish. The mean

TDO3 was 8.3°C during the period of greatest oxythermal stress (August profiles). These routinely collected measurements (mid-August) of each year will be valuable for assessing trends over time.

Zooplankton densities and biomass in Greenwood Lake were among the lowest of all the Sentinel lakes. The low zooplankton density and biomass is directly related to low nutrients and low algal productivity. Over the past few decades, an invasive zooplankton species (*Bythotrephes longimanus)*, commonly known as the spiny waterflea, has become established across the Great Lakes Region, invading many lakes along the Minnesota and Ontario border. Greenwood Lake has a well-established population, first detected in 2005, while Trout Lake has a newly infested population, first detected in 2012. Continued monitoring of zooplankton and phytoplankton in both lakes will be of value for understanding the impact of spiny waterflea on the base of the food chain of these lakes.

Figure 1 MDNR map of Sentinel lakes and major land types. Trout, Elk, and Carlos are "Super Sentinel" lakes.



Introduction

This report provides a relatively comprehensive analysis of physical, water quality, and ecological characteristics of Greenwood Lake in Cook County Minnesota (MN). This assessment was compiled based on Minnesota Department of Natural Resources (MDNR) surveys of the lake's fish community and aquatic plant communities, Minnesota Pollution Control Agency (MPCA) water quality monitoring, and analysis of various other sources of data for the lake. The water quality assessment focuses on data collected during the 2013-2014 seasons; however, historical data provide perspective on variability and trends in water quality. Water quality data analyzed includes all available data in EQuIS, the state repository for water quality data. Further detail on water quality and limnological concepts and terms in this report are described in the Guide to Lake Protection and Management: (http://www.pca.state.mn.us/water/lakeprotection.html).

History

In this section of the report we summarize historical fishery management, water quality monitoring, lakeshore development, and changes that may have occurred in the watershed over time. This information is a combination of MDNR, Cook County, MPCA, and/or lake association records.

1936 Minimal temperature-oxygen profile and water chemistry data were collected. Rainbow Trout, Brown Trout, Brook Trout, and Lake Trout were listed as the most abundant fish species, but no fish collecting was done.

1943 An investigation of Greenwood Lake was completed by L. E. Hiner, an aquatic biologist working for the Division of Game and Fish, Bureau of Fisheries Research. That report included general observations on the lake, some water quality data, information on prospects for a commercial Cisco fishery in the lake, and some late October fish population assessment data. Five experimental gill net sets apparently caught only Cisco, White Sucker, and Lake Trout. The report indicated that groundcover around the lake consisted of second-growth forest recovering from logging and subsequent fires. One resort was present on Greenwood Lake in 1943 (Greenwood Lake Lodge).

1955 An initial survey was completed in August. Cisco (41.0 fish/net), Lake Trout (1.2 fish/net), White Sucker (10.5 fish/net), and Walleye (1.1 fish/net) were collected in 14 gill net sets. The survey reported there were 12 cottages and 1 resort on the lake at that time.

1977-2013 Numerous re-surveys and fishery assessments were conducted. Resurveys were conducted in 1977, 1983, and 1986, and assessments were done in 1958, 1966, 1969, 1971, 1979, 1980, 1990, 1993, 1996, 1999, 2005, 2009, and 2013. In most years, 12 to 16 gill net sets were used. Trap nets were also used most years and electrofishing gear was used in 1986, 1996, and 1999. Small mesh gill nets were used in 1990 to check for the presence of Rainbow Smelt (none were collected) In the 2005 assessment, wire minnow traps baited with light sticks were set in deep water in an attempt to collect deep-water sculpin (without success). After 1993 gill net sets in all assessments were divided into deep and shallow sets, based on water temperature. Deep sets targeted Lake Trout, and most assessments used about twice as many deep sets as shallow.

1977 MDNR lake survey reported one resort and 17 homes or cottages were found on the lake, all on the lake's west side (in Section 28). The count did not include one boarded up cabin found on a point near the lake's outlet.

1983 Greenwood Lake was included in the Acid Precipitation Intensive Monitoring Program, run by MDNR Ecological Services. MDNR lake surveys were done as part of that program in 1983 and 1986.

1984 Greenwood Lake was selected as an ecoregion reference lake by MPCA, water quality sampling initiated.

1986 MDNR lake survey reported one resort and 30 homes or cottages were present.

1992-1993 New development of several home sites on the lake in the northeast basin.

1999 Parking at public access was upgraded and likely allowed for increased usage.

2005 Spiny water fleas first found in the lake. Firmly established by 2011

2006 Greenwood sampled in conjunction with Superior National Forest staff as part of a regional lake study

2013 Greenwood Lake added to Sentinel Lakes network.

Background

Lake Morphometric and Watershed Characteristics

Greenwood Lake is located in Cook County within the Brule River watershed (Figure 2) that is a part of the Lake Superior North major watershed (Appendix C). Greenwood Lake is located approximately 30.4 kilometers (19 miles) northeast of Grand Marais, MN, within Superior National Forest, just south of the Boundary Waters Canoe Area Wilderness. A public access is located on the south end of the lake. Greenwood Lake has been designated by the State of Minnesota as an Outstanding Resource Value Water (Minnesota Rules, Chapter 7050.0470).

Greenwood Lake is located in a smooth to undulating moraine of the Rainy Lobe. Rainy Lobe till is grayish brown, non-calcareous, and generally sandy with abundant fragments of igneous and metamorphic and greenstone volcanic rocks (Goebel and Walton 1979). The lake has a comparatively small watershed, made up of forest and wetland/water. Several small lakes are included in the "water" land use with Squash, Potato, and Celery to the NW, North Shady immediately north, Sunfish south, and Edith (Triangle) southeast. The watershed is drained through at least seven small tributaries and the lake outlets to the south through the Greenwood River, which flows toward the Brule River and Lake Superior. A barrier falls on the Greenwood River just below Greenwood Lake prevents the movement of fish from the Brule and lower Greenwood Rivers into the lake. In a 1986 MDNR lake survey, late-summer flows in the tributaries to Greenwood Lake were reported to have ranged from an unmeasurable trickle (in three streams) to a high of 0.4 cfs in "NALAC Creek." Similar tributary flows were noted in a 1983 lake survey. Mid-summer outlet flow measurements for the Greenwood River were made in 1941 (3.6 cfs), 1955 (0.8 cfs), 1977 (2.3 cfs), and 1986 (30.6 cfs). The Greenwood River is a designated trout stream, supporting a wild (unstocked) Brook Trout population.

Greenwood Lake's morphometric characteristics are summarized in Table 1. It is a large lake covering 972 hectares. The lake has a mean depth of 9.9 meters (32.5 feet), a maximum depth of 34.1 meters (112 feet) and 26 percent of the lake is littoral. Greenwood has numerous shoals and depths vary greatly; there are two deeper basins in the lake, one near the center and the other in the eastern bay (Figure 3).

Percent littoral area refers to that portion of the lake that is 4.6 meters (15 feet) or less in depth, which often represents the depth to which rooted plants may grow in the lake; on Greenwood this is limited to near-shore areas. The volume of Greenwood Lake was estimated at 66,160 acre-feet, and the residence time was estimated at ~15 years, reflective of the lake's deep basin, limited inlets and small outlet.

The watershed around the lake is relatively undeveloped as is much of the shoreline of the lake. Based on records from the Water Plan Coordinator for the Cook County Soil and Water District there are 55 total home-sites with residents on the lake. There are more potential home sites, which are not developed. Of the 55 developed sites, 49 are seasonal and 6 are residential, homesteaded. A recent on-site septic system inspection of 43 properties indicates 30 were deemed non-compliant and 13 compliant with current regulations. Of those non-compliant, 10 were deemed imminent public health threats. This suggests the possibility exists for these systems to pollute groundwater and the potential to impact drinking water sources.

For systems deemed imminent public health threats, the County follows up with a letter to the property owners. After the allotted time to fix the system has passed, and if the system is not brought into compliance, then the County works with the County attorney and purses legal action. The County also works with landowners to provide low interest loans to bring systems into compliance and provide grants for low income, homesteaded landowners.

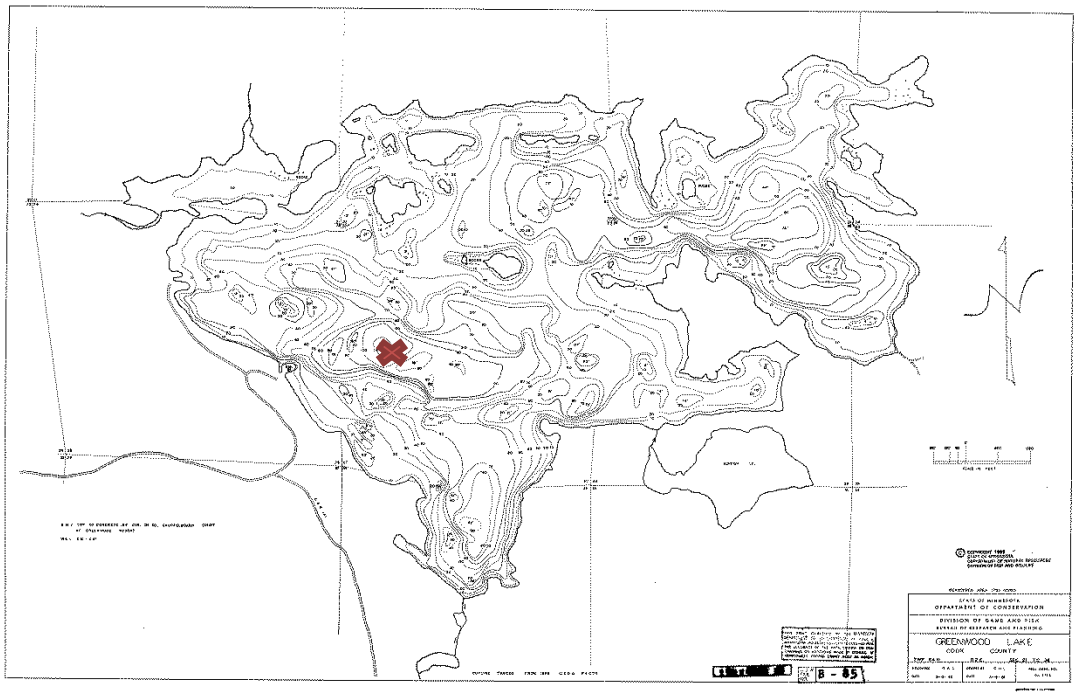
Table 1 Greenwood Lake and watershed morphometric characteristics. Lake bathymetry based on latest sounding map from 1987

Lake Name	Lake ID	Lake ha (acres)	Littoral Area (%)	Total Wshed Area ha (acres)	Wshed : Lake	Max. Depth meters (feet)	Mean Depth meters (feet)	Lake Volume acre-ft
Greenwood	16-0077	827 (2,042)	26%	2,824 (6,971)	3.4: 1	34.1 (112)	9.9 (32.4)	66,160

Figure 2 Aerial image of Greenwood Lake and immediate area around the lake (Google Earth image 8/2013)



Figure 3 Greenwood Lake bathymetric map. Red "x" indicates primary water quality monitoring site.



Ecoregion and Land Use Characteristics

Minnesota is divided into seven regions, referred to as ecoregions, as defined by soils, land surface form, potential natural vegetation, and land use (Omernik 1987). Data gathered from representative, minimally impacted (reference) lakes within each ecoregion serve as a basis for comparing the water quality and characteristics of other lakes. Greenwood Lake lies within the Northern Lakes and Forest (NLF; Figure 4) ecoregion. NLF values are used for land use (Table 2), summer-mean water quality comparisons and model applications. Omernik level III and IV ecoregions provided a basis for the "land type" delineations noted in Figure 1. This step was taken prior to selection of the Sentinel Lakes and provided a means to most closely characterize geomorphological differences in lake condition. In the NLF ecoregion, this allowed for differentiation between the "Canadian Shield" lakes and "Glacial Drift Northern Forest" lakes.

As anticipated, land use within the Greenwood Lake watershed is similar to the ecoregion norms and nearly all forest and open water/wetland. In general, there has been little change in basic land uses over time, primarily because most of the watershed is within the public lands of Superior National Forest. However, timber harvests in the watershed have been extensive, and are ongoing. The extent of past harvest activity may best be illustrated by comparison of 1992 and 2011 NLCD land use maps (Figure 5) and its summary (Table 3). This mapping indicates the extensive harvest of deciduous trees with about 40% remaining in 2011 as compared to 1992. This forest type was offset by increases in evergreen, mixed, and scrub shrub forest (Table 3). All lakes in the Greenwood Lake watershed, and the Greenwood River, are protected by the Shipstead-Newton-Nolan Act (SNN), which established a 400-ft no-harvest buffer around those waters. Tributaries to Greenwood Lake are protected by Forest Resource Council Guidelines for timber harvest along non-trout streams, but are not covered by the SNN.

Figure 4 USEPA ecoregion map with lakes noted.

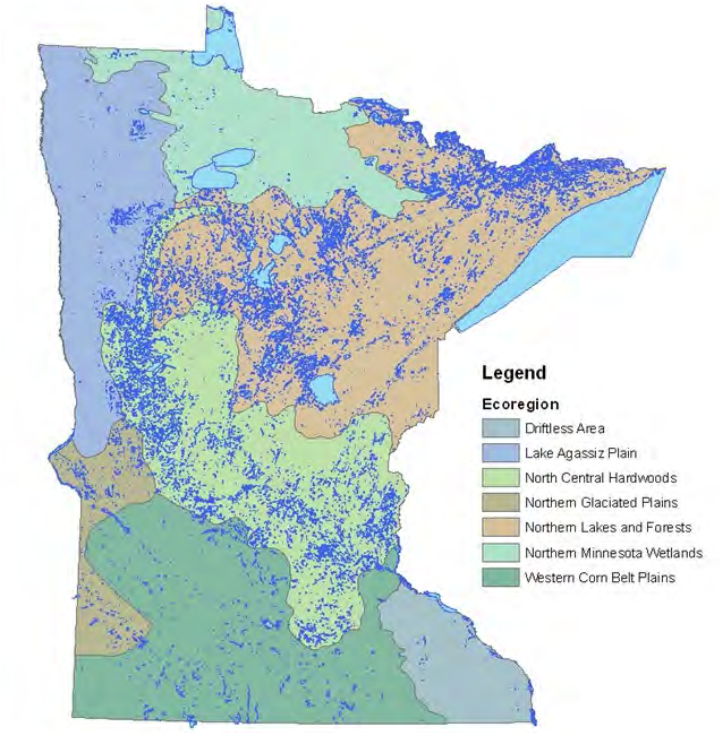


Table 2 Greenwood Lake watershed ecoregion land use comparison. Typical (interquartile) range based on NLF ecoregion reference lakes noted for comparison (Heiskary and Wilson 2005).

Land Use (%)	Greenwood (2011)[1]	NLF ecoregion
Developed	1	0 - 7
Cultivated (Ag)	0	< 1
Pasture & Open	1	0 - 6
Forest	66	54 - 81
Water & Wetland	32	14 - 31

[1] National Land Cover Database www.mrlc.gov/index.php

Figure 5 Greenwood Lake watershed. Mapped land use from 2011 NLCD (top) and 1992 NLCD (bottom).

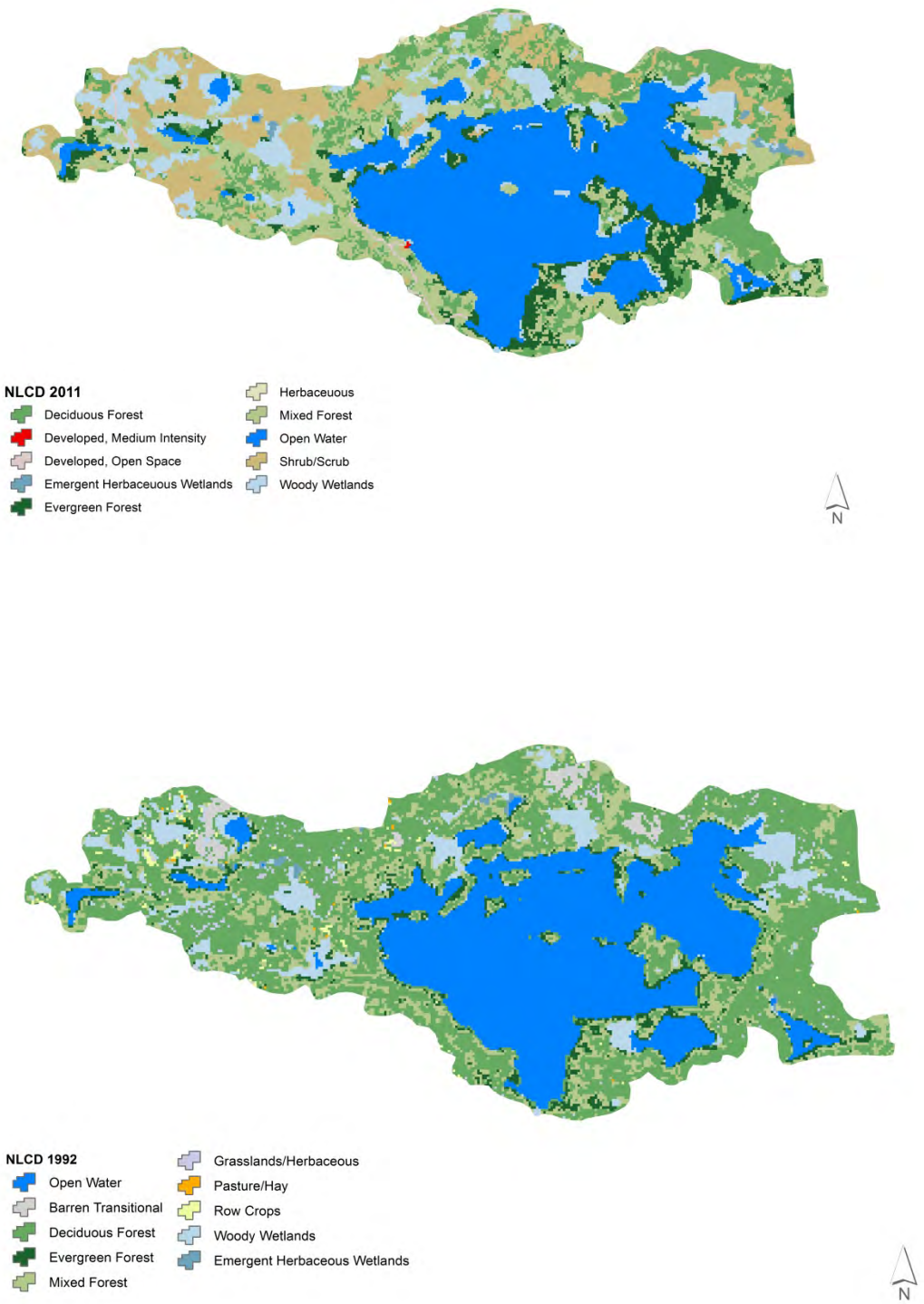


Table 3 Detailed comparison of Greenwood Lake watershed land use composition based on 1992 and 2011 NLCD (in hectares). % change and direction is relative to 1992.

