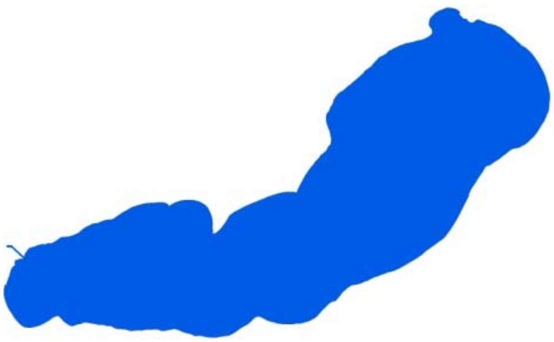
Lake Minnewaska 61-0130-00 POPE COUNTY

Lake Water Quality

Summary



Lake Minnewaska is located between Starbuck and Glenwood, MN in Pope County. It is a round lake covering 8,050 acres (Table 1).

Lake Minnewaska has nine inlets and one outlet, which classify it as a drainage lake. Water enters Lake Minnewaska from Trapper Run Creek and Perkins Creek to the east and and ground-fed streams in the southeast. Outlet Creek exits the lake on the west side of Lake Minnewaska and carries water westward to the Little Chippewa River.

Water quality data have been collected continuously at site 201 on Lake Minnewaska since 1973 (Tables 2 & 3). These data show that the lake is eutrophic (TSI = 49) with moderately clear water conditions most of the summer and good recreational opportunities.

Lake Minnewaska has an organized association that is involved in activities such as water quality monitoring and education.

Table 1. Lake Minnewaska location and key physical characteristics.

Location Data		Physical Characteristics	
MN Lake ID:	61-0130-00	Surface area (acres):	8,050.27
County:	Pope	Littoral area (acres):	944.76
Ecoregion:	North Central Hardwood Forest	% Littoral area:	40.88%
Major Watershed:	Chippewa River	Max depth (ft), (m):	32, 9.75
Latitude/Longitude:	45.613263/ -95.446317	Inlets:	9
Invasive Species:	Eurasian Milfoil, Zebra Mussels	Outlets:	1
		Public Accesses:	3

Table 2. Availability of primary data types for Lake Minnewaska.

Data Availability		
Transparency data	👍	Citizen Lake Monitoring Program: 1994-2016
Chemical data	👍	Pope COLA: 1996-2016
Inlet/Outlet data	👍	Lake Minnewaska CWP: 2014-2015
Recommendations		**For recommendations refer to page 22.**