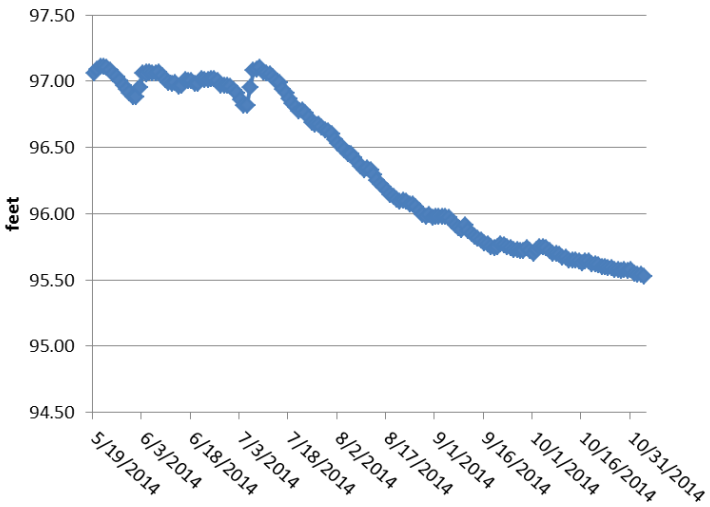
Land use	1992	2011	% Change from 1992	increase or decrease
open water	893	890	<1%	
barren, open space	44		100%	-
developed		14	NA	+
deciduous forest	1053	418	60%	-
evergreen forest	123	228	37%	+
mixed forest	387	541	40%	+
scrub shrub	41	355	92%	+
woody wetlands	206	302	46%	+

Lake Level

The MDNR Division of Ecological and Water Resources began lake level monitoring on Greenwood in 2014. The gauge is located at a high point on NE corner of a 4' x 4' x 2.5' boulder, 25' from southerly edge of boat ramp, at Public Access, on SW side of lake off Greenwood Lake Road. The highest recorded reading was 97.11 feet (05/21/2014) and lowest recorded: 95.53 feet (11/04/2014) with a range of 1.58 feet (Figure 6). Levels were stable from May through mid-July and then declined thereafter. This followed trends in precipitation during summer 2014 as precipitation tapered off after mid-July (Figure 7). Evaporation increases over the summer as well and when combined with lower precipitation this contributes to a decline in lake level.

Intermittent water level measurements were made by MDNR Fisheries at various benchmark locations between 1955 and 2014. Waters levels over the period from 1955 to 2014 varied across a maximum range of 4.5 ft.

Figure 6 Greenwood Lake level elevations in 2014. Based on MDNR data.



Precipitation and Climate Summary

Climate and precipitation for the 2014 field seasons varied considerably. Rain gage records from Grand Marais (the closest long-term climate station to Greenwood Lake) show five 2.5 centimeter (cm; 1 inch) plus rain events during the 2014 field season. Of these, four occurred from April 25- July 6. While there was continued precipitation after that point, it was reduced with 9.45 inches after as compared to 13.62 inches before July 6. Large rain events increase runoff into the lake and may influence in-lake water quality and lake levels. An examination of temperatures for the Grand Marias climate station indicate that the 2014 field season was slightly below normal with maximum of 84F, minimum of 27F, average of 51.6F, which was -0.9F below normal for the period. Overall, precipitation for 2013 was near-normal and 2014 was about 2-4 inches above normal, with rainfall on order of 32-36 inches for each water year (Figure 8).

Figure 7 2014 monitoring season rainfall based on records for Grand Marais, MN. State Climatology Office Data

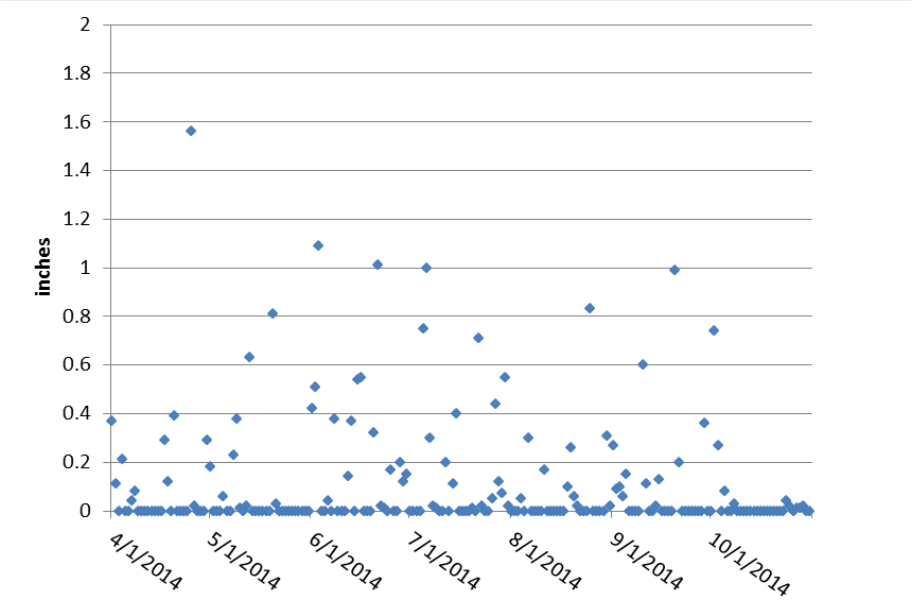
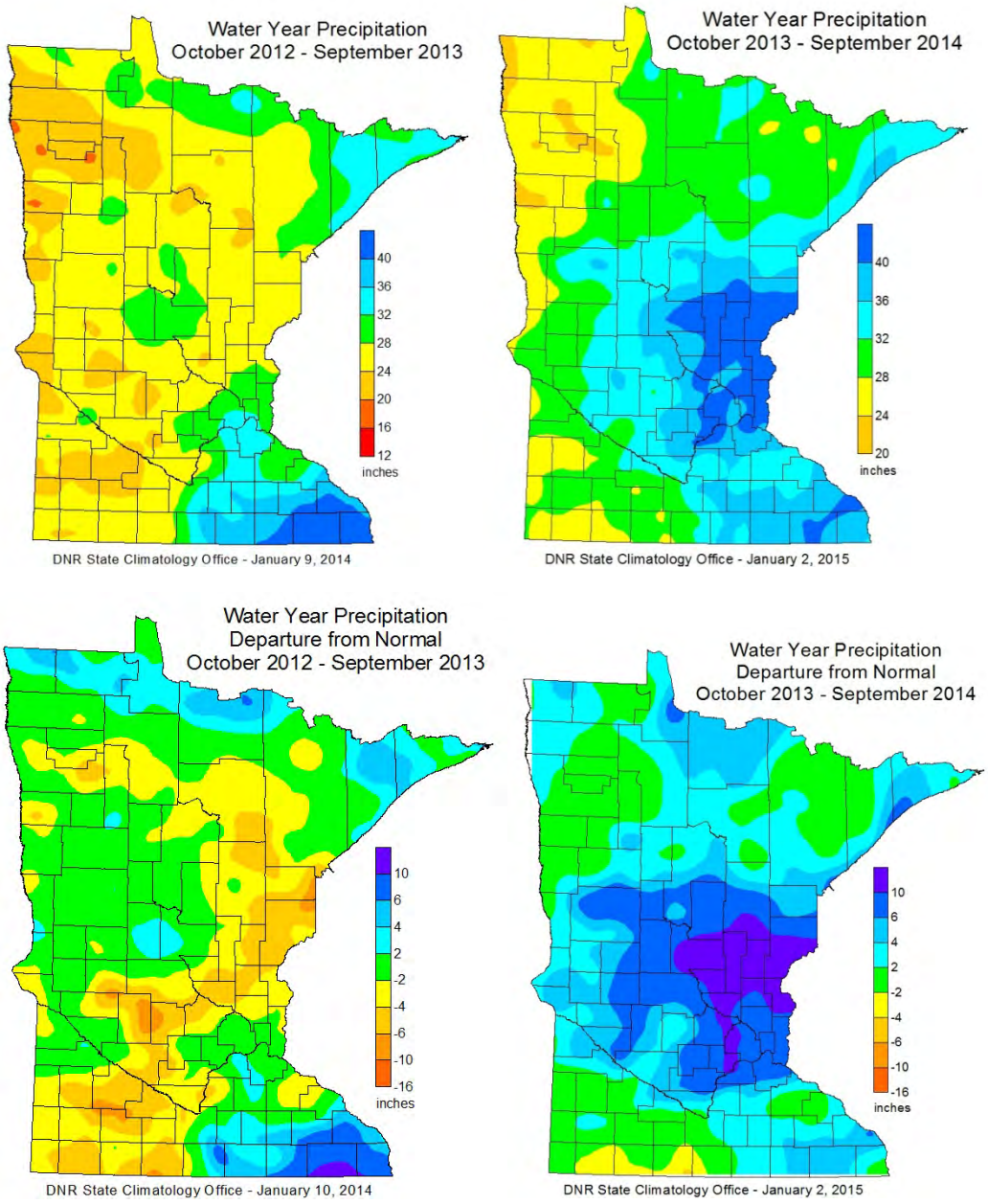
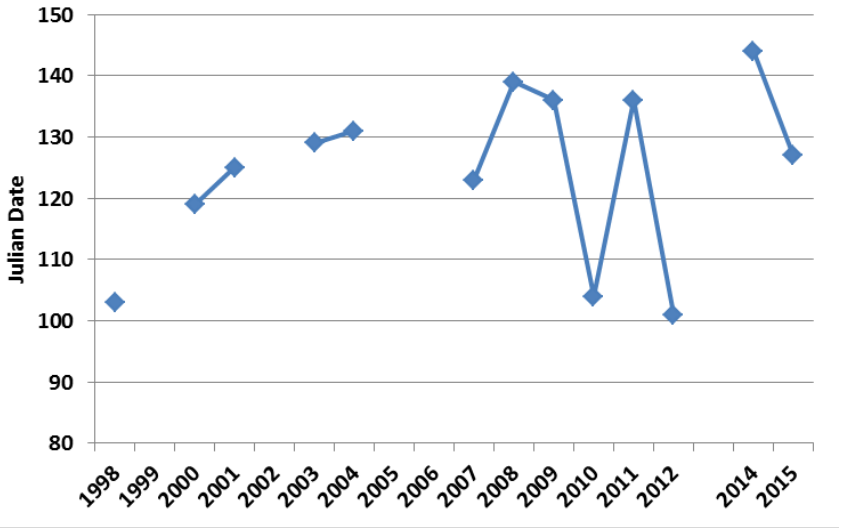


Figure 8 2013-2014 Minnesota water year precipitation and departure from normal (State Climatology Office data).



Ice-out dates can be a useful indicator of climate change. MDNR has recorded ice-out dates since 1998 (Figure 9). The median ice-out date was 127 (May 7, 2015) and ranged from the earliest date of 101 (April 4, 2012) to the latest 144 (May 24, 2014). No trend is evident based on these data; however, this is a relatively short record and there will be a need for continued annual recordings if this is to be a useful indicator. Ice-out data are found at this page http://www.dnr.state.mn.us/ice_out/ice_out_by_lake.html?downum=16007700.

Figure 9 Ice-out dates for Greenwood Lake as collected by MDNR. Dates range from the earliest Julian date 101 (4/10/2012) to latest 144 (5/24/2014).



Methods

Fisheries and Aquatic Plants

Most recent fisheries surveys follow guidelines outlined by MDNR Special Publication 147 (1993; Manual of Instructions for Lake Survey). Nearshore non-game fish surveys were also completed on each Sentinel lake following methods described by Drake and Pereira (2002). Survey methods vary somewhat over time and are addressed in more detail in Results and Discussion.

Frequency of occurrence of aquatic plant species will be assessed using the point-intercept method (Madsen 1999). This method entails visiting sampling points on a grid within the vegetated zone of the lake, throwing a two-sided rake over one side of the boat at each point, raking the bottom approximately 1 meter (m), then retrieving the rake and identifying all species present, and recording the depth. Survey points are typically spaced approximately 80-m (0.7 points per littoral acre). The report will be updated when this data set is available. Score the Shore (Perleberg et al. 2014) was conducted on Greenwood Lake in late summer of 2015 and emergent mapping of the lake is anticipated to occur in 2016. The results of those efforts will also be added when data are available.

Water Quality

In 2013 and 2014 MPCA lake surface samples were collected with an integrated sampler, a poly vinyl chloride (PVC) tube 2 meters (6.6 feet) in length, with an inside diameter of 3.2 cm (1.24 inches). Zooplankton samples were collected with an 80 micrometer (µm) mesh, 30 centimeter (cm) simple zooplankton net. Phytoplankton (algae) samples were taken with an integrated sampler. Deep total phosphorous (TP) samples were collected with a Kemmerer sampler. Temperature and dissolved oxygen (DO) profiles and Secchi disk transparency measurements were also taken by MPCA and MDNR staff. Most profiles and Secchi transparency measurements were done at a sampling site located in the deepest area of the central basin of the lake (Site 102; Figure 3). Sampling procedures were employed as described in the MPCA Standard Operating Procedure for Lake Water Quality document, which can be found here: http://www.pca.state.mn.us/publications/wq-s1-16.pdf . In addition to the individual DO and temperature profiles, continuous temperature measurements were made by a string of sensors (thermistor)

suspended at 1-2 m intervals from the surface of the lake to one meter above the bottom in 2013 and 2014. These sensors record temperature at pre-defined intervals (e.g. hourly) and serve to complement the discrete profiles.

Laboratory analysis was performed by the laboratories of the Minnesota Department of Health, using United States Environmental Protection Agency-approved methods. Samples were analyzed for nutrients, color, solids, pH, alkalinity, conductivity, chloride, metals, and chlorophyll-*a* (Chl-*a*). A list of methods and reporting limits (RL) used in the 2014 sampling are included in the Appendix.

Phytoplankton samples were analyzed at PhycoTech using a modified rapid assessment technique which was patterned after a method developed by MPCA staff. This technique allows for identification of major algal forms (typically to species level) and estimates of relative biovolume and is similar to the technique used on the other Sentinel Lakes; however, more species-level identification was provided by PhycoTech analysts as compared to MPCA analysts. These analyses were part of a larger project to analyze phytoplankton composition across several Sentinel Lakes, thus data from Trout Lake is available for comparison to Greenwood Lake.

Zooplankton

Zooplankton samples were collected monthly from ice-out (May) through October 2013-2014. Typical protocol calls for one vertical tow taken at each sampling event. Because Greenwood has spiny waterflea, four tows were taken, one with a standard 80µ net and three with a large 0.5m, 250µ net, which is intended to increase the likelihood of capturing spiny water flea (*Bythotrephes longimanus*. The nets were lowered to within 0.5 m of the bottom and withdrawn at a rate of approximately 0.5 meters per second. Contents were rinsed into sample bottles and preserved with 100% reagent alcohol for subsequent analysis by MDNR personnel.

Each zooplankton sample was adjusted to a known volume by filtering through 80 µm mesh netting and rinsing specimens into a graduated beaker. Water was added to the beaker to a volume that provided at least 150 organisms per 5-milliliter aliquot. A 5-milliliter aliquot was withdrawn from each sample using a bulb pipette and transferred to a counting wheel. Specimens from each aliquot were counted, identified to the lowest taxonomic level possible (most to species level), and measured to the nearest .01 millimeter using a dissecting microscope and an image analysis system. Densities (#/liter), biomass (µg/L), percent composition by number and weight, mean length (millimeter), mean weight (µg) and total counts for each taxonomic group identified were calculated with the zooplankton counting program ZCOUNT (Charpentier and Jamnick, 1994 in Hirsch, 2009).Total number of spiny waterfleas collected from each 250µ tow was enumerated separately. Densities were reported as number per cubic meter, averaged across tows

Results and Discussion

Fisheries Assessment

Historical (pre-Sentinel assessment and survey)

The native fish community in Greenwood Lake was probably very simple, with major species perhaps limited to Lake Trout, White Sucker, and Northern Pike. Over time, as a result of stocking done since 1926, and other introductions or movements of fish, the community has become more complex. Fish species collected in Greenwood Lake to date (with year first collected in parentheses) include: Lake Trout (1943), White Sucker (1943), Green Sunfish (1943), Northern Cisco (1943), Walleye (1955), Lake Whitefish (1958), Yellow Perch (1958), Rainbow Trout (1966), Brook Trout (1966), Kokanee

Salmon (1967), Coho Salmon (1969), Creek Chub (1977), Smallmouth Bass (1980), Longnose Dace (1986), Golden Shiner (1983), Splake (1983), and Northern Pike (2013). Of these, Rainbow Trout, Kokanee Salmon, Coho Salmon, and Splake are no longer present. If Walleye are still present, their numbers are very low. Meristic counts done by Dr. David Etnier on a sample of Northern Cisco taken from Greenwood Lake in 2005 confirmed that the fish taken were *Coregonus artedii*. Prior to 2013, Greenwood Lake was one of very few lakes in Cook County where no Northern Pike had ever been collected, and the apparent absence of Burbot was also unusual in a lake of this type.

Lake Trout gill net catches in MDNR surveys have ranged from 0.4 fish/net (1958) to 6.0 fish/net (1993; Table 4). Lake Trout gill net catches appeared to increase significantly between 1969 and 1980. Since 1980 they have generally fallen in the 1.5-3.0 fish/net range, showing no clear trend. Gill net catches in 2009 and 2013 fell short of the long range goal for the species (2.0 fish/set), and neither assessment captured any fish over 30 inches in length. Historically, Lake Trout size distributions in this lake have included fish up to 42 inches, but fish less than 19 inches dominate samples. Lake Trout have exhibited average growth during their first few years of life, but after age 4, their growth apparently slows (Table 7). Growth of age-6 and age-7 Lake Trout collected in various assessments has usually been below average when compared to means for Schupp Lake Class 1 lakes in this area (Schupp 1992).

Much of the past assessment effort on Greenwood Lake was directed at evaluating Lake Trout stocking. To aid in that evaluation, all Lake Trout stocked after 1985 were fin-clipped (adipose). In the 1990, 1993, and 1996 assessments, natural reproduction accounted for most of the Lake Trout collected. Very few fin-clipped Lake Trout over age 1 were collected in 1993; it appeared that stocked fish accounted for no more than 5% of the age 2-9 Lake Trout collected that year. Fin-clipped Lake Trout accounted for 25% of the Lake Trout collected in the 1999 assessment, but good natural year classes had been produced in 1994, 1995, and 1996. The 2005 assessment provided the clearest evidence that stocking of this lake was unnecessary; all of the Lake Trout collected that year were produced naturally, and the catch was as high as any, during the years the lake was stocked.

Smallmouth Bass were first collected in Greenwood Lake in 1980. From 1980 to 1996, trap net catches of Smallmouth Bass appeared to increase, with mean weight of trap-netted Smallmouth Bass increasing slightly as well (Table 5). Catches of Smallmouth Bass in trap nets in 1999 and 2005 were lower, with none taken in that gear in 2005; however, gill net catches over the same period (1996-2005) were stable and anglers in 2005 and 2006 reported large numbers of small Smallmouth Bass in the lake. Trap net catches rebounded in 2009 and 2013. In the 1980s, anglers reported an excellent fishery for large Smallmouth Bass, but by 1993 most of the Smallmouth Bass collected in trap nets were under 12 inches and the fish collected exhibited relatively slow growth. Age-4 Smallmouth Bass collected in 1993 averaged 8.1 inches at last annulus formation, compared to the Cook County average of 9.1 inches. Smallmouth Bass growth rates have since remained slow compared to rates observed in other Class 1 lakes in this area.

Cisco gill net catches declined through 2005, but rebounded to historic levels in 2009 and 2013 (Table 4). Catches in deep gill net sets fell below the current long range goal (5.9 fish/deep gill net set) in 1996 and 2005, and barely met it in 1999; however, the goal was exceeded by a wide margin in 2009 and 2013 (Table 6). Cisco size distributions have included fish from 5 to 17 inches and have usually been dominated by fish over 12 inches. Cisco collected in 1993 and 1999 exhibited relatively fast growth; age-3 fish collected in 1999 averaged 12.5 inches at last annulus formation, compared to a Cook County average of 10.1 inches. Growth of Cisco collected in 2013 was faster still; age-3 fish reached a mean length of 13.7 in at last annulus formation. The 1999 catch included just two strong year classes, with no fish older than age 3. In 2013 two strong year classes (2010 and 2011) contributed to the catch, and fish as old as age 5 were collected. Cisco collected in 2013 ranged in length from 9.5 to 20.0 in, with most in the 12-16-in length range.

Walleye were first sampled in Greenwood Lake in 1955, but they were never abundant, with gill net catches peaking at just over one fish per net. Walleye were last sampled in 1980. Their decline and eventual disappearance coincided with an increase in Lake Trout abundance, the introduction of Smallmouth Bass, and the reclamation of Sunfish Lake for stream trout management. The latter event removed that upstream Walleye population, and a barrier constructed on this lake's outlet stream at the shore of Greenwood Lake blocked access to what might have been a spawning area for Walleye in the connecting stream. MDNR resumed management of Sunfish Lake for Walleye in 2000, and the barrier between Greenwood and Sunfish lakes has washed out, so it is possible that some Walleye are again present in Greenwood Lake.

Brook Trout have frequently been taken in assessments of this lake, usually in trap nets, and usually in low numbers (Table 5). The lake apparently supports a small natural population, perhaps recruited from the portion of the Greenwood River accessible from the lake (above the barrier falls just downstream of the lake). Splake, when they were collected, probably entered the lake from Sunfish Lake, where they were stocked for many years. Rainbow Trout stocked in connected North Shady and Edith Lakes apparently did not move down into Greenwood Lake in detectable numbers.

Northern Pike had been reported by anglers and commercial fishers in Greenwood Lake on rare occasions, and one (a 25-in fish) was taken by a sport netter in 2010; however, they were first sampled in a DNR assessment in 2013. In 2013, a few Northern Pike were taken in gill net and trap net sets. They ranged in length from 16.2 to 27.2 in. Three year classes (2010-2012) contributed to the catch. Growth had apparently been fairly fast; fish reached a mean length of 18.9 in at age-2 annulus formation, compared to an area mean of 15.1 in for Class 1 lakes (data through 2010). The source of these fish and the reason for their modest surge in numbers in 2013 are unknown. Northern Pike had become well established in Sunfish Lake by 2007 from an unknown source, and that lake may have been a recruitment source for Greenwood. Northern Pike had also been reported (by anglers) from Edith Lake, which also drains to Greenwood Lake, and that may have been the original source of fish found in Greenwood and Sunfish lakes.

Aquatic vegetation in Greenwood Lake was surveyed by the Minnesota County Biological Survey in 2012. Diversity seemed to have been low; most of the species identified were shoreline plants.

Greenwood Lake served as a study lake in a research project examining Lake Trout-Smallmouth Bass interactions and population characteristics, conducted in 1989 and 1990 (Eiler and Sak 1993). Results of that study were inconclusive. In 1993, the lake served as a study lake in a research project aimed at comparing and evaluating the use of short-term monofilament gill net sets to assess Lake Trout populations (Siesennop 1997). Short-term gill nets were effective in sampling Lake Trout in Greenwood Lake, with minimal mortality.

A winter creel survey in 1982 estimated fishing pressure at 0.2 angler-hour/acre (Persons 1985). Estimated Lake Trout harvest rate, harvest, and yield were 0.14 fish/angler-hour, 74 fish, and 0.1 lb/acre, respectively. Estimated mean length of harvested Lake Trout was 19.8 inches. No summer data and no more-recent winter creel survey data are available.

Past management: Lake Trout were stocked frequently from the 1920s through 1993. Lake Trout yearlings were stocked every odd year, 1981-1993, except 1989, and all stocked lake trout were fin-clipped starting in 1985. Lake Trout stocking quotas in the 1980s and 1990s ranged from 7,030 to 23,126 yearlings/stocking. Lake Trout stocking in this lake was discontinued in the 1994 lake management plan (LMP) revision, and Lake Trout were last stocked in 1993.

A brief sentence in the 1943 investigational report states that Lake Trout spawn was taken on Greenwood Lake sometime in or before 1933. No mention was made of the ultimate use of those eggs.

Cisco were introduced from Lake Superior in 1926. There is no record of Lake Whitefish stocking, but they may also have been introduced during the same period. The 1943 report states that the native fish community in Greenwood Lake consisted of White Suckers and Lake Trout, and possibly Northern Pike.

Rainbow Trout were stocked frequently in the 1930s, 1940s, and 1960s and Brown Trout were stocked a few times in the 1930s and 1940s. Kokanee and Coho Salmon were stocked several times in the 1960s. At that time, a large rock filter-barrier was built across the outlet of Greenwood Lake (the Greenwood River) just downstream of the lake to block the movement of Kokanee and Coho salmon out of the lake. The barrier has since washed out, although most of the structure remains.

Walleye were introduced from stocking done in Sunfish Lake in the 1930s and 1940s and possibly from an accidental stocking in Greenwood Lake in 1936 (described in the 1943 investigation report). Walleye appear to have become scarce or absent after Sunfish Lake was reclaimed and managed for stream trout in 1965. In 1957, a request from the United Northern Sportsmen to remove Walleye from Greenwood Lake in order to rehabilitate the Lake Trout population was rejected as being biologically and economically unsound. It is interesting to note (although it may be coincidental) that increases in Lake Trout abundance occurred at about the time Walleye abundance was declining.

Commercial fishing for Cisco, and to a lesser extent Lake Whitefish, started in 1943 and conducted annually from 1947 through 1960, in 1967-68, annually from 1974-1978, in 1980, and annually from 1983 to about 2010. One of the early goals for this commercial fishery was to reduce Cisco abundance, since they were considered an introduced species that was having an adverse effect on the Lake Trout population. From 1974 through 1978, Cisco eggs were taken by state crews during commercial operations and these eggs were used to produce fry for stocking in Lake Superior. In the 1990s and through about 2010, commercial fishing was largely confined to the winter season, and annual harvests ranged from 1,185 to 13,961 lb.

Current Management: Current MDNR Fisheries management goals for this lake are to maintain a Lake Trout population with a minimum gill net catch of 2.0 fish/set (deep and shallow sets combined), with some fish over 30 inches, and to maintain a Cisco population with a minimum gill net catch of 5.9 fish/set in deep gill net sets (2015 Lake Management Plan). Goals for this lake have evolved over time. The initial (1986) lake management plan (LMP) for this lake established long-range goals of providing Lake Trout averaging 2-4 lb. and Smallmouth Bass averaging 1-2 lb., while maintaining adequate numbers of trophy Lake Trout. The 1991 LMP revision established the current long-range goal for Lake Trout, with the catch goal based, apparently, on a rough average for the lake. Although Smallmouth Bass were retained as the secondary management species in the 1991 plan, no long-range goal was set. Long range goals were not changed in the 1994 LMP revision. In the 2000 LMP revision, Cisco replaced Smallmouth Bass as the secondary species because of their importance in the lake commercially. The Cisco long-range goal was based on the median catch in deep gill net sets in the Grand Marais area at the time (data through 1996). Smallmouth Bass were considered a recently introduced exotic, and while they provided an important fishery in the lake, they were not to be the subject of any management designed to maintain their abundance at any particular level. Goals from the 2000 LMP revision were retained in the 2007 LMP revision, and were again retained in the most recent (2015) revision, since they still seemed realistic and relevant for this lake. Although the lake no longer supports a commercial Cisco fishery, the presence of a thriving Cisco population is considered is desirable for providing forage for Lake Trout, its status as an indicator species, and its value for sport harvest (angling and netting).

Public input: Public input on the management of Greenwood Lake was sought prior to preparation of revised lake management plans in 2000, 2007, and 2015. Comments have been sparse. One cabin owner on the lake expressed concern that continued stocking was needed to maintain the Lake Trout fishery, a view that has been shared by a few others. One or two anglers expressed concerns about the

loss of quality in the Smallmouth Bass fishery. These anglers wanted regulations implemented that would preserve the high quality fishery that they experienced in the late 1980s.One angler (and cabin owner) was concerned about an over-abundance of Smallmouth Bass and favored any measures that would reduce or eliminate them in trout streams and trout lakes. A few anglers have suggested an effort be made to restore the Walleye population in Greenwood Lake.

Social considerations: Greenwood Lake is about 37 km (23 miles) by road from Grand Marais. Shoreline development observed in the 1986 survey included a USFS owned boat launch, one private resort, and 30 private lake homes and cabins, but development on the lake has increased significantly since 1986. The lake is well known for its Lake Trout fishing and its potential to produce trophy size fish over 20 or even 30 pounds. However, it also has a reputation for being difficult to fish in the summer and fishing pressure is probably light overall. The Smallmouth Bass fishery on the lake has attracted some anglers. A handful of anglers participate in the fall sport netting season.

Although most of the shoreline of Greenwood Lake is federally owned, development of the lake has been increasing. Greenwood Lake was the site for a new series of private developments in 1992-1993. Lots for ~ 20 cabins were platted on lands in the NE corner of the lake that were acquired from the USFS by a private developer; construction was underway at the time of the 1993 assessment. In winter 2000, the private resort (NALAC, North American Life and Casualty - formerly Greenwood Lake Lodge) was placed on the market, it was rumored that the property was to be broken up; however, as of 2013 that had apparently not occurred. At about the same time, a private landowner along the southern end of the lake platted several lots on his land, with intent to develop.

Prior to 1999 the public access on Greenwood Lake was small, with very limited parking. The site was upgraded by DNR Trails and Waterways in 1999. They improved the turn-around space and providing better parking. The access remains fairly small, and it seems unlikely that the improvements resulted in much increase in fishing pressure.

Present limiting factors: Lake Trout reproduction appears to be capable of sustaining a Lake Trout population that would meet or exceed the long-range goal for this lake. Assessments since 1990 indicated that Lake Trout stocking contributed relatively little to the population. There were some indications in the 1993 assessment that stocked Lake Trout showed poorer long-term survival than natural fish; stocked fish made up 44% of the 1986 year class in 1990, but only 15% of the same year class in 1993.

Slow growth of Lake Trout has been a chronic problem in this lake. Lake Trout collected during the 1955 survey averaged 12.4 (N=7) and 14.3 (N=4) inches at age-4 and age-5 annulus formation, respectively. In 1990, Lake Trout averaged 10.9 (N=15) and 13.0 (N=5) inches at age-4 and age-5, respectively. Growth rates of Lake Trout collected in 1993 were similar to those observed in 1990, and slow growth was also observed in later samples (Table 7). Competition with Cisco has long been hypothesized as a factor contributing to slow growth in small Lake Trout; however, Cisco also provide high-quality forage for large Lake Trout, allowing the lake to produce some trophy-sized fish.

The Smallmouth Bass population has probably reached a point of stability and it appears that growth rates have slowed. Development of a high quality Smallmouth Bass fishery will likely be hampered by slow growth rates, as it has been in similar lakes in this area.

Commercial fishery: With Greenwood Lake now included in the Sentinel Lakes program, a resumption of commercial Cisco harvest is unlikely (also, there is no good management reason for the harvest and no interested harvesters). The Sentinel Lakes program will be monitoring the Cisco population for changes that may occur due to development or climate change, and adding commercial harvest could very well mask the effects of those factors.

Stocking plans: Natural reproduction appears to be adequate to sustain the Lake Trout population in Greenwood Lake, thus supplemental Lake Trout stocking should not be necessary. Lake Trout stocking should only be resumed if assessment data indicate that it is needed to meet the long range goal for this lake. No other fish species should be stocked. In particular, Walleye should not be stocked, due to potential adverse effects such a stocking might have on the Lake Trout population.

Other management tools: Sport netting for Cisco and Lake Whitefish has been a popular pursuit with some local anglers, and has served to use some under-utilized resources. One of the more popular local lakes for this pursuit, Flour Lake, was dropped from the netting list due to a heavy infestation of *Triaeanophorus* (a tapeworm that can form cysts in the flesh of whitefish). To replace that opportunity, Greenwood Lake was added to the list of lakes open to sport netting, with the first open season in fall 2000. Sport netting may continue on this lake. To minimize bycatch of Lake Trout, the netting season in Greenwood should be opened later than most other seasons in the area and the netting season should be monitored closely to determine how much Lake Trout bycatch occurs.

Sentinel survey and assessment

Lake Trout were fairly abundant in Greenwood Lake in 2013, and although most of the fish present were small, the presence of a good Cisco forage base gave the lake potential for producing much larger fish. The Lake Trout gill net catch was within the normal range for this lake type, and was similar to most catches seen in this lake historically. Lake Trout that were collected ranged in length from 11.2 to 29.3 inches (mean 16.2 inches), with most in the 13-19-inch range. Several year classes, all naturally produced, contributed to the catch, although none stood out as being exceptionally strong. Growth of young Lake Trout had been about average; they reached an average length of 12.3 inches by the end of their fourth year, compared to an average of 12.1 inches for fish taken in similar lakes in this area.

Forage for larger Lake Trout was provided by relatively high numbers of Cisco. The 2013 gill net catch was well within the normal range for a lake of this class, and was one of the higher catches seen in this lake in recent years. The 136 Cisco collected in gill nets ranged in length from 9.5 to 20.0 inches (mean 14.5 inches), with most in the 12-16-inch range. Five year classes contributed to the catch, with the strongest apparently produced in 2010 and 2011. Cisco growth had been relatively fast; fish reached an average length of 13.7 inches at the end of their third year.

Vertical gill netting was done by Sentinel Lake program staff in August 2013 to assess the spatial distribution of the cisco population, and this was followed by a hydroacoustic assessment of the lake-wide population. Fifty-two cisco were collected in three vertical sets. Cisco collected averaged 13.7 inches (349.2 mm) in length, with a range of 4.1 to 18.3 inches. Lake trout (2.3 fish/set) and Smallmouth Bass (0.6 fish/set) were also collected. Cisco were captured at an average depth of 11.7 m (38.4 ft), while the average depth at which Lake Trout were captured was 24.6 m (80.7 ft).

The Smallmouth Bass catch in MDNR Fisheries gill net sets in 2013 was low, but was similar to past catches seen in this lake. The catch in 0.75-in-mesh trap nets exceeded the normal range for Class 1 lakes, suggesting high Smallmouth Bass abundance, at least in nearshore areas. Smallmouth Bass collected in gill nets ranged in length from 12.0 to 13.8 inches, while those taken in trap nets ranged from 5.6 to 15.0 inches. Although most of the Smallmouth Bass taken were small, enough fish larger than 11 inches were present to provide some quality-sized fish for anglers. Seven year classes contributed to the Smallmouth Bass catch, including what appeared to have been a fairly strong year class produced in 2010. Growth had apparently been somewhat slower than average; five-year-old fish reached a mean length of 9.5 in by the end of their fifth year.

Northern Pike were collected for the first time in this lake in the 2013 assessment. There had been rare reports of Northern Pike (usually large) being taken by anglers, or in commercial nets, but none had

ever been captured in Fisheries survey gear. In 2013, two Northern Pike were taken in shallow gill net sets, and five were taken in 0.75-in-mesh trap nets. Northern Pike collected ranged in length from 16.2 to 27.2 inches. Three year classes contributed to the catch. Growth of young fish had been fast; they reached a mean length of 18.8 inches by the end of their second year. If the Northern Pike population density remains low (as it probably will), the presence of an excellent Cisco forage base and many coolwater refuge areas should allow for the production of some trophy-sized fish in this lake.

MDNR Fisheries staff sampled the nearshore fish community in August 2013 to collect data that could eventually be used (in conjunction with gill net and trap net data) to calculate an Index of Biotic Integrity (IBI) score for Greenwood Lake. Sampling used quarter-inch-mesh trap nets, a 15-ft beach seine, and backpack electrofishing gear at 24 randomly located sites. Nearshore sampling added no species to the list of those previously known to be present in Greenwood Lake. The catch consisted of relatively small numbers of Cisco, Golden Shiner, Green Sunfish, Northern Pike, Smallmouth Bass, White Sucker, and Yellow Perch. IBI scoring criteria for lakes in Northeastern Minnesota have not yet been established.

SLICE fish sampling protocols for Greenwood Lake: Fish sampling protocols for sentinel lakes in the SLICE program were published internally in 2014 (Sentinel Lakes Sampling Fish Protocols.pdf; 5/27/2014). The following protocols may apply to Greenwood Lake, although final sampling details for the lake have yet to be determined.

- Summer gill netting: None currently scheduled in the protocol; however, to establish a good baseline its likely gill netting would be needed in 2015, 2017, and 2019. Gill netting may be done at three-year intervals thereafter (starting in 2022). Collect scales and otoliths from Yellow Perch and determine sex and maturity when possible. Collect scales and otoliths from all Lake Trout and determine sex and maturity for all fish. Collect scale samples and otoliths or cleithra from all Walleye and Northern Pike. Collect individual fish weights from yellow perch that have been scale-sampled, and from all cisco, lake trout, northern pike, and walleye.

- Summer trap netting: Structures collected during gill netting follow lake survey protocols.

- Spring electrofishing: Will be conducted to assess Smallmouth Bass, using Sentinel Lakes (not standard lake survey) protocols.

- Vertical gill netting: Done to assess Cisco populations. Although not addressed in the protocol, this may be done (as it is on Trout Lake) in one of every three years.

Table 4 Number of fish per set, and mean weight (pounds/fish) for Lake Trout, Cisco, Lake Whitefish, Smallmouth Bass, and Yellow Perch taken in gill net sets (deep and shallow combined) in surveys of Greenwood, Cook County, Minnesota, 1955-2013. Walleye were last collected in gill nets in 1980. Northern Pike were collected in gill nets for the first time in 2013 (0.17 fish/set).