Lake Map

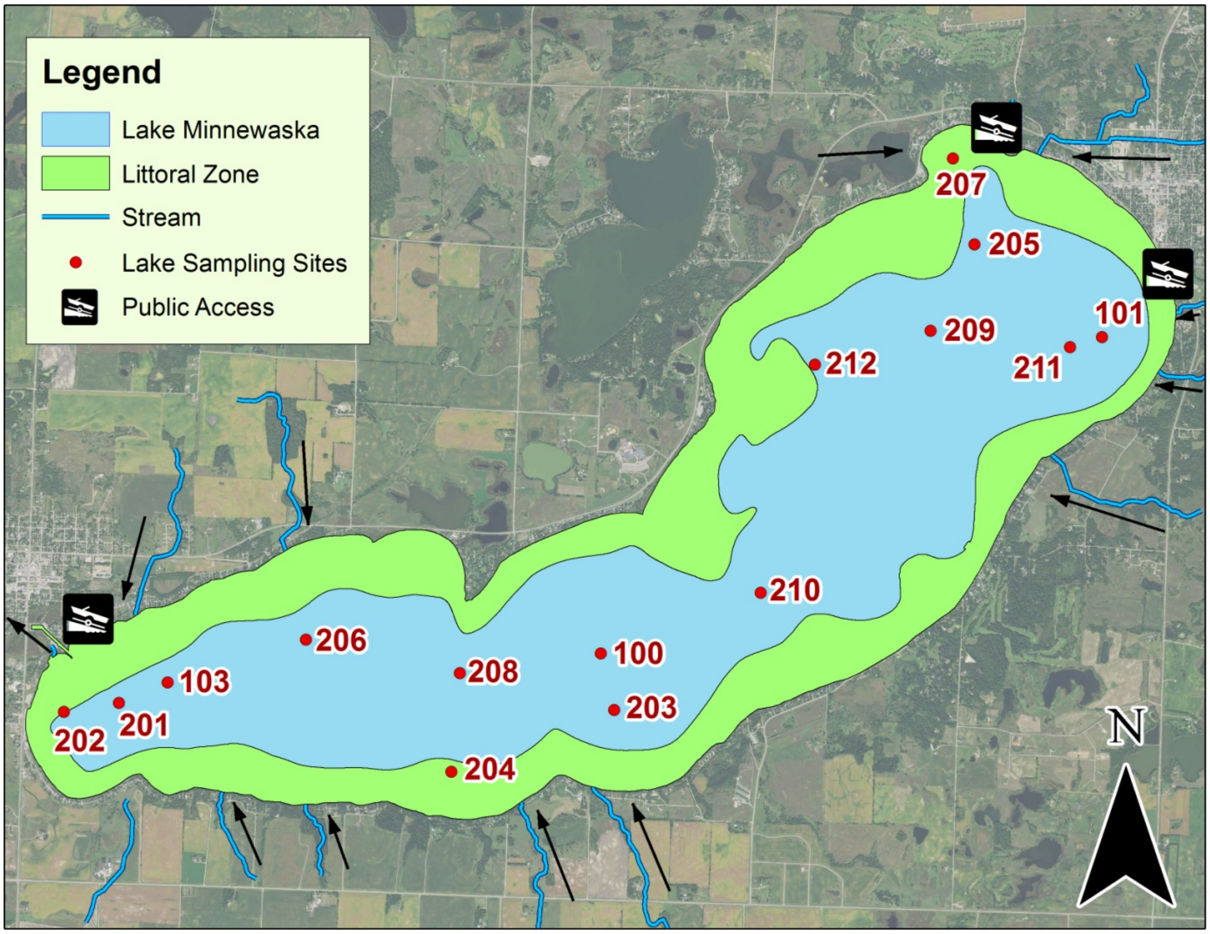


Figure 1. Map of Lake Minnewaska with 2015 aerial imagery and illustrations of lake depth contour lines, sample site locations, inlets and outlets, and public access points. The light green areas in the lake illustrate the littoral zone, where the sunlight can usually reach the lake bottom, allowing aquatic plants to grow.

Table 3. Monitoring programs and associated monitoring sites. Monitoring programs include the Citizen Lake Monitoring Program (CLMP), MPCA Lake Monitoring Program Project (LMPP), Pope Coalition of Lake Association Monitoring (COLA), Lake Trend Monitoring (LTM), and RMB Environmental Laboratory Monitoring Program (RMBEL). Sites with only one year of data were eliminated from this table due to space.

Lake Site	Depth (ft)	Monitoring Programs
101	24	LMPP: 1977-1978,1995
103	25	LMPP:1977-1978,1995
201	25	CLMP: 1973-1974,1983,1991-1992,1994-1996; COLA: 1994-1995; RMBEL: 1996-2014
202	20	CLMP: 1977-1980,1982; LMPP: 1979-1981
203	25	CLMP: 1977,1991-1992,1994-1996
205	20	CLMP: 1991-1996; COLA: 1994-1995; RMBEL: 1996-2014
208	25	CLMP: 1993,2005-2015; LTM: 2005; LMPP: 1977-1978,1995; RMBEL: 2015
209	20	CLMP: 2004-2015; LTM: 2005
210	32	CLMP: 2004-2015
211	24	CLMP: 2004-2015; RMBEL: 2015
212	20	CLMP: 2005-2011,2013-2015

Average Water Quality Statistics

The information below describes available chemical data for Lake Minnewaska through 2014 (Table 4). Data for Secchi depth, chlorophyll-a, and phosphorous are from the primary site 201.

Minnesota is divided into 7 ecoregions based on land use, vegetation, precipitation and geology. The MPCA has developed a way to determine the "average range" of water quality expected for lakes in each ecoregion. For more information on ecoregions and expected water quality ranges, see page 11. Lake Minnewaska is in the Central Hardwood Forest Ecoregion.

Table 4. Water quality means compared to ecoregion ranges and impaired waters standard.

Parameter	Mean	Ecoregion Range[1]	Impaired Waters Standard[2]	Interpretation
Total phosphorus (ug/L)	25.7	23 – 50	> 40	Results are within the expected ecoregion ranges and well below the Impaired Waters Standards.
[3]Chlorophyll *a* (ug/L)	7.8	5 – 22	> 14	
Chlorophyll *a* max (ug/L)	18.0	7 – 37		
Secchi depth (ft)	8.8	4.9 – 10.5	< 7	
Dissolved oxygen	*See page 8*			Dissolved oxygen depth profiles show that the lake mixes periodically in summer.
Total Kjeldahl Nitrogen (mg/L)	0.90	<0.6 – 1.2		Within the ecoregion range. Indicates insufficient nitrogen to support summer nitrogen-induced algae blooms.
Alkalinity (mg/L)	232.6	75 – 150		Indicates a low sensitivity to acid rain and a good buffering capacity.
Color (Pt-Co Units)	11.4	10 – 20		Indicates moderately clear water with little to no tannins (brown stain).
pH	8.5	8.6 – 8.8		Indicates a hard water lake. Lake water pH less than 6.5 can affect fish spawning and the solubility of metals in the water.
Chloride (mg/L)	27.1	4 – 10		Above the expected range for the ecoregion. Chloride comes from runoff from road salts and waste water.
Total Suspended Solids (mg/L)	6.2	1 – 2		Indicates cloudy water at times from algae or sediment.
Specific Conductance (umhos/cm)	563.3	300 – 400		Above the expected range for the ecoregion. Indicates watershed or wastewater loading and is related to chloride levels.
TN:TP Ratio	35.0	25:1 - 35:1		Within the expected range for the ecoregion, and shows the lake is phosphorus limited.

[1]The ecoregion range is the 25th-75th percentile of summer means from ecoregion reference lakes
[2]For further information regarding the Impaired Waters Assessment program, refer to http://www.pca.state.mn.us/water/tmdl/index.html
[3]Chlorophyll *a* measurements have been corrected for pheophytin
Units: 1 mg/L (ppm) = 1,000 ug/L (ppb)

Water Quality Characteristics - Historical Means and Ranges

Table 5. Water quality means and ranges for primary sites from 1996-2016.