Survey	No.	Lake Trout		Cisco		Lake Whitefish		Smallmouth Bass		Yellow Perch	
Date	Sets	Number	Weight	Number	Weight	Number	Weight	Number	Weight	Number	Weight
8/22/55	14	1.21	1.40	41.00	0.31						
7/14/58	14	0.36	1.22	18.79	0.44	0.29	1.70			0.07	
7/14/66	24	1.17	3.41	22.29	0.66	0.42	1.38			18.58	0.10
9/24/69	8	0.75	2.08	9.50	0.54					18.88	0.20

Survey Date	No. Sets	Lake Trout		Cisco		Lake Whitefish		Smallmouth Bass		Yellow Perch	
		Number	Weight	Number	Weight	Number	Weight	Number	Weight	Number	Weight
8/5/77	16	2.56	1.61	13.94	0.49	0.31	1.84			0.94	0.09
8/22/80	16	3.06	1.06	19.88	0.65	1.06	1.41			1.38	0.12
8/19/83	12	2.17	3.37	17.42	0.56	1.08	1.88			1.58	0.11
8/29/86	12	1.83	2.02	6.83	0.83	0.83	1.50	0.50	1.49	1.58	0.14
9/1/90	12	3.08	1.09	8.42	0.64	0.67	1.54	1.25	0.34	0.92	0.16
8/2/93	12	6.00	1.51	12.00	0.53	1.08	2.38	0.50	0.55	0.58	0.23
8/5/96	12	2.08	1.98	3.42	0.73	0.42	2.55	0.25	0.49	0.25	0.33
8/23/99	12	2.00	1.36	5.25	0.69	0.67	2.78	0.42	0.59	0.17	
8/29/05	12	2.75	1.15	5.83	0.82			0.42	0.32	0.08	
8/17/09	15	1.47	1.56	17.87	0.88			0.20	0.50		
8/19/13	12	1.92	1.83	11.33	0.36	0.08		0.25	0.87	0.17	
Class 1											
Median		2.08	1.79	7.65	0.42	2.33	1.86	0.71	0.97	1.50	0.16
1st Q		0.85	1.22	1.40	0.14	1.07	1.31	0.25	0.65	0.28	0.12
3rd Q		4.25	3.06	17.38	0.72	9.28	2.34	2.19	1.35	2.83	0.20

Table 5 Number of fish per set, and mean weight (pounds/fish) for Smallmouth Bass, Yellow Perch, White Sucker, Green Sunfish, and Brook Trout taken in 0.75-in-mesh trap net sets in surveys of Greenwood, Cook County, Minnesota, 1955-2013.

Survey Date	No. Sets	Smallmouth Bass		Yellow Perch		White Sucker		Green Sunfish		Brook Trout	
		Number	Weight	Number	Weight	Number	Weight	Number	Weight	Number	Weight
8/22/55	8					5.63	0.62				
7/14/66	8			3.00	0.15	10.00	0.63			0.13	
8/5/77	12			4.08	0.15	17.00	0.72	0.25	0.13		
8/22/80	14	0.07		0.50	0.24	17.86	0.93	0.07			
8/19/83	10	0.60	0.33	1.60	0.54	15.90	0.89	0.40	0.10	0.10	
8/29/86	14	0.64	0.22	0.07		3.64	1.46	0.86	0.08	0.64	0.67
9/1/90	20	2.15	0.23			1.85	1.30	0.20	0.06	0.25	ND
8/2/93	12	1.00	0.30	0.08		1.00	2.60	0.75	0.10	0.17	
8/5/96	12	4.75	0.38	0.25	0.40	1.67	1.14	0.08			
8/23/99	12	2.58	0.34	0.33	0.21	0.08		0.17	0.08		

Survey	No.	Smallmouth Bass		Yellow Perch		White Sucker		Green Sunfish		Brook Trout	
Date	Sets	Number	Weight	Number	Weight	Number	Weight	Number	Weight	Number	Weight
8/29/05	12					0.25	2.16		0.08		
8/17/09	15	1.47	0.37	0.07		0.80	0.66	0.20	0.12	0.13	
8/19/13	12	3.92	0.34					0.17			
Class 1											
Median		1.19	0.35	0.50	0.21	1.33	1.52	0.25	0.10	ND	ND
1st Q		0.60	0.23	0.25	0.14	0.54	1.07	0.10	0.07		
3rd Q		3.53	0.55	2.33	0.36	3.44	2.03	0.77	0.11		

Table 6 Number of fish per set, and mean weight (pounds/fish) for White Sucker and Smallmouth Bass taken in shallow gill net sets (GSH), and Lake Trout and Cisco taken in deep gill net sets (GDE), in surveys and assessments of Greenwood Lake, Cook County, Minnesota, 1980-2013.

	No.	No.	Shallow Gill Net Sets				Deep Gill Net Sets			
Survey	GSH	GDE	White Sucker		Smallmouth bass		Lake trout		Cisco	
Date	Sets	Sets	Number	Weight	Number	Weight	Number	Weight	Number	Weight
8/22/80	3	10	19.00	1.26			3.80	1.07	18.80	0.66
8/2/93	4	8	6.00	2.70	1.50	0.50	9.00	1.51	10.13	0.56
8/5/96	4	8	0.75	0.33	0.75	0.49	3.13	1.98	3.63	0.77
8/23/99	4	8	0.50		1.25	0.59	3.00	1.36	6.13	0.70
8/29/05	4	8	1.50	2.12	1.25	0.32	4.00	1.14	4.25	1.03
8/17/09	5	10	1.20	1.45	0.60	0.50	2.20	1.58	15.90	1.04
8/19/13	4	8	2.50	2.30	0.75	0.87	2.88	1.83	13.38	0.33
Local Medians[1]			2.42	2.08	1.10	0.90	3.00	1.65	8.01	0.53

[1] Grand Marais area data, 1993-2009.

Table 7 Mean length (in) at last annulus formation for age-3, age-4, age-5, age-6, and age-7 Lake Trout collected in assessments or surveys of Greenwood Lake, Cook County, Minnesota, 1955-2013. N equals the number of fish in age class; only means for collections with N > 2 within an age class are reported.

Survey	Age 3		Age 4		Age 5		Age 6		Age 7	
Date	Length	N	Length	N	Length	N	Length	N	Length	N
8/22/55	10.0	3	12.4	7	14.3	4				
8/25/86					12.8	3	12.9	6	18.1	5

Survey Date	Age 3 Length	N	Age 4 Length	N	Age 5 Length	N	Age 6 Length	N	Age 7 Length	N
8/27/90			10.9	15	13.0	5	13.4	7	14.3	3
8/2/93	10.1	9			12.8	3	14.2	9	15.5	12
8/5/96			11.1	14						
8/23/99	9.3	3	11.1	4	12.2	4	12.9	4	14.0	5
8/29/05	10.3	5	12.1	10	14.1	4	16.3	5	16.6	3
8/17/09	8.3	3							16.4	4
8/19/13	11.1	3	12.3	5	13.7	4				
Class 1 Means[1]	9.6	70	12.1	86	14.4	88	16.1	88	18.1	83

[1] Mean of collection means, Grand Marais area data, 1984-2010; N = number of collections.

Water Quality

Standard summer-mean water quality data for 2013 and 2014 are presented in Table 8. In addition, major cations, anions, and dissolved organic carbon (DOC) were analyzed on three sample dates, and those values and typical ranges as derived from the National Lakes Assessment (NLA) database for Minnesota are summarized in Table 9. The NLA was a statistically-based survey of the nation's lakes administered by the United States Environmental Protection Agency in 2007 and 2012. The typical range provided in Table 9 is based on 150 Minnesota lakes that were included in that NLA study and is intended to provide a state-wide perspective. Ecoregion percentiles were based on the 50 NLF ecoregion lakes sampled during the survey and are based on "weighted" cumulative distribution functions. Thus, the reported percentiles reflect the percent of lakes in the ecoregion with concentrations higher or lower than the reported value.

Table 8 Greenwood Lake 2013-2014 summer-mean water quality data. Typical range based on 32 NLF ecoregion reference lakes (Heiskary and Wilson 2008) noted for comparison. A value of half the detection limit was substituted for those values reported as less than the detection limit.

Parameter	Greenwood Lake 2013+2014	NLF
Total phosphorus (µg/L)	7	14 - 27
Chlorophyll mean (µg/L)	2.5	4 - 10
Chlorophyll max (µg/L)	4	<15
Secchi disk (feet) (meters)	16.4 (5)	8 – 15 2.4 – 4.6
Total Kjeldahl Nitrogen (mg/L)	0.4	<0.4 – 0.75
Alkalinity (mg/L)	<10	40 - 140
Color (Pt-Co Units)	10	10 - 35
pH (SU)	7.4	7.2 – 8.3
Chloride (mg/L)	<1.0	0.6 – 1.2
Total suspended solids (mg/L)	2.0	<1 - 2
Total suspended inorganic solids (mg/L)	1.5	<1 - 2
Conductivity (µmhos/cm)	24	50 - 250
Total nitrogen: Total phosphorus ratio	57: 1	25:1 - 35:1

Table 9 Greenwood Lake cation, anion, and total organic carbon measurements. Typical interquartile (IQ) range derived from 150 NLA lakes sampled in 2012 is provided as a basis for comparison. Weighted percentiles reflect number (%) of lakes in the ecoregion that have values less than Greenwood.

Date	Ca mg/L	Mg mg/L	K mg/L	Na mg/L	SO_4 mg/L	Cl mg/L	Si mg/L	DOC mg/L
2014 Average	2.7	1.0	0.5	0.8	2.2	<1.0	1.2	4.9
NLA statewide IQ range [1]	15.5- 34.9	6.9-36.0	1.2-8.1	1.9-12.1	2.4-78.2	3.1-19.1	3.4-17.7	9.0-17.1
NLF % tile [2]	10^{th}	10^{th}	10^{th}	10^{th}	10^{th}	10^{th}	10^{th}	10^{th}

[1] Statewide IQ range from un-weighted concentrations from 150 lakes in Heiskary (2015)
[2] Weighted percentile based on 50 northern forested ecoregion lakes (Heiskary 2015)

Dissolved oxygen and temperature profiles

Dissolved oxygen (DO) and temperature profiles are typically collected on all MPCA sample visits. Profiles from 2013 and 2014 provide a good basis for examining thermal and DO stratification from spring through early fall with 2014 being the most complete. Thermal stratification was beginning by May 29, 2014 with a thermocline forming at 16-18 m (Figure 10). DO was consistent from surface to bottom on this date. By June in both years, formation of the thermocline was yet underway and DO was consistent from the surface to the bottom of the lake. A metalimnetic maximum was noted in June 19, 2013and extended through July 16, 2013. This is common in oligotrophic and some mesotrophic lakes and is often a function of algal DO production in these lower cooler layers of the lake. A metalimnetic maxima was not apparent in 2014 monitoring. By July 16, 2013 the thermocline formed between 5-7 m and then deepened, thereafter to about 14-16 m by October.

Fall mixing was beginning in October in both years but was not yet complete when the October profiles were taken. A review of the continuous temperature readings for 2014 indicated a 1°F or greater difference between the surface and near-bottom (28.5 m) depth existed until October 25 when it fell to 0.5 F suggesting mixing was almost complete and finally reached 0°F (2.8°C [37.2°F] on top and bottom) on November 14. In 2013, complete mixing was attained by October 26 (7.6°C [45.9 °F] on top and bottom). This indicates how long the mixing process takes in a deep lake like Greenwood and how temperature at mixing and timing of mixing can vary.

DO remained above 7 mg/L (MN Rules Ch 7050 Class 2A water quality standard for trout lakes) down to a depth of about 7-8 m in both years (Figure 10). With the formation of the thermocline DO begins to decline in the hypolimnion and is most pronounced in September and October when DO falls below 3 mg/L at ~22 m in 2013 and 20 m in 2014. The corresponding temperature at these depths was ~6.0°C (2013) and ~7.5 (2014).

A collaborative study of select lakes in the Superior National Forest (SNF) by MPCA and SNF staff in 2006 provides additional DO and temperature profiles for Greenwood Lake (Anderson et al. 2007). An among-lake comparison of July 10 and 11, 2006 DO and temperature profiles from these lakes is provided in Figure 11. Greenwood and Trout profiles are similar in shape, though temperature and DO are slightly higher in Trout compared to Greenwood. Both lakes maintain DO >4 mg/L well into the hypolimnion. DO in the other three lakes studied declined more rapidly with depth, but remained above 0 mg/L to the bottom of each lake.

MDNR Fisheries has a long running record of DO and temperature profiles taken in late August (Figure 12), which is often the peak of stratification and can be the most stressful time for coldwater fish. Based on records that date back to 1986 surface temperatures have ranged from 75°F (23.8°C) in 2013 to about 63°F (17°C) in 1987. The thermocline was typically extended from 7-12 m in most profiles. DO remained >3.0 mg/L down to a depth of 24 m in all years. The corresponding temperatures at this depth ranged from 43°F (6°C)-52°F (11°C).

The surface temperature measurements from the profiles are useful for tracking seasonal change in temperatures within and across years, as well as among lakes. MPCA data dating back to 1986 are provided as an example (Figure 13). Based on these data, peak temperatures vary among years and occur most often in July with peaks of ~21-22°C. A comparison of northern Sentinel lakes from 2013 shows similar patterns among lakes, with Greenwood exhibiting slightly cooler temperatures from June through August. In addition, Greenwood Lake's surface water temperature remains below the minimum preferable temperature for blue-green algae (20°C; Knopka and Brock 1978).

Figure 10 Greenwood Lake temperature and dissolved oxygen (DO) profiles 2013 and 2014 (MPCA).

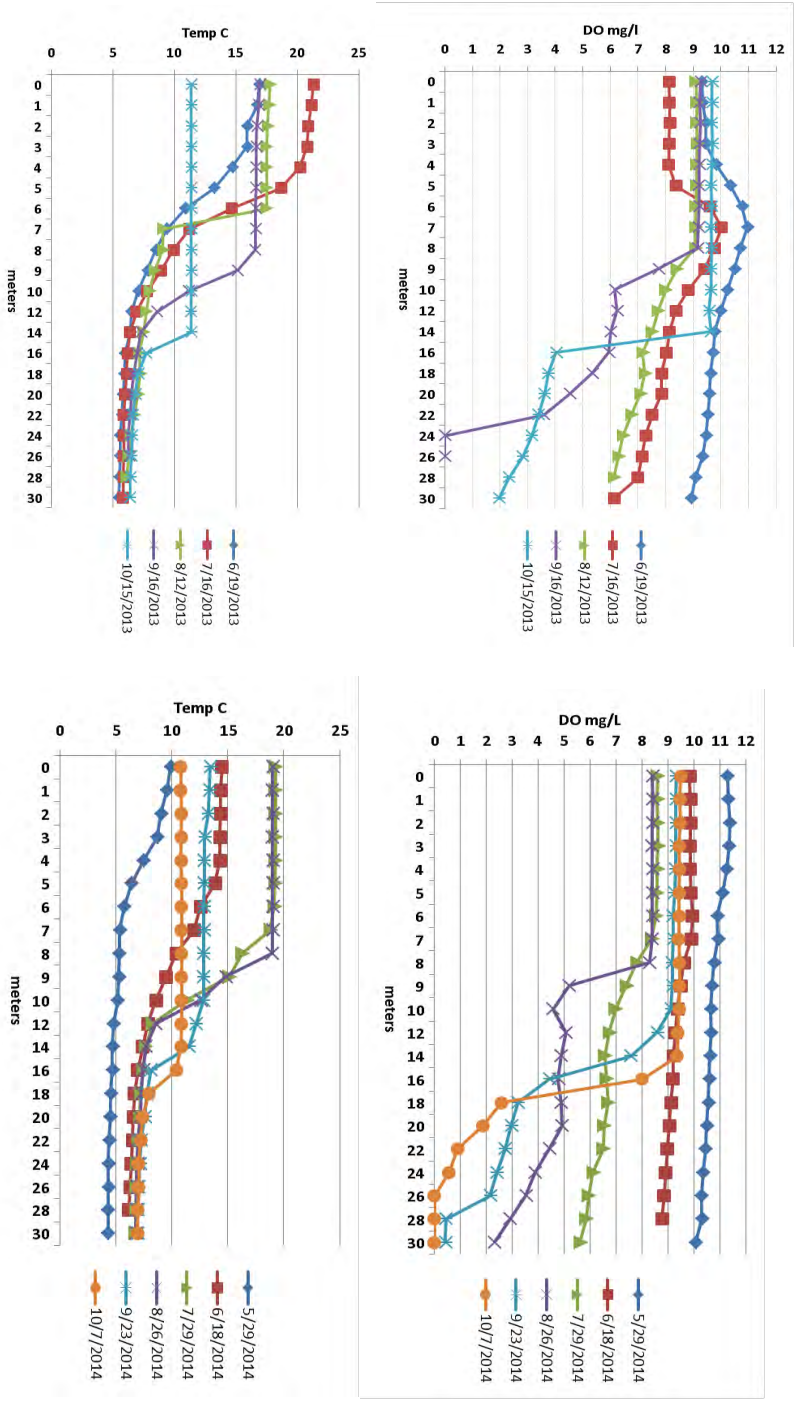


Figure 11 Greenwood Lake 2006 profiles and a comparison of July 10 and 11 2006 dissolved oxygen and comparison of temperature profiles for Greenwood, Devils Track, Wilson, Moose, and Trout Lakes.