Parameters	West	East
Total Phosphorus Mean (ug/L):	**28.8**	**28.8**
Total Phosphorus Min:	12.0	14.0
Total Phosphorus Max:	65.0	65.0
Number of Observations:	98	98
Chlorophyll *a* Mean (ug/L):	**8.5**	**8.8**
Chlorophyll-a Min:	<1	<1
Chlorophyll-a Max:	28.0	34.0
Number of Observations:	86	86
Secchi Depth Mean (ft):	**9.4**	**8.7**
Secchi Depth Min:	4.5	3.5
Secchi Depth Max:	23.0	19.0
Number of Observations:	97	98

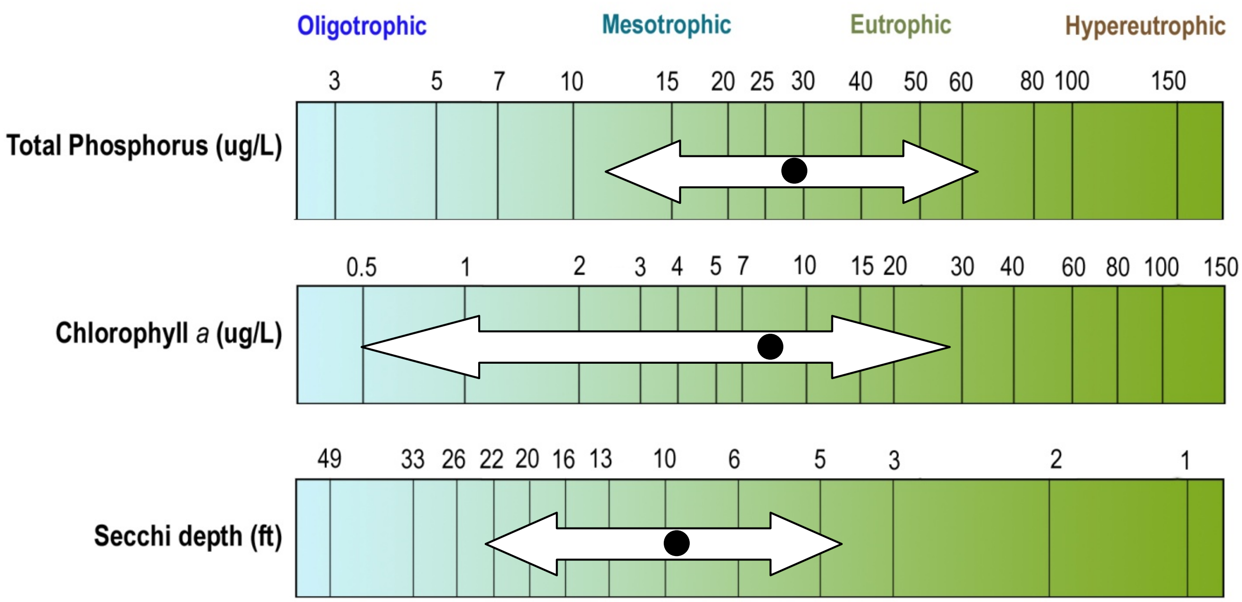


Figure 2. Lake Minnewaska total phosphorus, chlorophyll a and transparency historical ranges. The arrow represents the range and the black dot represents the historical mean. Figure adapted after Moore and Thornton, [Ed.]. 1988. Lake and Reservoir Restoration Guidance Manual. (Doc. No. EPA 440/5-88-002)

Transparency (Secchi Depth)

Transparency is how easily light can pass through a substance. In lakes it is how deep sunlight penetrates through the water. Plants and algae need sunlight to grow, so they are only able to grow in areas of lakes where the sun penetrates. Water transparency depends on the amount of particles in the water. An increase in particulates results in a decrease in transparency. The transparency varies year to year due to changes in weather, precipitation, lake use, flooding, temperature, lake levels, etc.

The annual mean transparency in Lake Minnewaska ranges from 6.0 to 13.5 feet (Figure 3). The annual means hover fairly close to the long-term mean. For trend analysis, see page 10. Transparency monitoring should be continued annually in order to track water quality changes.