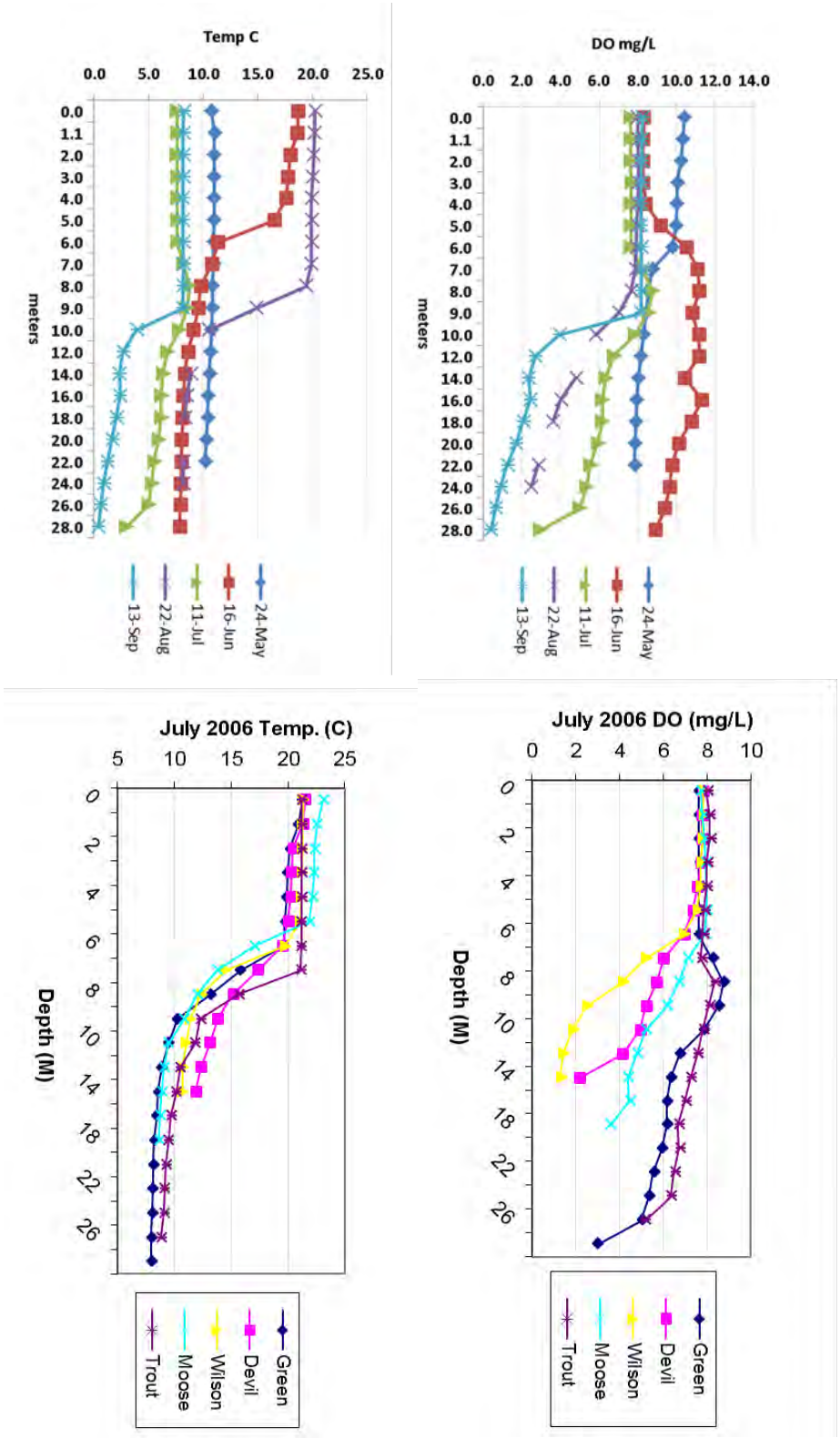


Figure 12 MDNR late summer (August) DO and temperature profiles for Greenwood

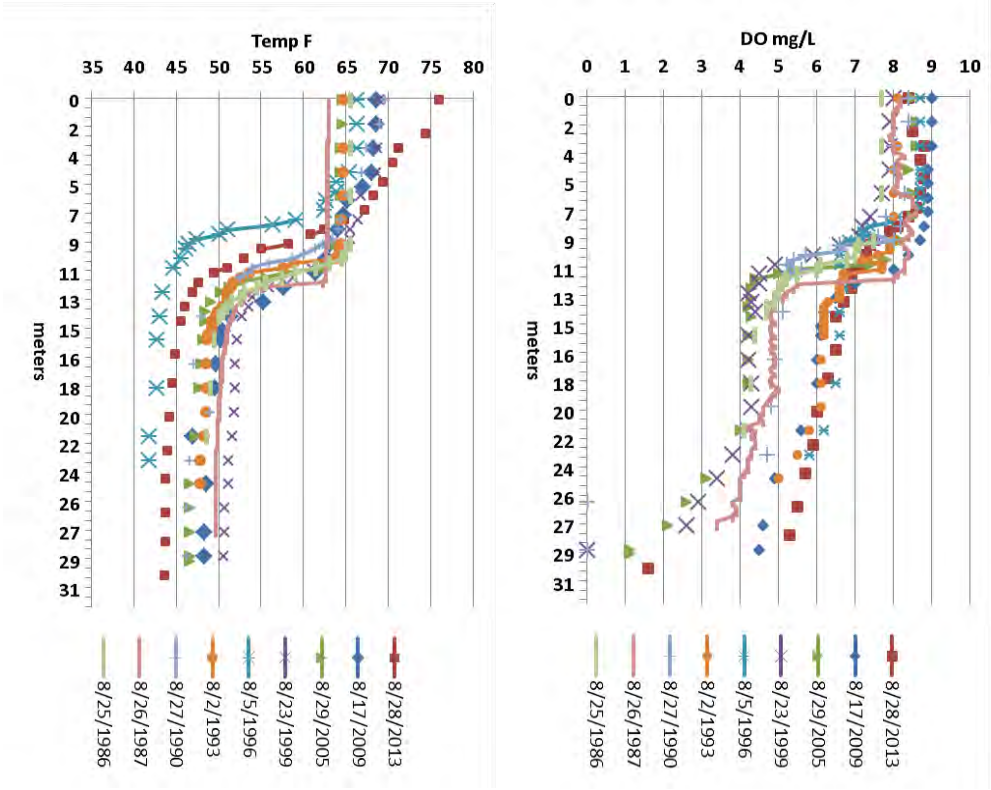
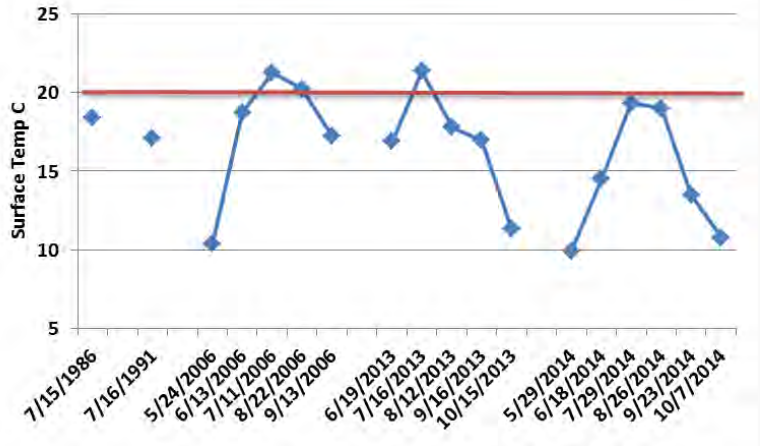
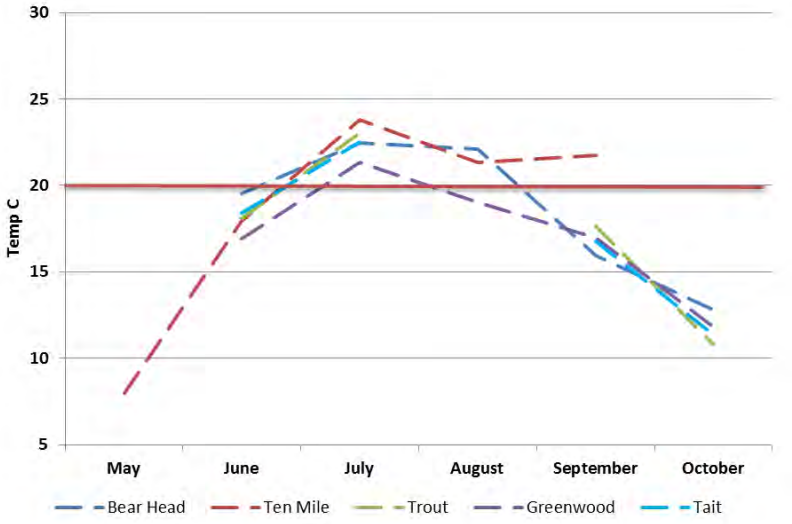


Figure 13 Surface temperatures (MPCA) for Greenwood Lake (a) and northern Sentinel lakes in 2013 (b). 20C is lower boundary of preferred temperature for blue-green algae (Knopka and Brock 1978).

a)



b)



One benchmark measure of coldwater habitat (temperature at 3 mg O_2 - TDO_3; Jacobson et al. 2010) suggests that coldwater resources in Greenwood are excellent for Cisco and Lake Whitefish. The mean TDO3 was 8.2°C during the period of greatest oxythermal stress (August profiles; Table 10). On a scale of 0 to 100 (with 0 being worst and 100 best), Greenwood Lake has a Cisco Habitat Suitability Index of 99 and a Lake Whitefish Suitability Index of 77. However, the coldwater Habitat Suitability index for Lake Trout was considerably less (a value of 5).

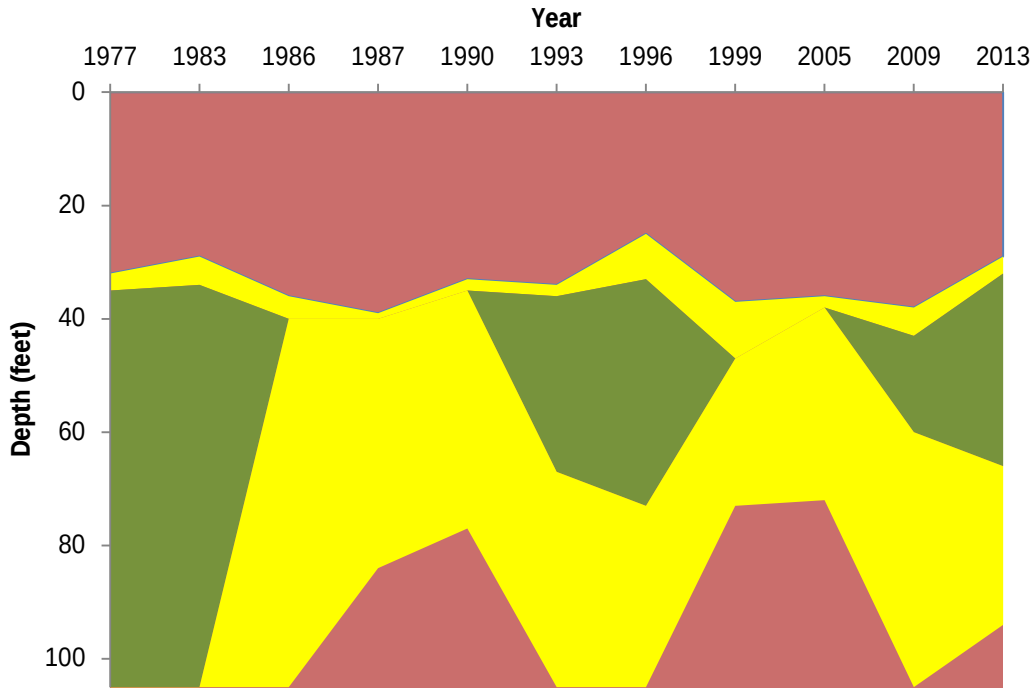
Table 10 TDO_3 values from DNR and MPCA profiles measured in August in Greenwood Lake from 1986 through 2014

Year	August TDO_3 (°F)	August TDO_3 (°C)
1986	48.5	9.2
1987	49.6	9.8
1990	46.2	7.9
1993	47.8	8.8
1996	41.7	5.4
1999	50.6	10.3
2005	46.4	8.0
2009	48.2	9.0
2013	43.6	6.4
2014	44.2	6.8
Mean	**46.8**	**8.2**

Since Lake Trout are an important part of the fish community in Greenwood Lake, other measures of Lake Trout habitat were calculated in addition to TDO_3. Recent assessments of Lake Trout thermal habitat (Siesennop 2000; Plumb and Blanchfield 2009) allow for calculation of lake volumes and depth layers specifically suitable for Lake Trout. Optimal Lake Trout habitat was defined by Siesennop (2000) and others to be the portion of the lake with temperatures between 8 and 12°C and with oxygen concentrations greater than 6 mg/L. Further research by Plumb and Blanchfield (2009) suggest that Lake Trout commonly use water colder than 8°C and suggested that all water less than 12°C and oxygen concentrations greater than 6mg/L comprises optimal Lake Trout habitat. They also

suggest using values of 15°C and oxygen concentrations of 4mg/L as a measure of suitable habitat that represent survivable, rather than optimal conditions. Using these criteria, Greenwood Lake always had suitable Lake Trout habitat in August for the years profiled, but only some years with optimal habitat (Figure 14). The hypolimnion became sufficiently depleted in oxygen to eliminate optimal conditions for Lake Trout in the Augusts of 1986, 1987, 1990, 1999, and 2005. Years with significant amounts of optimal Lake Trout habitat occurred in 1977, 1983, 1993, 1996, 2009, and 2013. The Lake Trout population appears sustainable based on the continued availability of suitable habitat in August. However, any stressors that reduce hypolimnetic oxygen (e.g. eutrophication and/or climate change) will likely reduce that availability and possibly place the population at risk. Given the wide annual variability in quality of Lake Trout thermal habitat in Greenwood Lake and the vulnerability of the population to eutrophication and climate change, long-term monitoring of the temperature and oxygen characteristics of the lake will be of critical importance.

Figure 14 Depth layers of optimal (green), suitable (yellow), and unsuitable (red) Lake Trout thermal habitat in Greenwood Lake from 1977 through 2013 based on August profiles. Optimal habitat includes the depth layer with temperatures less than 12°C and oxygen concentrations greater than 6mg/L, suitable habitat includes the depth layer with temperatures less than 15°C and oxygen concentrations greater than 4mg/L, and unsuitable habitat includes all remaining layers with temperatures greater than 15°C and oxygen concentrations less than 4mg/L.



Total phosphorus (TP) measurements date back 1986 in the earliest MPCA sampling. However, MDNR records date to August 22, 1955 when a TP of 5 µg/L was recorded. Over that time there have been some changes in analytical methods as well as report limits (RL). With that said, the actual range in surface TP is rather small with a minimum of 3 µg/L and maximum of 13 µg/L and overall average of 6 µg/L (Figure 15). Relatively complete monthly records are available for 2006, 2013, and 2014. Based on these data, May (spring overturn) TP is often the highest and TP declines from there through the summer months. The decline from May to June is most likely caused by diatom uptake of P followed by their senescence. Hypolimnetic samples were routinely collected about one meter above the bottom of the lake, typically 29-30 m. Based on data from 2013 and 2014 (Figure 16) there is a small difference among surface and bottom measurements, which suggests minimal internal recycling.

In 2014 bottom DO did fall below 1 mg/L in September and October (Figure 10); however August hypolimnetic TP was higher than September or October and DO was well above 2 mg/L at that time.

Chlorophyll-a (Chl-a) concentrations provide an estimate of the amount of algal production in a lake. During 2013-14, Chl-a levels were low in Greenwood and indicated oligotrophic conditions. Concentrations ranged from 2 to 4 µg/L on most dates, with a summer average of 2.5 µg/L (Figure 15). Peak concentrations are typically in the spring or fall (at or near turnover) when TP is higher. Chl-a concentrations greater than 20 µg/L will typically be perceived as a nuisance bloom in northern Minnesota lakes (Heiskary and Walker, 1988). Nuisance blooms were not observed on Greenwood and during most sampling events algae levels in the epilimnion were sparse. Algal growth is limited by the lake's low TP concentration and cool temperatures.

Secchi disk transparency averaged 5.0 m during summers of 2013 and 2014, which is higher than the typical range for ecoregion reference lakes (Table 8). Since Greenwood does not have a long-term CLMP observer, transparency records are spotty with the most complete data from 2006, 2013, and 2014 (Figure 17). Based on these data Secchi ranges from a high of 6.0 m to a low of 3.5 m. The June maximum likely corresponds with senescence of spring diatom blooms. The low readings occur in September to October as algal biomass increases (Figure 15**).**

Transparency can vary at different locations across the lake on a single day. On September 3, 2014 MDNR Fisheries crews measured Secchi disk transparencies at multiple locations on Greenwood Lake. Readings ranged from 2.6 to 3.5 m, with the highest reading obtained at the MDNR/PCA temperature profile site in the central basin, and the lowest obtained in the lake's northeast basin.

Additional water quality parameters were measured, as part of the long-term monitoring of Greenwood and other Sentinel lakes, including some of the standard MPCA lake monitoring measures of total suspended solids (TSS), alkalinity, conductivity and color (Table 8), as well as major cations, anions, and total organic carbon (Table 10). While several of these parameters have "typical" ecoregion-based concentrations, some do not. For parameters without ecoregion–based comparisons, data from the 2012 NLA study were used to provide perspective on reported concentrations. Since the NLA lakes were selected randomly, they provide a basis for describing typical ranges and distributions at the ecoregion and statewide level.

For the conventional lake monitoring parameters listed in Table 8 most measurements from Greenwood were outside (lower than) the typical NLF range, because few of the NLF ecoregion reference lakes were oligotrophic trout lakes. The low alkalinity, cation, and anion concentrations indicate soft water, typical of other area lake trout lakes. Chloride is an excellent tracer of human impacts to water resources, and is typically found in low concentrations in NE MN lakes, absent man-induced inputs from road salting or wastewater discharges. In comparison to 50 randomly selected lakes in NLF ecoregion, Greenwood values are generally at or below the 10^{th} percentile, which implies that 10 percent or less of the lakes in this region have values lower than those measured in Greenwood. Further details on the 2012 NLA data set may be found in Heiskary (2015).

TSS is low as compared to NLF reference lakes (Table 8) and most of the TSS can be attributed to organic SS (TSS-TSIS), i.e. suspended algae. The low color value (Table 9) indicates the water is clear and has minimal amount of dissolved organic carbon (DOC). DOC exhibits minimal seasonal change based on the available data (Figure 19). The single value from 1991 is consistent with the recent data and suggests no change in this variable over time.

Most cation and anion concentrations were quite stable across sample events (Figure 18), which is consistent with the literature. Mg, Na, K and Cl are noted to be relatively conservative and undergo

only minor spatial and temporal change (Wetzel 2001). Mg is required by algae to produce Chl-a and Ca is used by rooted plants. Given the paucity of rooted vegetation and low levels of algae, Ca and Mg remain relatively stable. Silica (Si), which is required by diatoms to form their "glass" shells, varied slightly from spring to fall. The slight decline in summer may result from the spring diatom bloom.

Calcium (Ca) and magnesium (Mg) are the dominant cations and concentrations of both are at or below the 10th percentile for northern forested lakes (Table 9). The other two major cations – sodium (Na) and potassium (K) are low as well. Bicarbonate is the dominant anion, followed by sulfate (SO_4).and chloride (Cl). Sulfate exhibits minimal change across the sample events (Figure 19). All Cl measurements were below the RL of 1 mg/L.

Figure 15 Greenwood Lake surface (0-2m) TP & Chl-a based on data in STORET.

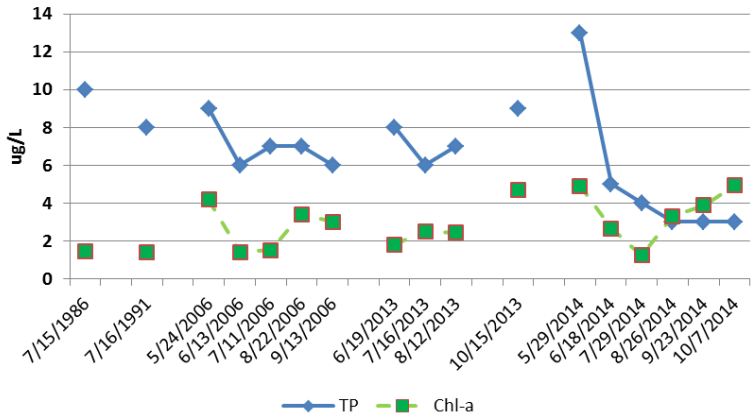


Figure 16 Greenwood Lake 2013 & 2014 surface (0-2m) and near bottom (30m) TP.

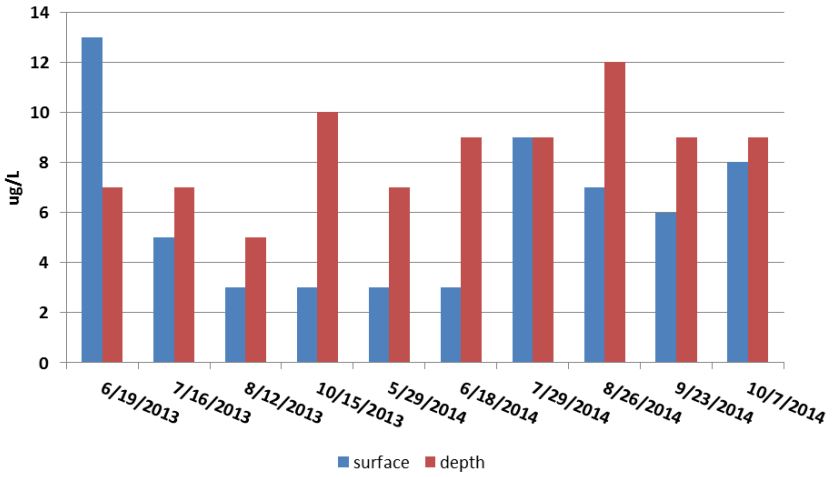


Figure 17 Greenwood Lake Secchi transparency measurements for 2006, 2013 and 2014

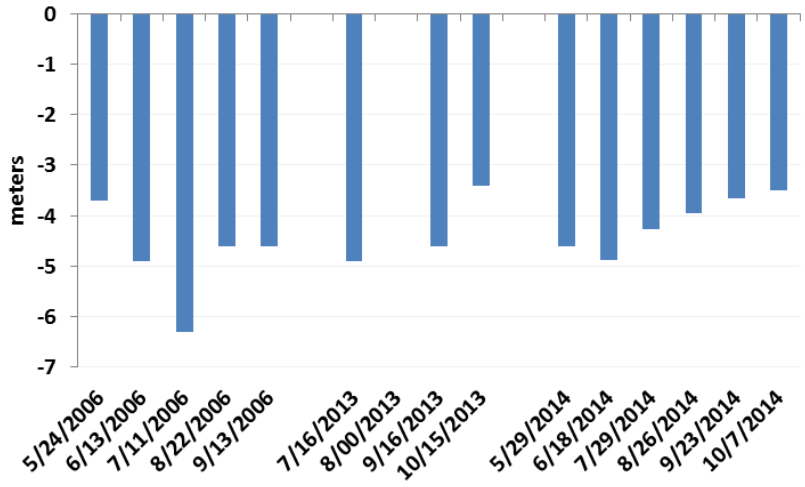


Figure 18 Greenwood Lake cation concentrations: 1991 and 2013-2014

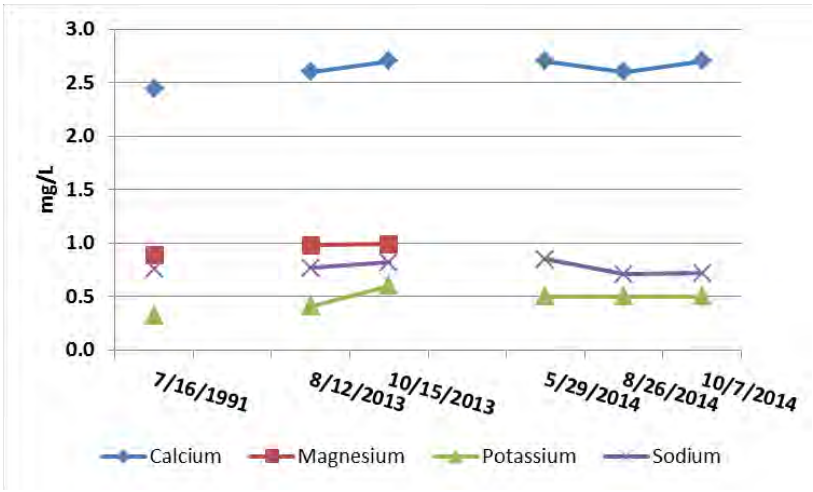
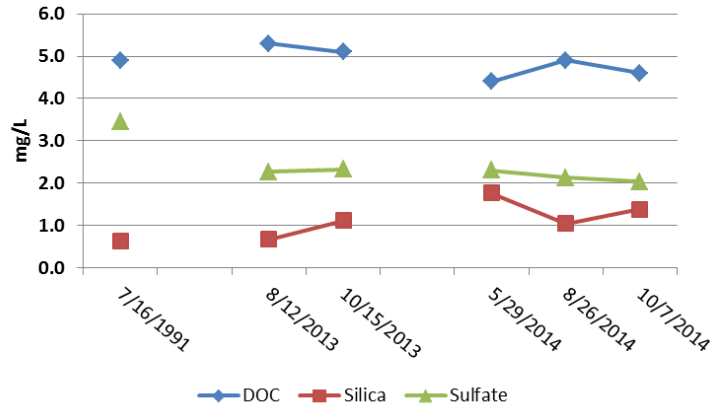


Figure 19 Greenwood Lake dissolved organic carbon, silica and sulfate: 1991 and 2013-2014



Phytoplankton

Phytoplankton (algae) data for Greenwood Lake collected in 2013 and 2014 are presented in terms of algal type (percent composition) and their relative contribution to biomass based on Chl-*a*. Data for nearby Sentinel Lake - Trout Lake have been included as a basis for comparison. Prominent species in Greenwood and Trout Lakes are included in Table 11 and Table 12.

Algal biomass in Greenwood was very low with maximum Chl-*a* less than 5 µg/L in both years (Figure 20). Diatoms were common or present on all sample dates with *Tabellaria*, *Cyclotella*, *Synedra*, and *Asterionella* present in both years (Figure 20). These are generally considered "clean water forms" (APHA et al. 1998). They prefer low nutrient, low pH waters, high DO, and tolerate low concentrations of organic N (Wetzel 2001). Chrysophytes were present at low levels with exception of *Uroglena* in May 2014, which comprised 23% of the sample and *Dinobryon* in June 2014 at 51%. Blue-greens were found in all months and most notable from July through October with *Aphanocapsa*, *Anabaena*, and *Lyngbya* among the most common. The maximum percent blue-greens, based on all samples was 62% in August 2013 (Figure 20); however, Chl-*a* was very low at 2.4 µg/L and biomass was very low on all dates. Blue-greens will be limited by nutrients (P) and temperature (Figure 14) in Greenwood Lake. Total taxa richness averaged 25 across the two summers, peaked at 36 taxa in 2013 with no consistent pattern among the two years (Table 13). Diatom taxa richness averaged 4 and the maximum was 6. The general seasonal progression was diatoms and Chrysophytes in May and June to an increasing presence of blue-greens from July through October. However, there were numerous forms and taxa represented on all dates and seldom any distinct dominant species, as reinforced in the richness, diversity, and evenness metrics (Figure 21).

Algal biomass in Trout was very low and did not exceed 3 µg/L on any sample date over the two years (Figure 20). Diatoms were not prominent on most dates, with the exception of the June 2013 and May 2014 samples with *Cyclotella*, *Synedra*, and *Asterionella* among the more prominent forms (Table 12). These forms prefer low nutrient conditions. Chrysophytes were present on all dates with *Dinobryon* and *Uroglena* among the more common forms. Blue-greens were found in all months and comprised 20% or more of the algal community with the exception of June 2013 (Figure 20); however as was the case with Greenwood, Chl-*a* was very low and though common, blue-greens were not at bloom levels. The most common blue-green genera were *Aphanocapsa*, *Aphanothece*, and *Planktolyngbya*. Total taxa richness averaged 2.2 across the two summers, which was lower than Greenwood. Diatoms were only prominent in May and June and gave way to Chrysophytes and blue-greens for the remainder of the months. The other forms were at very low levels and often represented by a few individuals. Though both lakes are of similar trophic state and support coldwater fisheries, Greenwood exhibits slightly higher algal biomass that is more taxa rich than that of Trout Lake (Figure 20). It is also more taxa rich than nearby Tait Lake (Table 13), which is shallow and slightly more nutrient-enriched. For a more complete description on these algal forms and patterns in the Sentinel Lakes, see Heiskary and Hirsch (2015).

Figure 20 Greenwood and Trout Lake percent composition of algal forms and relative contribution to algal biomass based on Chl-*a*

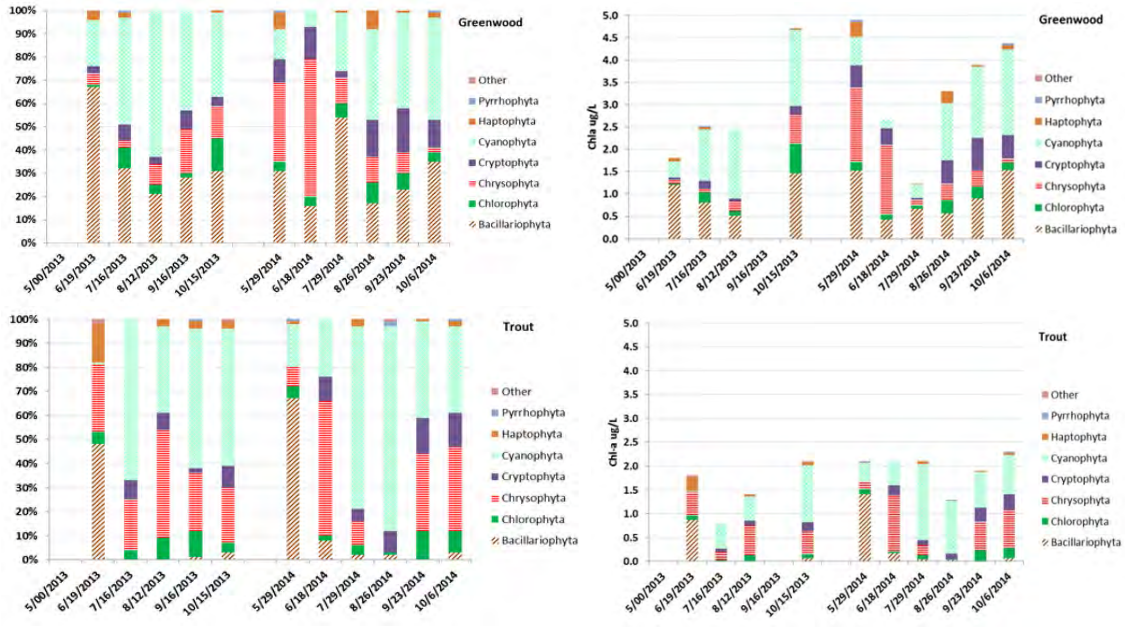


Table 11 Prominent algal species present in Greenwood. Includes species with ~10% or greater occurrence in samples.

Greenwood	2013	2014
May		*Synedra filiformis, Uroglena*
June	*Tabellaria flocculosa, Cyclotella bodanica*	*Synedra filiformis, Dinobryon bavaricum, Cryptomonas erosa*
July	*Tabellaria flocculosa Cyclotella bodanica, Aphanothece nidulans, Rhabdoderma lineare*	*Tabellaria flocculosa, Cyclotella bodanica, Asterionella formosa, Aphanothece nidulans, Aphanocapsa elachista*
August	*Asterionella formosa, Aphanizomenon gracile, Aphanizomenon flos-aquae*	*Cyclotella bodanica, Rhodomonas minuta, Lyngbya limnetica, Aphanocapsa elachista, Aphanothece nidulans*
September	*Tabellaria flocculosa, Dinobryon bavaricum, Dinobryon divergens, Aphanizomenon flos-aquae, Anabaena planctonica*	*Asterionella formosa, Rhodomonas minuta, Anabaena planctonica*
October	*Cyclotella bodanica, Aphanocapsa elachista*	*Asterionella formosa, Cryptomonas erosa, Anabaena planctonica, Aphanocapsa elachista*

Table 12 Prominent algal species present in Trout. Includes species with ~10% or greater occurrence in samples.

Trout	2013	2014
May		*Cyclotella stelligera (2 sp), , Pseudanabaena*
June	*Synedra filiformis, Asterionella formosa, Cyclotella ocellata, Chromulina, Chrysochromulina parva*	*Uroglena, Planktolyngbya, Rhodomonas minuta*
July	*Aphanothece nidulans, Pseudanabaena, Dinobryon sociale*	*Planktolyngbya*
August	*Dinobryon sociale, Aphanocapsa elachista, Pseudanabaena*	*Planktolyngbya, Aphanocapsa elachista*
September	*Aphanothece nidulans, Aphanocapsa elachista, Pseudanabaena, Dinobryon bavaricum*	*Dinobryon bavaricum (3 sp), Rhodomonas minuta, Aphanocapsa elachista, Aphanothece nidulans*
October	*Aphanothece nidulans, Pseudanabaena, Aphanocapsa elachista, Dinobryon bavaricum*	*Dinobryon sociale, Dinobryon sertularia, Aphanocapsa elachista, and Aphanothece nidulans*

Figure 21 Greenwood Lake phytoplankton metrics

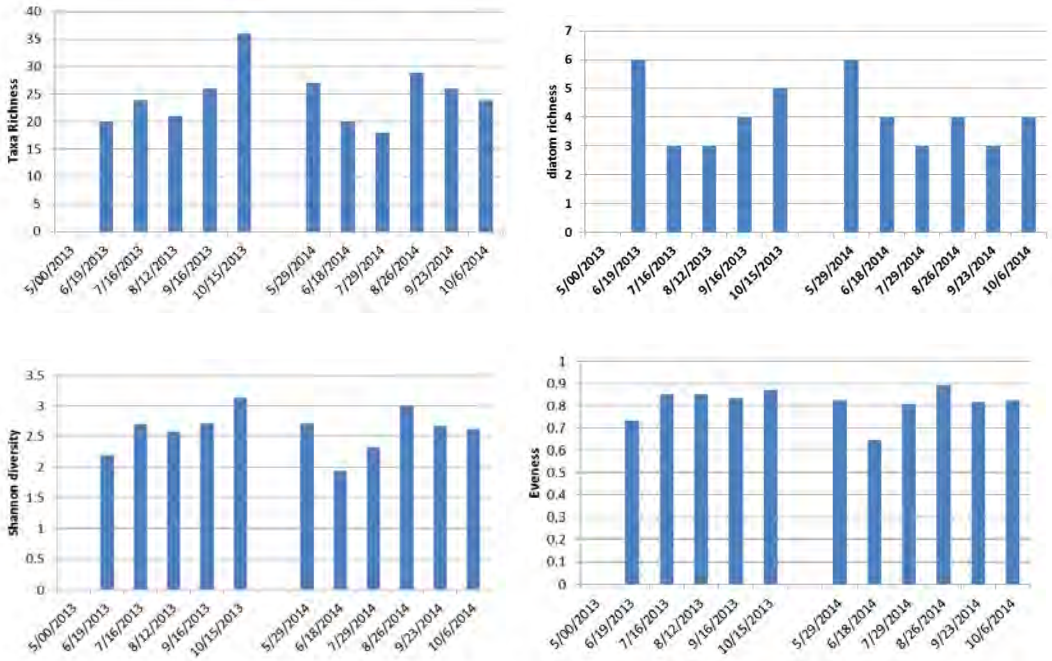


Table 13 Total phytoplankton taxa and diatom richness metrics for Greenwood. Nearby Sentinel Lakes Trout and Tait included for comparison. Mean values derived from an analysis of 13 Sentinel Lakes (Heiskary and Hirsch 2015).

Lake-year	Total taxa richness	Diatom richness mean	Diatom richness max	% diatoms of total
Greenwood 2013	25.4	4.2	6	17%
Greenwood 2014	24.0	4.0	6	17%
Trout 2013	20.0	1.8	6	9%
Trout 2014	18.5	2.6	4	14%
Tait 2013	20.8	3.2	5	15%
Mean	**17.9**	**2.8**	**5**	**16%**

Zooplankton

Zooplankton densities and biomass in Greenwood Lake were among the lowest of all the Sentinel Lakes (Heiskary and Hirsch 2015). Both densities and biomass peaked during mid-summer, but were relatively low, with maximum densities less than 10 individuals per liter and maximum biomass less than 35 µg per liter (Figure 22). Cyclopoid copepods were the dominant group throughout the season, contributing to over 50% of the community composition during all sampling events (Figure 22). Calanoid copepods were relatively rare; with the very small *Leptodiaptomus minutus* being the only Diaptomidae present. The

larger cladoceran grazer, *Daphnia galeata mendotae* became relatively abundant during mid-summer, contributing to the increase in total biomass during this period, and more notably, maintained presence throughout the latter part of the season (Table 14). *Holopedium gibberum* was also present in Greenwood Lake, with highest densities in June and July (Figure 22). *H. gibberum* is generally confined to soft water, less productive lakes such as Greenwood Lake. Taxa richness was below average among the Sentinel lakes, with only 10 taxa identified (Table 16). Spiny waterfleas have been present in Greenwood Lake since at least 2005, and therefore has a well-established population. Similar to other spiny waterflea infested lakes, very few if any small cladocerans were present, due to direct predation, which may contribute to lower taxa richness.

The low zooplankton density and biomass is a function of low nutrients (Table 8) and low algal productivity. Phytoplankton (Figure 20) and zooplankton (Figure 22) seasonal patterns were inversely related. Peak zooplankton density and biomass resulted in a reduced algal biomass. This likely accounts for the higher Chl-*a* in 2014 as compared to 2013 (Figure 15). The diaptomid - *Leptodiaptomus minutus* is a small species that feeds on small algae (nanoplankton) and is usually present in oligotrophic lakes, as is the case in Greenwood.

Figure 22 Greenwood and Trout Lake 2013 and 2014 zooplankton density and biomass

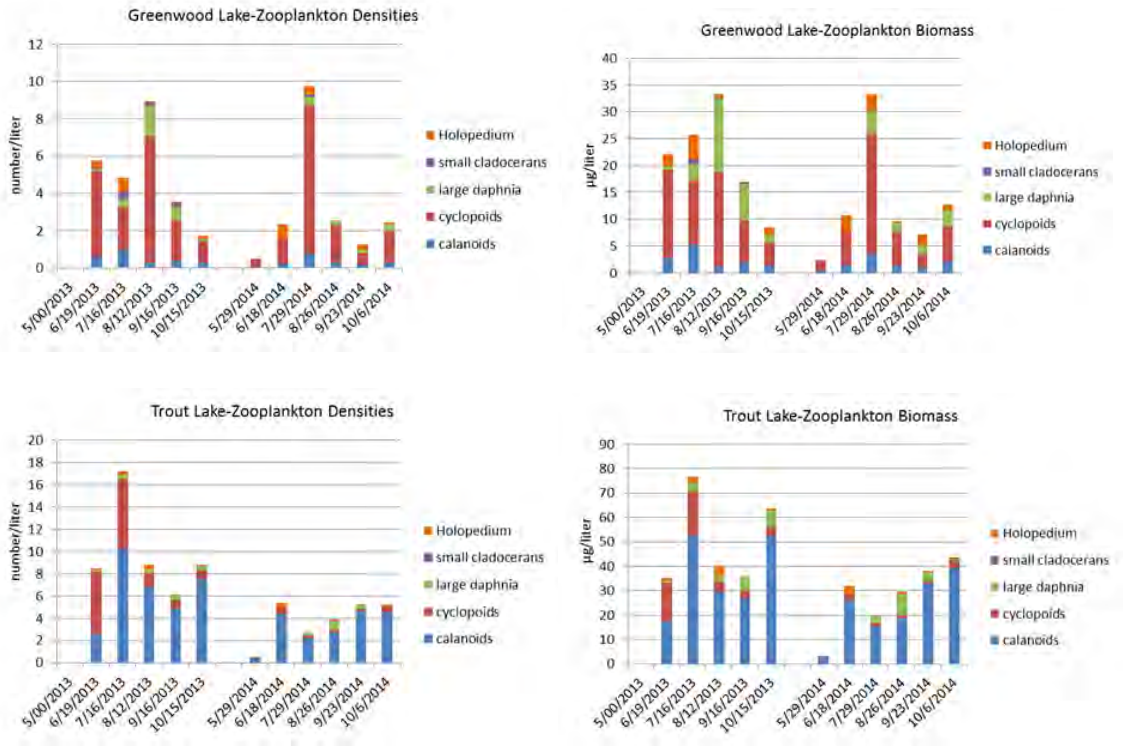


Table 14 Prominent zooplankton taxa present in Greenwood Lake. Taxa with ~10% or greater occurrence in samples noted.