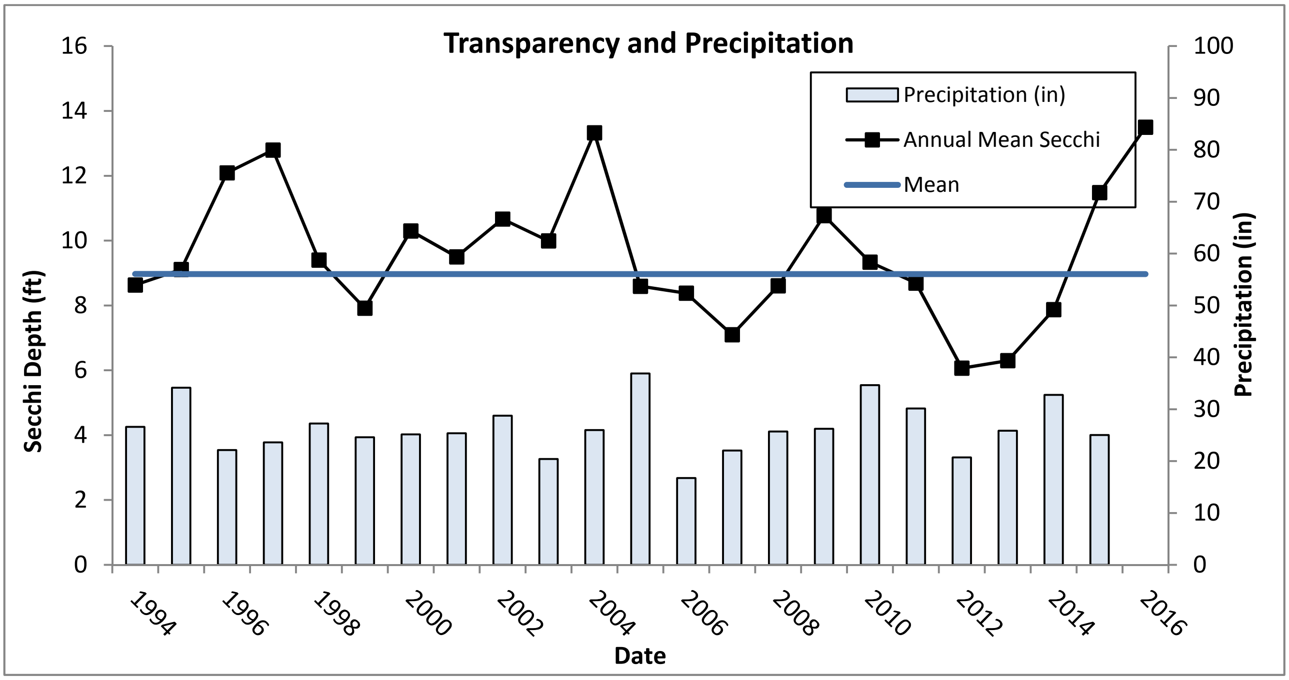


Figure 3. Annual mean transparency compared to long-term mean transparency, west end of lake.

Lake Minnewaska transparency ranges from 4.5 to 23.0 ft at the primary site (201, west). Figure 4 shows the seasonal transparency dynamics. The maximum Secchi reading is usually obtained in early summer. Lake Minnewaska transparency is high in May and June, and then declines through August. This transparency dynamic is typical of a Minnesota lake. The dynamics have to do with algae and zooplankton population dynamics, and lake turnover.

It is important for lake residents to understand the seasonal transparency dynamics in their lake so that they are not worried about why their transparency is lower in August than it is in June. It is typical for a lake to vary in transparency throughout the summer.

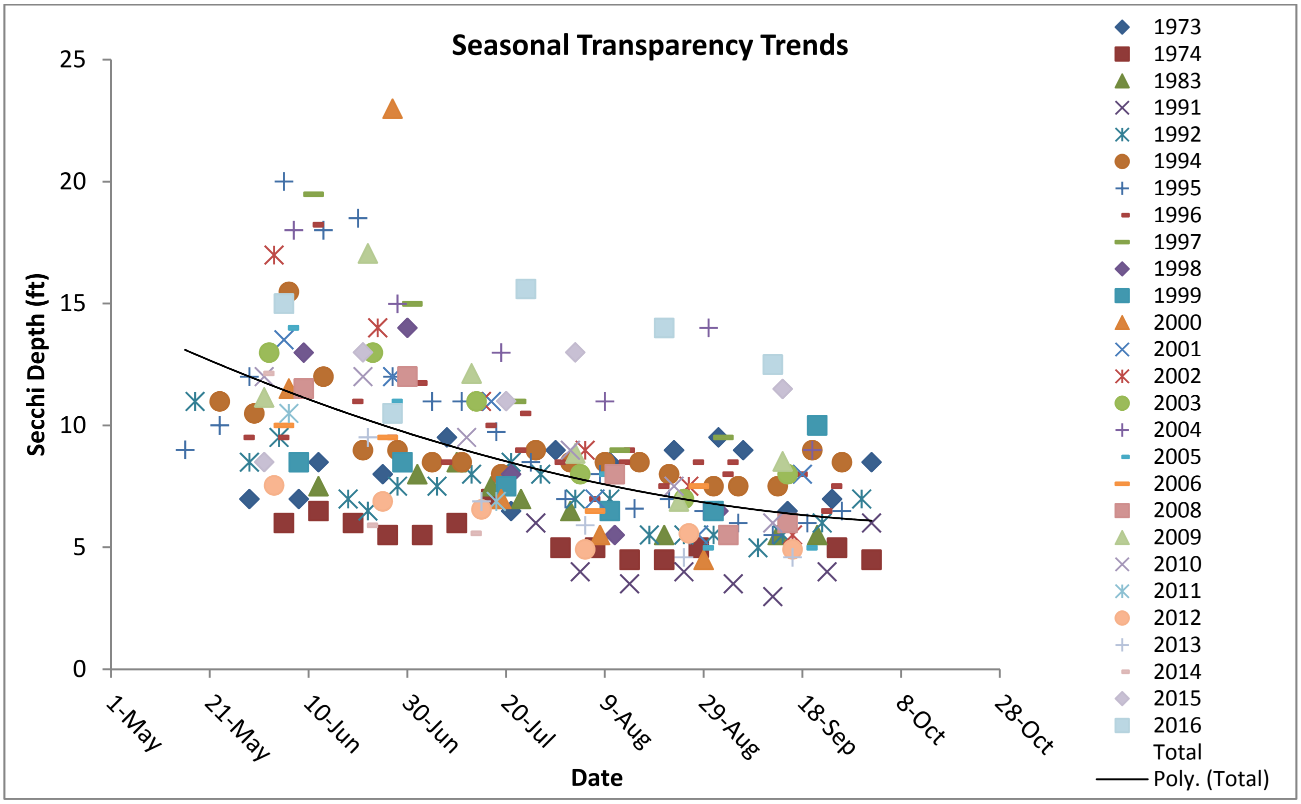
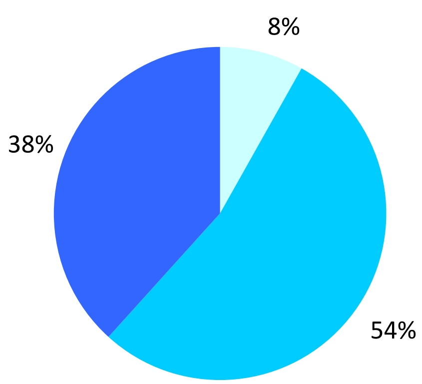


Figure 4. Seasonal transparency dynamics and year to year comparison (Primary Site 201). The black line represents the pattern in the data.