Greenwood	2013	2014
May	No data	cyclopoids, *Leptodiaptomus minutus*
June	cyclopoids, *Leptodiaptomus minutus*	cyclopoids, *Holopedium gibberum*
July	cyclopoids, *Leptodiaptomus minutus, Holopedium gibberum*	cyclopoids
August	cyclopoids, *Daphnia galeata mendotae*	cyclopoids, *Leptodiaptomus minutus, Daphnia galeata mendotae*
September	cyclopoids, *Daphnia galeata mendotae*	cyclopoids, *Leptodiaptomus minutus, Holopedium gibberum, Daphnia galeata mendotae*
October	cyclopoids, *Leptodiaptomus minutus, Daphnia galeata mendotae, Holopedium gibberum*	cyclopoids, *Daphnia galeata mendotae, Leptodiaptomus minutus*

Similar to Greenwood Lake, Trout Lake total zooplankton densities were relatively low among the Sentinel Lakes, although total biomass was higher (Table 16) due to the presence of larger calanoids. Both densities and biomass were lower in 2014 than during 2013. In July 2013, densities peaked at a maximum of 17 individuals per liter, but in 2014, maximum densities were less than 6 individuals per liter (Figure 22). In contrast to Greenwood Lake, calanoid copepods were the dominant group in Trout Lake both years, contributing to over 50% of the community composition (Figure 22). Three species of Diaptomidae were present (*Onychodiaptomus sanguineus*, *Leptodiaptomus minutus* and *Leptodiaptomus sicilis*), which are all grazers of algae of different size ranges (Table 15). The dominant species, *Onychodiaptomus sanguineus*, is unique to Trout Lake, as this species has not been documented from any other lake in Minnesota. Cyclopoid copepods were abundant early in the season during 2013, but were relatively scarce throughout the remainder of 2013 and the entire 2014 season. *Daphnia galeata mendotae* was present in Trout Lake throughout the season, but in lower densities than in Greenwood Lake. *Holopedium gibberum* was also present in low densities, but no small cladocerans were found in Trout Lake. Taxa richness was below average among the Sentinel lakes, with only 10 taxa identified, similar to Greenwood Lake (Table 16). Spiny waterfleas were first detected in Trout Lake in the fall of 2012 (based on plankton tows by MDNR staff), therefore the lake is in an early infestation stage, yet differences in densities and biomass between 2013 and 2014 could be due to changes from impacts of spiny waterfleas.

Zooplankton density and biomass was higher in 2013 relative to 2014 (Figure 22) and algal biomass was lower in 2013 as compared to 2014. *D. galeata mendotae* were present during entire season and this may be because of good food sources such as diatoms and Chrysophytes that were present on most dates (Table 12). Trout had lower Chl-*a* than Greenwood and this might be attributed to more grazing pressure by three different species of Diaptomidae, which all graze on different size ranges of algae.

Table 15 Prominent zooplankton taxa present in Trout Lake. Taxa with ~10% or greater occurrence in samples noted.

Trout	2013	2014
May	No data	*Onychodiaptomus sanguineus*, *Leptodiaptomus minutus,* cyclopoids
June	Cyclopoids, *Onychodiaptomus sanguineus*, *Leptodiaptomus minutus*	*Onychodiaptomus sanguineus,* cyclopoids*, Holopedium gibberum*
July	*Onychodiaptomus sanguineus*, cyclopoids	*Onychodiaptomus sanguineus,* cyclopoids, *Daphnia galeata mendotae*

August	*Onychodiaptomus sanguineus*, cyclopoids	*Onychodiaptomus sanguineus, Daphnia galeata mendotae*
September	*Onychodiaptomus sanguineus*, cyclopoids, *Daphnia galeata mendotae*	*Onychodiaptomus sanguineus*
October	*Onychodiaptomus sanguineus*	*Onychodiaptomus sanguineus,* cyclopoids

Table 16 Zooplankton taxa richness, average seasonal densities and average seasonal biomass (excludes nauplii and copepodites). Nearby Sentinel Lakes Trout and Tait included for comparison. Mean values derived from an analysis of 13 Sentinel Lakes (Heiskary and Hirsch 2015).

Lake-year	Total taxa richness	Average seasonal densities	Average seasonal biomass
Greenwood 2013	10	5.0	21.3
Greenwood 2014	10	3.2	12.6
Trout 2013	10	9.9	50.3
Trout 2014	10	3.8	27.7
Tait 2013	11	18.2	77.6
Mean	**11.9**	**29.0**	**148.8**

Over the past few decades, the invasive zooplankton species, *Bythotrephes longimanus*, commonly known as the spiny waterflea, has become established across the Great Lakes Region, infesting many lakes along the Minnesota and Ontario border (Kerfoot *et al.*, 2011). To date, two of the Sentinel lakes in Minnesota have spiny waterfleas. Greenwood Lake has a well-established population, first detected in 2005, while Trout Lake has a newly infested population, first detected in 2012. Spiny waterfleas are large predacious zooplankters, which prey on smaller zooplankton species and have been associated with significant reductions in native zooplankton densities, biomass and species richness in lakes (Yan *et al*., 2001, 2002). In Minnesota, lakes infested with spiny waterfleas have experienced significant losses in small cladocerans due to direct predation impacts (Kerfoot *et al*., in peer review).

Spiny waterfleas are generally most abundant during late summer or early autumn in infested lakes in Minnesota. In Greenwood Lake, densities peaked in September in 2013 and in August in 2014 (Figure 23). Maximum spiny waterflea densities were higher in 2013 than in 2014, peaking at 7 individuals per cubic meter in September 2013. In an earlier study (Kitson, 2008) maximum spiny waterflea densities from Greenwood Lake were estimated at 14 individuals per cubic meter. Spiny waterflea densities in Trout Lake were similar to Greenwood, although maximum densities were higher in 2014 than in 2013, which is expected as Trout Lake is in an early infestation stage (Figure 24).

Figure 23 Spiny waterflea densities (number individuals/cubic meter) from Greenwood Lake, 2013-2014.

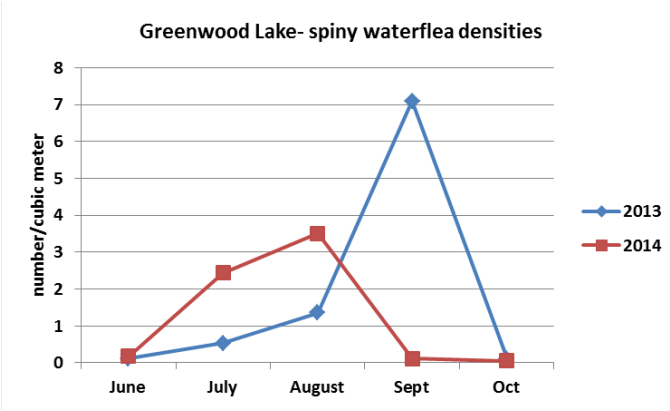
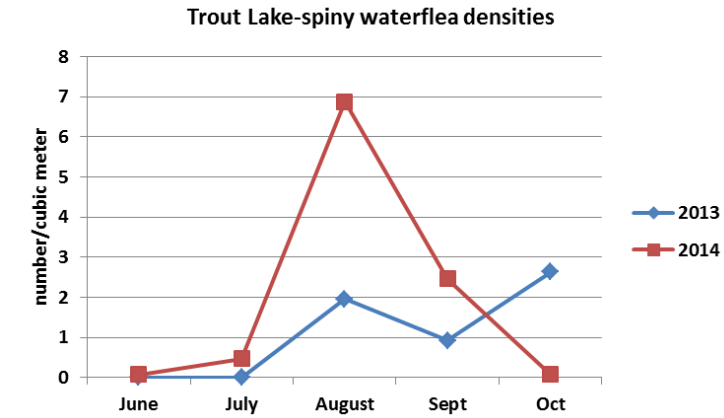


Figure 24 Spiny waterflea densities (number individuals/cubic meter) from Trout Lake, 2013-2014.



Trophic level impact from *Bythotrephes*, beyond the zooplankton community, is not well documented, but under conditions of significant losses of zooplankton grazers, one would expect increases in phytoplankton biomass. Strecker and Arnott (2008) found a weak trophic cascade where *Bythotrephes* introductions reduced zooplankton biomass and subsequently increased phytoplankton growth in experimental mesocosms in boreal lakes. Jeppesen et al. (2003) suggest that less productive lakes such as these may not respond to top-down trophic changes as much as more productive lakes.

Greenwood and Trout Lakes provide a unique opportunity for tracking the impact of spiny waterflea on other zooplankton, phytoplankton, and potentially water quality. However, only Trout has pre-infestation data. Heiskary and Hirsch (2015) offer a comparison of TSI values from Greenwood, Trout, and Bear Head Lakes to see if there are any patterns that may be attributable to spiny water flea. While there were no distinct patterns evident, this may be worth checking on in the future when there is more data and spiny water flea has become more established.

Trophic State Index

One way to evaluate the trophic status of a lake and to interpret the relationship between TP, Chl-*a*, and Secchi disk transparency is Carlson's Trophic State Index (TSI) (Carlson 1977). TSI values are calculated as follows:

Total Phosphorus TSI (TSIP) = 14.42 ln (TP) + 4.15

Chlorophyll-*a* TSI (TSIC) = 9.81 ln (Chl-*a*) + 30.6

Secchi disk TSI (TSIS) = 60 – 14.41 ln (SD)

TP and Chl-*a* are in µg/L and Secchi disk is in meters. TSI values range from 0 (ultra-oligotrophic) to 100 (hypereutrophic). In this index, each increase of ten units represents a doubling of algal biomass. Comparisons of the individual TSI measures provides a basis for assessing the relationship among TP, Chl-*a*, and Secchi (Figure 25). Chlorophyll-*a*, and Secchi TSI values for Greenwood Lake are in close correspondence with each other, while TP is a bit lower. Differences in TP analytic methods and RL account for this in part. Based on an average TSI score of 34 Greenwood Lake is considered as oligotrophic.

Trophic Status Trends

There is a reasonably good data set for establishing baseline condition for Greenwood and describing inter-year variability; however more years of data collection is needed to assess long-term trends. The data employed for this purpose includes summer-mean TP, Chl-a and Secchi as downloaded from EQuIS and satellite-inferred transparency from the University of Minnesota Remote Sensing laboratory. The water quality data were largely collected by MPCA and the most complete data date back to 2006. Some of the early collections were a bit sparse (only one or two samples in a summer) and while valuable for characterizing conditions on a given sample date, they may be less useful for estimating summer-mean condition. Data collected from 2006 through 2014 provide a good basis for describing current condition and year-to-year variability (Figure 26). Based on these data, summer-mean TP ranges from about 3-7 µg/L. It is important to acknowledge that there were some changes in the MDH TP analytic technique and report limits, which may have had some impact on the data. Chl-a methodology, in contrast, has been quite consistent and indicates summer-means ranging from ~1.5-3.0 µg/L.

Greenwood Lake's Secchi transparency record is a bit sparse; however, there are observations that date to 1983 (Figure 27). Based on these summer-means, the long-term mean is ~5.1 m with individual means ranging from 3.9 m to 6.6 m. There is no long-term trend based on these data; however, summer-means and residuals indicate recent transparency is less than the long-term mean (Figure 27). Figure 26 indicates slight, but not significant increases in Chl-a since 2010.

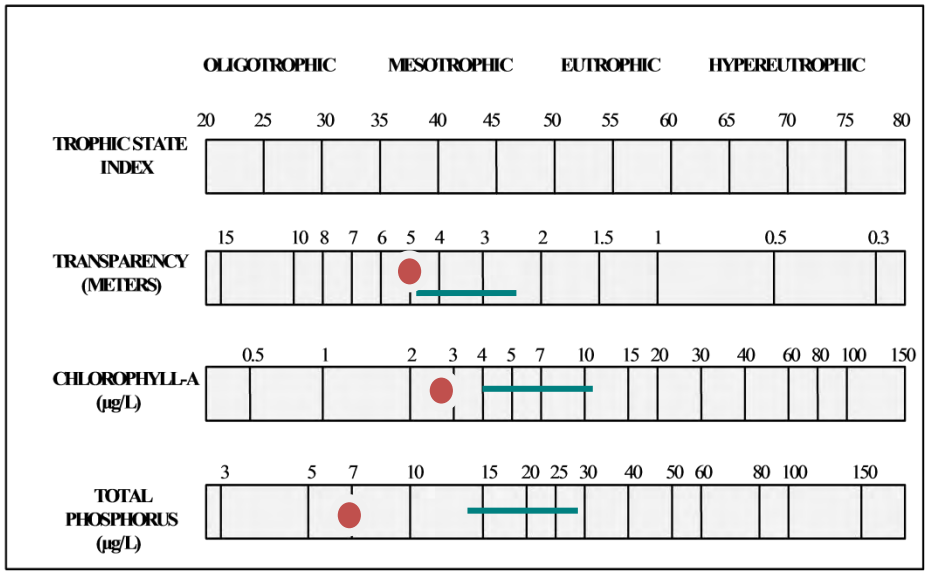
Remote sensing provides another option for characterizing trends for Greenwood. The images used are from late summer at ~ 5-10 year intervals dating back to 1975. Based on these inferred measures, transparency averaged 4.3 m and ranged from 2.2 m (2008) to 6.6 m (2000; Figure 28). This suggests there has been a decrease in transparency from 2000-2008 that is greater than the typical variability in measures from 1975-2005. An extension of this record (more recent time intervals) will help us determine if this is simply part of the "year-to-year" variability or if an actual trend has occurred. More details on satellite-inferred measurements may be found at the U of M Remote Sensing Lab web page at http://lakes.gis.umn.edu/#16007700 .

Charting trends in the individual TSI variables provides further insight into variability and trends (Figure 29). What might be most important from this analysis is the relationship among the three variables. In 2006, the first year with all three measures, there was relatively good correspondence among the measures. This was also the case for 2010. However, there was a strong departure of TP from Chl-a and Secchi for 2012-2014. Changes in TP analytic method may have had some influence on this but considering the method was refined in 2014 and shown to be comparable to the method used prior to 2011 this may not be the complete explanation. Overall it appears TP TSI is declining (more oligotrophic) while the Chl-a and Secchi TSI's are increasing (near mesotrophic boundary). Future monitoring is essential to determine if this is indeed a trend or just part of the overall variability. Zooplankton and phytoplankton monitoring will be valuable as well to discern whether this is a long-term

response to spiny waterflea (consuming zooplankton that feed on algae), which is an interesting hypothesis, given the trajectory of Chl-a since 2006 (Figure 26)

Figure 25 Greenwood Lake TSI values from 2008-2010 MPCA Sentinel Lake monitoring data

TSI < 30	Classical Oligotrophy: Clear water, oxygen throughout the year in the hypolimnion, salmonid fisheries in deep lakes.
TSI 30 - 40	Deeper lakes still exhibit classical oligotrophy, but some shallower lakes will become anoxic in the hypolimnion during the summer.
TSI 40 - 50	Water moderately clear, but increasing probability of anoxia in hypolimnion during summer.
TSI 50 - 60	Lower boundary of classical eutrophy: Decreased transparency, anoxic hypolimnia during the summer, macrophyte problems evident, warm-water fisheries only.
TSI 60 - 70	Dominance of blue-green algae, algal scums probable, extensive macrophyte problems.
TSI 70 - 80	Heavy algal blooms possible throughout the summer, dense macrophyte beds, but extent limited by light penetration. Often would be classified as hypereutrophic.
TSI > 80	Algal scums, summer fish kills, few macrophytes, dominance of rough fish.



After Moore, l. and K. Thornton, [Ed.]1988. Lake and Reservoir Restoration Guidance Manual. USEPA>EPA 440/5-88-002.

NLF Ecoregion Range ——— Greenwood Lake 2013-2014 ●

Figure 26 Greenwood Lake TP, chlorophyll-a and Secchi trends: 2006-2014

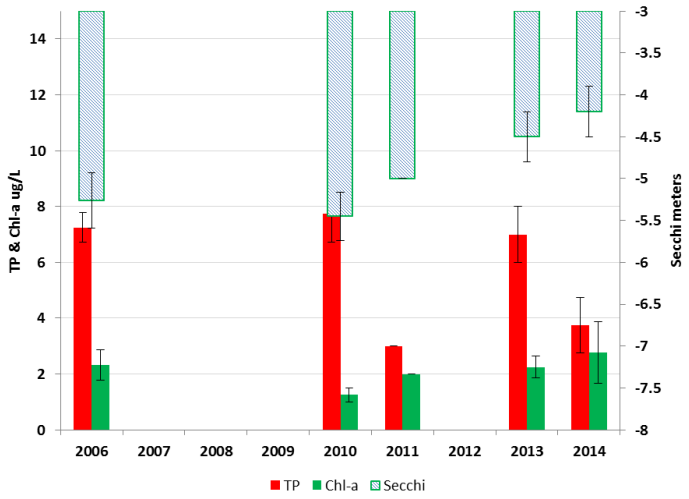
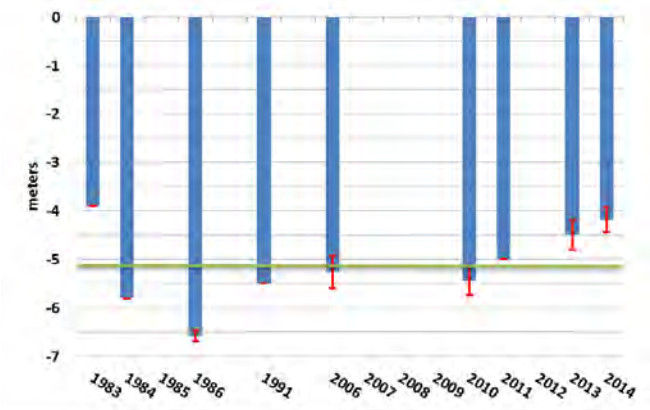


Figure 27 Greenwood Lake transparency trends: a) summer-mean Secchi (long-term mean [5.1 m] indicated by green line). Standard error of the mean noted for Secchi (Note if SE=0 implies only one measurement).and b) Secchi residuals. Residual calculated as long-term mean - annual mean (positive implies annual mean is <long term).

a)



b)