User Perceptions

When volunteers collect Secchi depth readings, they record their perceptions of the water based on the physical appearance and the recreational suitability. These perceptions can be compared to water quality parameters to see how the lake "user" would experience the lake at that time. Looking at transparency data, as the Secchi depth decreases the perception of the lake's physical appearance rating decreases. Lake Minnewaska was rated as being "not quite crystal clear" 54% of the time by samplers between 1991 and 2016 (Figure 5).



Physical Appearance Rating

- 8% Crystal clear water
- 54% Not quite crystal clear – a little algae visible
- 38% Definite algae – green, yellow, or brown color apparent
- 0% High algae levels with limited clarity and/or mild odor apparent
- 0% Severely high algae levels

Figure 5. Lake Minnewaska physical appearance ratings by samplers.

As the Secchi depth decreases, the perception of recreational suitability of the lake decreases. Lake Minnewaska was rated as being "good" 52% of the time from 1991 to 2016 (Figure 6).

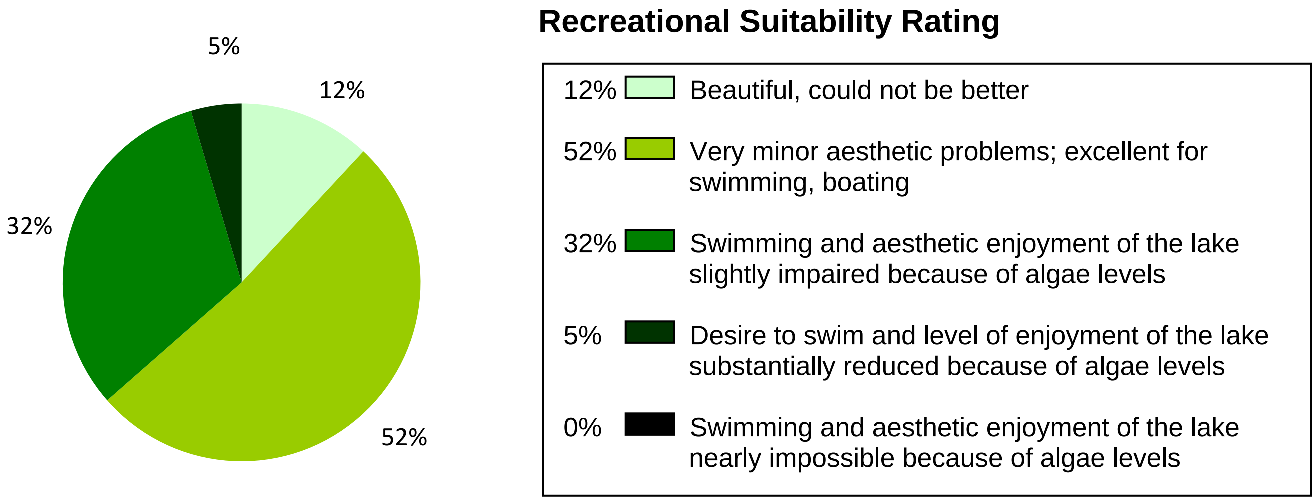


Figure 6. Recreational suitability rating, as rated by the volunteer monitor.

Total Phosphorus

Lake Minnewaska is phosphorus limited, which means that algae and aquatic plant growth is dependent upon available phosphorus.

Total phosphorus was evaluated in Lake Minnewaska in 1977-1981,1994-2016. Figure 7 shows data from 1996-2016. The phosphorus concentrations were higher in 1998-1999 than they were in 2015-2016 (Figure 7).

Phosphorus should continue to be monitored to track any future changes in water quality.

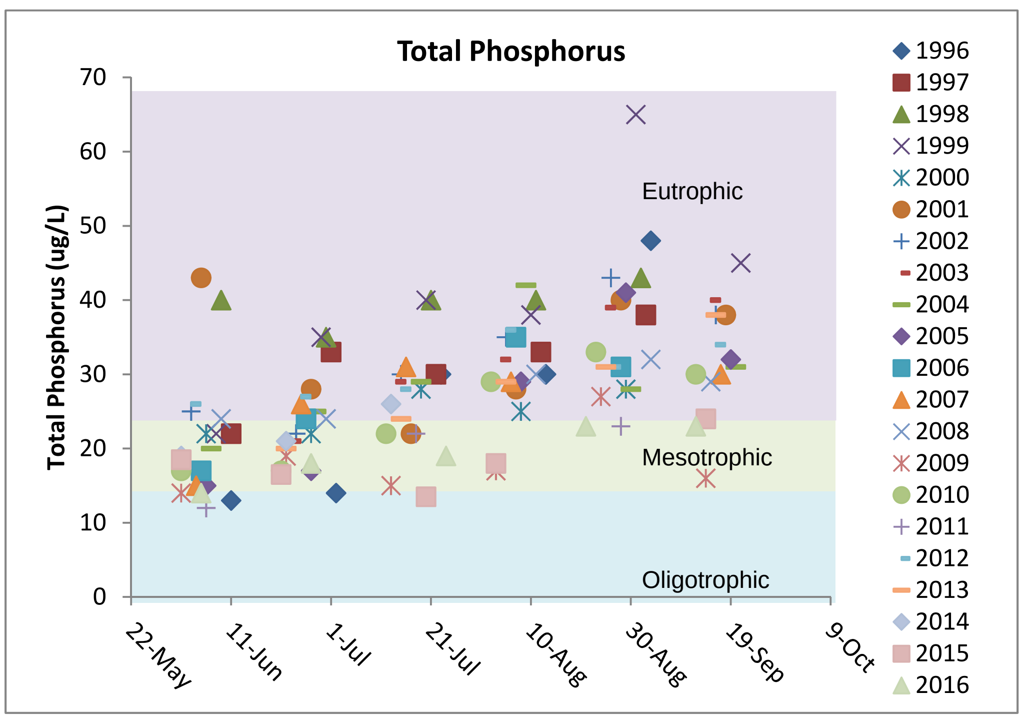


Figure 7. Historical total phosphorus concentrations (ug/L) for Lake Minnewaska, West.

Chlorophyll *a*

Chlorophyll *a* is the pigment that makes plants and algae green. Chlorophyll *a* is tested in lakes to determine the algae concentration or how "green" the water is.

Chlorophyll *a* concentrations greater than 10 ug/L are perceived as a mild algae bloom, while concentrations greater than 20 ug/L are perceived as a nuisance.

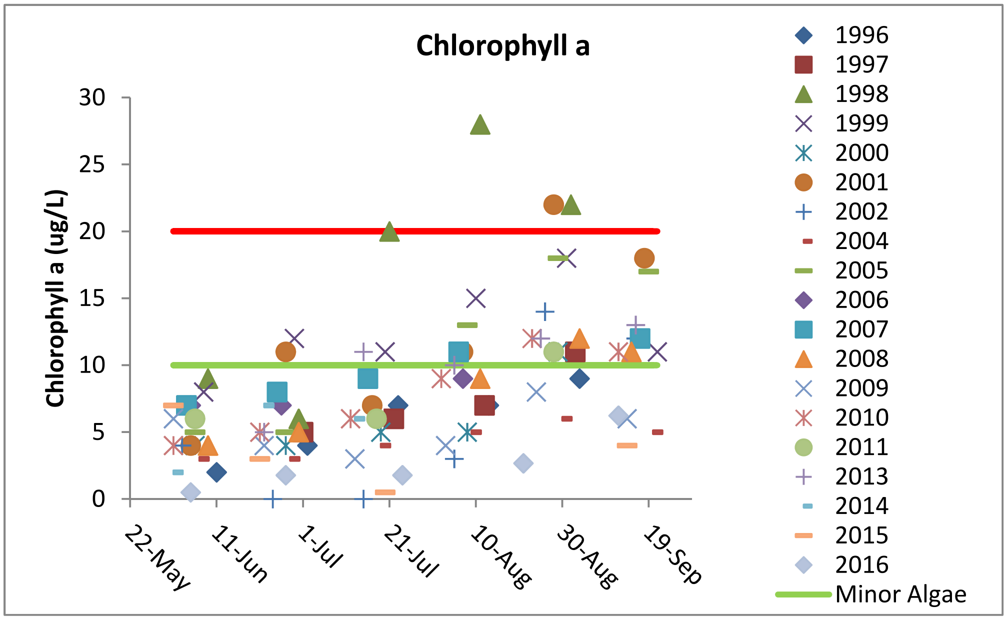
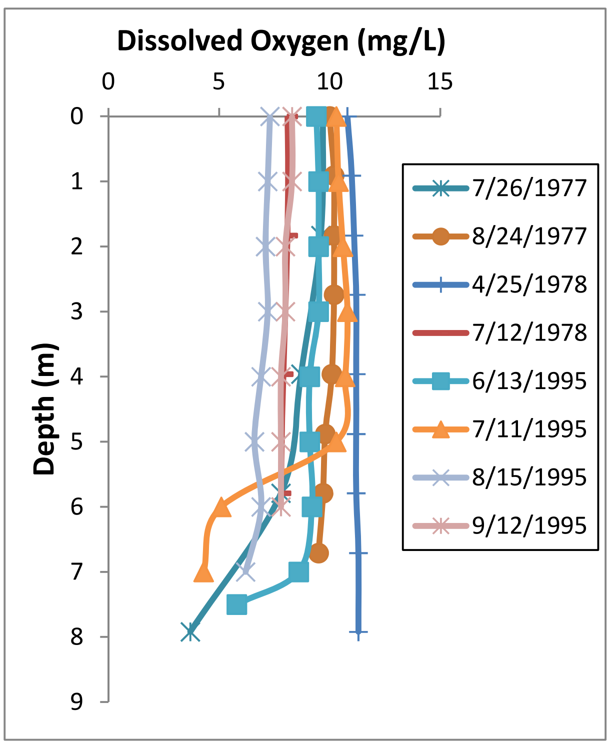


Figure 8. Chlorophyll *a* concentrations (ug/L) for Lake Minnewaska at site 201, west.

Chlorophyll *a* was evaluated in Lake Minnewaska at site 201 from 1996-2016 (Figure 8). Chlorophyll *a* concentrations show minor algae blooms most years and major algae blooms in 1998 and 2001.

Dissolved Oxygen



Dissolved Oxygen (DO) is the amount of oxygen dissolved in lake water. Oxygen is necessary for all living organisms to survive except for some bacteria. Living organisms breathe in oxygen that is dissolved in the water. Dissolved oxygen levels of <5 mg/L are typically avoided by game fisheries.

Lake Minnewaska is a moderately deep lake, with a maximum depth of 32 feet. Dissolved oxygen profiles from data collected in 1977, 1978 and 1995 at site 208 do not show much stratification (Figure 9). The lake likely stratifies periodically, but not strongly. A few windy days have the potential to mix the lake.

Figure 9. Dissolved oxygen profile for Lake Minnewaska.

Trophic State Index (TSI)

TSI is a standard measure or means for calculating the trophic status or productivity of a lake. More specifically, it is the total weight of living algae (algae biomass) in a waterbody at a specific location and time. Three variables, chlorophyll a, Secchi depth, and total phosphorus, independently estimate algal biomass.