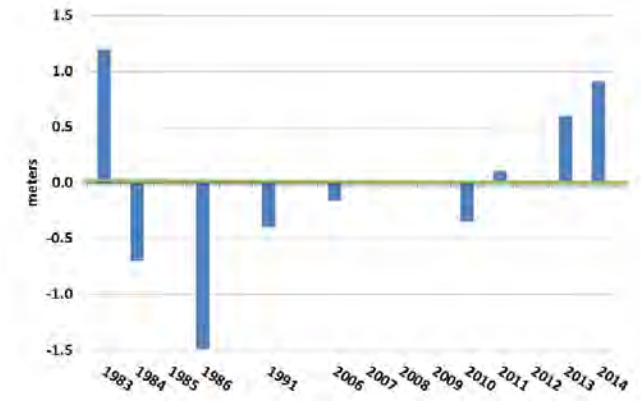
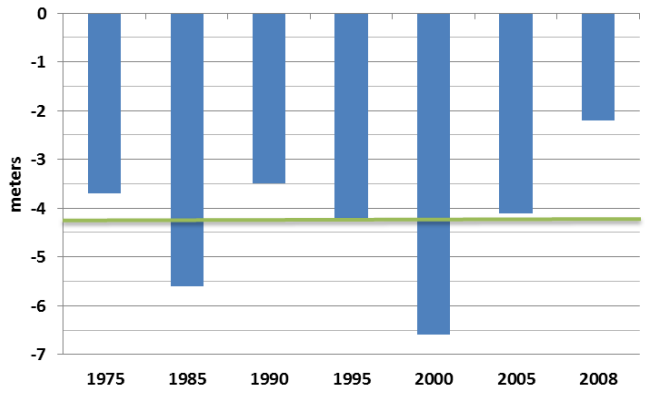


Figure 28 Greenwood Lake remote-sensed transparency (a) and long-term mean = 4.3m (green line) and b) Secchi residuals. [Residual calculated as long-term mean - annual mean; positive implies annual mean is <long term]

a)



b)

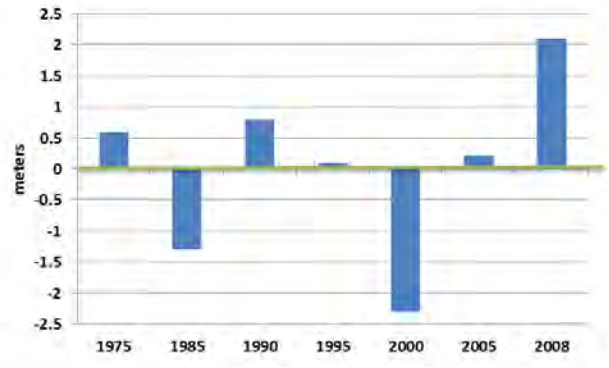
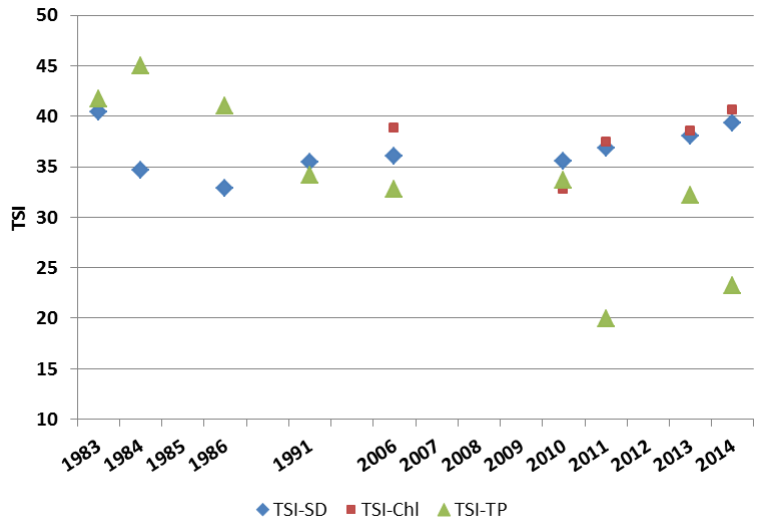


Figure 29 Greenwood Lake Trophic State Index values based on summer-means



Modeling

Numerous complex mathematical models are available for estimating nutrient and water budgets for lakes. These models can be 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 in the watershed) or altering the flow or amount of water that enters the lake. To analyze the recent water quality of Greenwood Lake, the Minnesota Lake Eutrophication Analysis Procedures (MINLEAP) model (Wilson and Walker, 1989) was used. A comparison of MINLEAP predicted vs. observed values is presented in Table 17.

MINLEAP was developed by MPCA staff based on an analysis of data collected from the ecoregion reference lakes. It is intended to be used as a screening tool for estimating lake conditions with minimal input data and is described in greater detail in Wilson and Walker (1989). The model predicts in-lake TP from these inputs. Chl-*a* and Secchi predictions are derived from Minnesota-based regression equations. For analysis of Greenwood Lake, MINLEAP was applied as a basis for comparing the observed TP, Chl-*a*, and Secchi values with those predicted by the model based on the lake size and depth and the area of the watershed.

Greenwood Lake is located in the NLF ecoregion and the model was run using NLF-based inputs. The observed and predicted Chl-*a* and Secchi values for Greenwood Lake are nearly identical. The predicted P was slightly, but not significantly higher than observed. MINLEAP predicts a P loading rate of about 361 kilograms per year entering Greenwood Lake from its small forested watershed based on an estimated stream P of 52 µg/L. If this value is calibrated to 30 µg/L (more typical of streams in NE MN, the predicted in-lake TP is 9 µg/L and loading rate of 260 kg/yr. The model predicts approximately 82% of the TP will be retained in the lake, a reasonable estimate given the lake's small watershed, and long residence time (estimated at 14 years). An additional subroutine in the MINLEAP model estimates the "background" TP for the lake based on its alkalinity and mean depth and a regression equation developed by Vighi and Chiaudani (1985). For Greenwood Lake, this value is estimated to be 7 µg/L, which is equivalent to the observed concentration (Table 17).

Table 17. MINLEAP model results for Greenwood Lake

Parameter	2013- 2014 Greenwood Lake Observed	MINLEAP Predicted NLF Ecoregion
TP (µg/L)	7	11±4.5
Chl-*a* (µg /L)	2.0	2±1.5
Secchi (m)	5.2	4.8±2.1
P loading rate (kg/yr.)	-	361
P retention (%)	-	82
P inflow conc. (µg/L)	-	64
Water Load (m/yr.)	-	0.68
Outflow volume (hm^3/yr.)	-	5.62
Residence time (yrs.)		~14
Vighi & Chiaudani		7

303(d) Assessment

The Federal Clean Water Act requires states to adopt water quality standards to protect waters from pollution. These standards define how much of a pollutant can be in the water and still allow it to meet designated uses, such as drinking water, fishing and swimming. The standards are set on a wide range of pollutants, including bacteria, nutrients, turbidity and mercury. A water body is "impaired" if it fails to meet one or more water quality standards.

Under Section 303(d) of the Clean Water Act, Minnesota is required to asses all waters of the state to determine if they meet water quality standards. Waters that do not meet standards (i.e., impaired waters) are added to the 303(d) list and updated every even-numbered year. In order for a lake to be considered impaired for aquatic recreation use, the average TP concentration must exceed the water quality standard for its ecoregion. In addition, either the Chl-*a* concentration for the lake must exceed the standard or the Secchi data for the lake must be below the standard. A minimum of eight samples collected over two or more years are needed to conduct the assessment. There are numerous other water quality standards for which we assess Minnesota's water resources. An example is mercury found in fish tissue. If a water body is listed, an investigative Total Maximum Daily Load (TMDL) study must be conducted to determine the sources and extent of pollution, and to establish pollutant reduction goals needed to restore the resource to meet the determined water quality standards for its ecoregion. The MPCA is responsible for performing assessment activities, listing impaired waters, and conducting TMDL studies in Minnesota.

Greenwood Lake was assessed relative to the NLF Class 2A ecoregion standards (Table 18). The 2013 & 2014 summer TP mean for Greenwood Lake are below this value. Likewise, Chl-*a* is below the standard for the NLF ecoregion. Based on these results, Greenwood Lake meets the eutrophication criteria for NLF 2A lakes (i.e. those waters that support a Lake Trout fishery).

Table 18. Eutrophication standards by ecoregion and lake type (Heiskary and Wilson, 2005). Greenwood Lake 2013-2014 summer means; long-term means provided for comparison.

Ecoregion	TP µg/L	Chl-*a* µg/L	Secchi meters
NLF – Lake trout (Class 2A)	**< 12**	**< 3**	**> 4.8**
NLF – Stream trout (Class 2A)	< 20	< 6	> 2.5
NLF – Aquatic Rec. Use (Class 2B)	< 30	< 9	> 2.0
NCHF – Stream trout (Class 2a)	< 20	< 6	> 2.5
NCHF – Aquatic Rec. Use (Class 2b)	< 40	< 14	> 1.4
NCHF – Aquatic Rec. Use (Class 2b) Shallow lakes	< 60	< 20	> 1.0
WCBP & NGP – Aquatic Rec. Use (Class 2B)	< 65	< 22	> 0.9
WCBP & NGP – Aquatic Rec. Use (Class 2b) Shallow lakes	< 90	< 30	> 0.7
Greenwood Lake long-term mean	**7**	**1.2**	**5.4**

Recommendations

Fishery survey needs

To develop a good fish survey baseline for the Sentinel Lakes program, standard surveys using a minimum of 15 gill net sets (five shallow and 10 deep), 15 3/4-in trap net sets, and 15 1/4-in trap net sets, should be done in August, ideally every other year from 2015 (completed) - 2019 and at three-year intervals thereafter (starting in 2022). If this lake is withdrawn from the SLICE program, or becomes one of the split-panel lakes under that program, this survey frequency may be reduced to once every four years, beginning in 2015, with similar adjustments made to timing and frequency of other scheduled surveys listed below. To update information available on habitat and water quality in this lake, the appropriate habitat and water quality components should be added to one of the standard surveys planned for 2015, 2017, or 2019.

Additional sampling should be done in conjunction with the planned standard surveys. To better assess the Smallmouth Bass population, targeted surveys using open water angling should be done in late June in alternate years from 2015 (completed) - 2019, and in conjunction with each standard survey scheduled thereafter. If funding is available, it is important that creel surveys be conducted in summer and winter of 2019 and 2022 to monitor the Smallmouth Bass and Lake Trout fisheries and to provide data needed to protect or improve those fisheries.

As part of the Sentinel Lakes program, the following sampling would be desirable, if funding or staffing permit.

1. Supplement Lake Trout monitoring by conducting targeted surveys using short-term gill netting targeting Lake Trout in spring 2015, fall 2016 or spring 2017, fall 2018 or spring 2019, and in fall 2021 or spring 2022. All Lake Trout taken in these would be marked with numbered tags, and released alive whenever possible.

Plankton and plant assessment needs

1. Because spiny waterfleas are well established in the lake, it is important to continue zooplankton monitoring on some type of routine basis for the lake. This is essential for establishing trends in native zooplankton species composition as well as documenting densities and biomass. This can be informative for not only Greenwood Lake, but other lakes like Trout Lake where infestations are much more recent and implications for the lake's ecology remain to be seen.

Water quality and quantity measurement and assessment needs

1. A CLMP volunteer should be found and encouraged to make consistent transparency measurements on the lake. A minimum frequency would be two times per months from June through September and weekly measurement would be even better.
2. MDNR has a good long-term late summer DO and temperature profile for Greenwood. This program should be continued indefinitely. Updating Figure 12 annually would be a good practice to ensure data is assessed each year. As resources permit, measure temperature-oxygen profiles May-November, annually.
3. The use of the thermistor chain is a valuable addition. Data from this source should be analyzed annually. Developing a standard method for charting this data would be desirable.
4. Consider water quality monitoring in conjunction with visits to Trout Lake (a Super Sentinel Lake). If there are time or analytic funding constraints this additional monitoring could be conducted on a seasonal basis: May, August, and October.

5. Lake level monitoring was just initiated in 2014. It would be desirable to have a volunteer monitor a consistent gauge so that a long-term record might be developed.
6. Greenwood is a very dilute lake with low ion and nutrient concentrations. Any future trend assessments must consider lab methodology and reporting limits for the analyte being measured. Lack of insight on this can lead to erroneous trend assessments. The existing data record from the early 1980s through 2014 includes various parameters such as TP where methods and RLs have changed over time. This also applies to ions such as Ca and Cl.
7. Ice-out records date back to 1998; however, the record is not continuous. If date of ice-out is to be a useful indicator for evaluating impacts of climate change, this measure must be made every year. One option may be to install a camera to aid in recording both ice-in and ice-out.

Watershed land use changes

1. While no major land use changes are likely in this watershed, it will be important to be aware of forestry practices and any further changes in forest composition (e.g. shift from deciduous to evergreen or mixed forest) and any implications this may have for water quality or related in-lake factors.
2. If it has not already been done, MDNR should designate Greenwood Lake as a priority for protection and this should be incorporated into the Watershed Restoration and Protection Plan (WRAP) for Lake Superior North watershed.

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List of Appendices

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Appendix A

Water quality analytical methods and reporting limits (2014)

MDH#	Parameter	Standard Method or EPA number	Report level (RL)
59	Total phosphorus	SM 4500P I	0.03 mg/L
68	Total Kjeldahl nitrogen	EPA 351.2	0.20 mg/L
69	Nitrite + nitrate-N	EPA 353.2	0.05 mg/L
450	Chlorophyll-a	SM 10200H	0.46 µg/L
451	Pheophytin	SM 10200H	
3	Total suspended solids	SM 2540D	1.0 mg/L
4	Total suspended volatile solids	EPA 160.4	1.0 mg/L
12	Color	SM 2120B	5 PCU
22	Alkalinity	SM 2320B	10 mg/L
297	Chloride	EPA 300.1	1.0 mg/L
293	Sulfate, IC	EPA 300.1	1.0 mg/L
70	Soluble ortho-P	EPA 365.1	
77	Ammonia-N, dissolved	EPA 350.1	0.05 mg/L
30	Silica, dissolved	SM 4500-SiO2 C	0.5 mg/L
98	Total organic carbon	SM 5310C	1.0 mg/L
99	Dissolved organic carbon	SM 5310C	1.0 mg/L
703	Calcium	EPA 200.7	0.10 mg/L
703	Magnesium	EPA 200.7	0.10 mg/L
703	Sodium	EPA 200.7	0.10 mg/L
703	Potassium	EPA 200.7	0.30 mg/L

Appendix B

Minnesota Biological Survey: List of plant species observed at Greenwood Lake

Survey Date: 8/21/2012 Area surveyed: south end of the lake.

Submersed Plants (Plants with most leaves growing beneath the water surface)

Eriocaulon aquaticum Pipewort
Hippuris vulgaris Mare's-tail
* *Isoetes echinospora* Braun's quillwort
Lobelia dortmanna Water lobelia
Myriophyllum alterniflorum Small Leaved Milfoil
cf *Myriophyllum farwellii* Farwell's Watermilfoil
Ranunculus aquatilis var. *diffusus* White water-crowfoot Greenwood Lake

Floating-leaf Plants (Plants with leaves that float on the water surface)

* *Callitriche palustris* Marsh Water Starwort
Nuphar variegata Yellow Water Lily
Sparganium angustifolium Narrow Floatingleaf Burreed

Emergent Plants (Plants with leaves extending above the water surface)

Carex utriculata Beaked Sedge, Bottle-shaped
Eleocharis palustris Small's Spikerush
Equisetum fluviatile Water horsetail

Shoreline Plants (Plants associated with the wetland habitat)

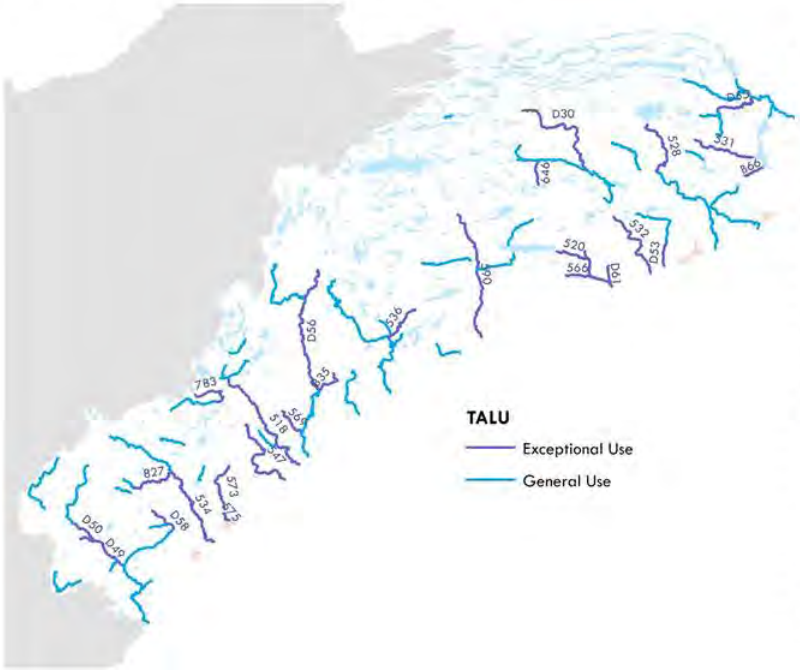
Alnus incana ssp. *rugosa* Speckled alder
Alnus viridis ssp. *crispa* Green alder
Chamaedaphne calyculata Leather-leaf
Cornus sericea Red-osier dogwood
Eleocharis acicularis Needle Spike-rush
Iris versicolor Blue Flag
Juncus tenuis Path rush
Lycopus uniflorus Northern bugleweed
Lysimachia terrestris Swamp Candles, Loosestrife
Menyanthes trifoliata Buck-bean
Myrica gale Sweet gale
Phalaris arundinacea Reed canary grass
Rhododendron groenlandicum Labrador tea
Rumex sp. Dock; Sorrel
* *Scirpus hattorianus* Mosquito Bulrush
Scirpus microcarpus Red-tinged bulrush
Scutellaria lateriflora Mad-dog skullcap
Sium suave Water-parsnip
Triadenum fraseri Marsh St. John's-wort
* specimen echosounder. Minnesota Department of Natural Resources, Staff Report Number 59.

Appendix C

Map of rivers of the North Shore of Lake Superior and TALU classification.

Lake Superior North
MPCA Watershed Assessment Professional Judgment Group meeting
May 28, 2015

Rivers and streams assessed for Aquatic Life, and associated Tiered Aquatic Life Use classification
(Exceptional Use waters identified individually)



WID	Stream Name
04010101-518	Cross River
04010101-520	Devil Track River
04010101-528	Greenwood River
04010101-531	Irish Creek
04010101-532	Kimball Creek
04010101-534	Manitou River
04010101-536	Mistletoe Creek
04010101-547	Two Island River
04010101-566	Little Devil Track River
04010101-569	Heartbreak Creek
04010101-571	Houghtaling Creek
04010101-573	Caribou River
04010101-575	Caribou River
04010101-581	Crown Creek
04010101-590	Cascade River
04010101-646	Bluff Creek
04010101-717	Elbow Creek
04010101-783	Wanless Creek
04010101-827	Manitou River, South Branch
04010101-835	Sixmile Creek
04010101-866	Swamp River
04010101-D30	Brule River
04010101-D49	Baptism River, West Branch
04010101-D50	Baptism River, West Branch
04010101-D53	Kadunce River (Kadunce Creek)
04010101-D55	Portage Brook
04010101-D56	Temperance River
04010101-D58	Baptism River, East Branch
04010101-D61	Woods Creek