Phosphorus (nutrients), chlorophyll *a* (algae concentration) and Secchi depth (transparency) are related. As phosphorus increases, there is more food available for algae, resulting in increased algal concentrations. When algal concentrations increase, the water becomes less transparent and the Secchi depth decreases. If all three TSI numbers are within a few points of each other, they are strongly related. If they are different, there are other dynamics influencing the lake's productivity, and TSI mean should not be reported for the lake.

The mean TSI for Lake Minnewaska falls into the eutrophic range (Figure 10). There is good agreement between the TSI for phosphorus and chlorophyll *a*, indicating that these variables are related (Table 6). The TSI for Secchi is lower, and could be an effect of zebra mussels in the lake.

Eutrophic lakes (TSI 50-70) are characteristic of "green" water most of the summer. "Eu" means true and the root "trophy" means nutrients therefore, eutrophic literally means true nutrients or truly nutrient rich (phosphorus). Eutrophic lakes are usually shallow, and are found where the soils are fertile. Eutrophic lakes usually have abundant aquatic plants and algae.

Table 6. Trophic State Index for Lake

Trophic State Index	Primary Site 202
TSI Total Phosphorus	53
TSI Chlorophyll-a	52
TSI Secchi	45
TSI Mean	50
Trophic State:	Eutrophic

Numbers represent the mean TSI for each parameter.

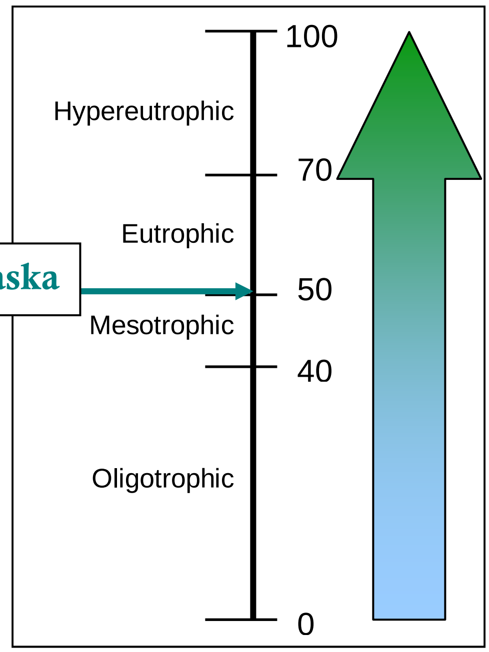


Figure 10. Trophic state index chart with corresponding trophic status.

Table 7. Trophic state index attributes and their corresponding fisheries and recreation characteristics.

TSI	Attributes	Fisheries & Recreation
<30	Oligotrophy: Clear water, oxygen throughout the year at the bottom of the lake, very deep cold water.	Trout fisheries dominate
30-40	Bottom of shallower lakes may become anoxic (no oxygen).	Trout fisheries in deep lakes only. Walleye, Cisco present.
40-50	Mesotrophy: Water moderately clear most of the summer. May be "greener" in late summer.	No oxygen at the bottom of the lake results in loss of trout. Walleye may predominate.
50-60	Eutrophy: Algae and aquatic plant problems possible. "Green" water most of the year.	Warm-water fisheries only. Bass may dominate.
60-70	Blue-green algae dominate, algal scums and aquatic plant problems.	Dense algae and aquatic plants. Low water clarity may discourage swimming and boating.
70-80	Hypereutrophy: Dense algae and aquatic plants.	Water is not suitable for recreation.
>80	Algal scums, few aquatic plants	Rough fish (carp) dominate; summer fish kills possible

Source: Carlson, R.E. 1997. A trophic state index for lakes. *Limnology and Oceanography*. 22:361-369.

Trend Analysis

In assessing water quality, agencies and other lake data users want to know if the amount of algae has been changing over time. Scientists test hypotheses using statistics, and the hypothesis used in a trend analysis is that no trend exists. In other words, we begin with the assumption that there is no trend. We collect data and use statistics to determine the probability of collecting our data if this hypothesis of no trend is indeed true. The output from a statistical test is called the probability value (or p-value for short) of collecting data given the hypothesis of no trend is true. The smaller this probability value, the more likely the null hypothesis of no trend can be rejected. The MPCA has set the acceptable p-value to be less than 10%. In other words, if $p < 0.10$ we reject the hypothesis of no trend and accept that a trend likely exists. Another way to think of this is to say that there is in reality an existing trend, there is a 90% chance we would have collected the data we collected and that a 10% chance that the trend is a random result of the data. For detecting trends, a minimum of 8-10 years of data with four or more readings per season are recommended by the MPCA. Where data does not cover at least eight years or where there are only few samples within a year, trends can be misidentified because there can be different wet years and dry years, water levels, weather, and etc., that affect the water quality naturally.

Lake Minnewaska had enough data to perform a trend analysis on all three parameters (Table 8). The data was analyzed using the Mann Kendall Trend Analysis.

Table 8. Trend analysis for Lake Minnewaska.

Lake Site	Parameter	Date Range	Trend	Probability
West	Total Phosphorus	1996-2016	Improving	99%
West	Chlorophyll *a*	1993-2013	No trend	
West	Chlorophyll *a*	1993-2016	Improving	95%
West	Transparency	1996-2013	Decreasing	99.9%
West	Transparency	1996-2016	No Trend	-
East	Total Phosphorus	1996-2016	Improving	95%
East	Chlorophyll *a*	1996-2016	Improving	90%
East	Transparency	1996-2013	Decreasing	95%
East	Transparency	1996-2016	No Trend	-

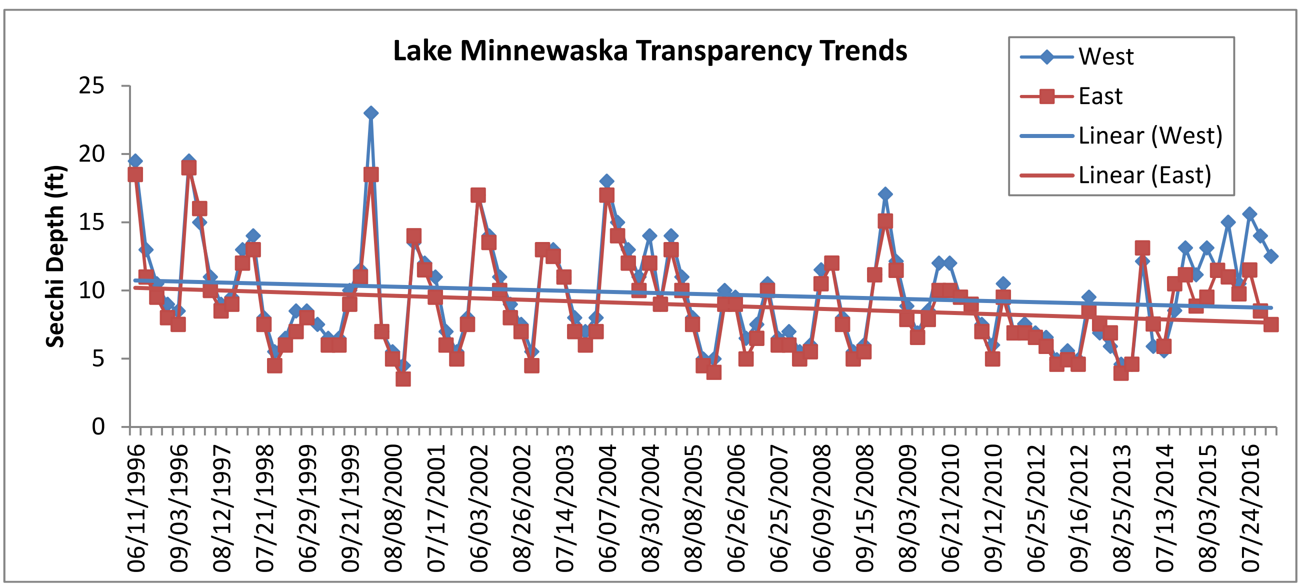


Figure 11. Transparency (feet) trend for site 201 from 1996-2016.

Lake Minnewaska data are showing some changes in the lake's condition. There is evidence of a declining transparency trend from 1996-2013, but no trend from 1996-2016 (Figure 11). Zebra mussels were discovered in Lake Minnewaska in 2012. Usually they take about two years to start impacting water clarity, so it could be that the zebra mussels have improved water transparency in Lake Minnewaska in 2015-2016. The chlorophyll a has also decreased in 2015-2016, which could be due to Zebra mussels (Figure 12). Monitoring should continue so that these trends can be tracked in future years. Due to zebra mussels, the transparency and chlorophyll a in the lake will not follow phosphorus concentrations anymore. This is evident already in the TSI comparison (Table 6).

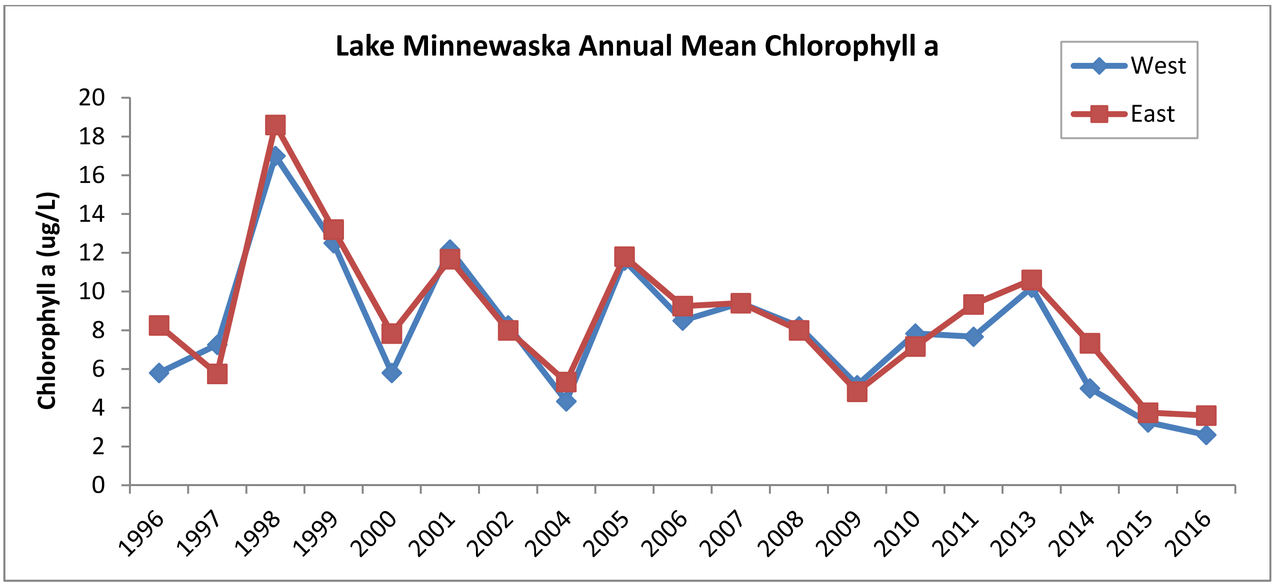


Figure 12. Annual mean chlorophyll a concentrations in Lake Minnewaska.

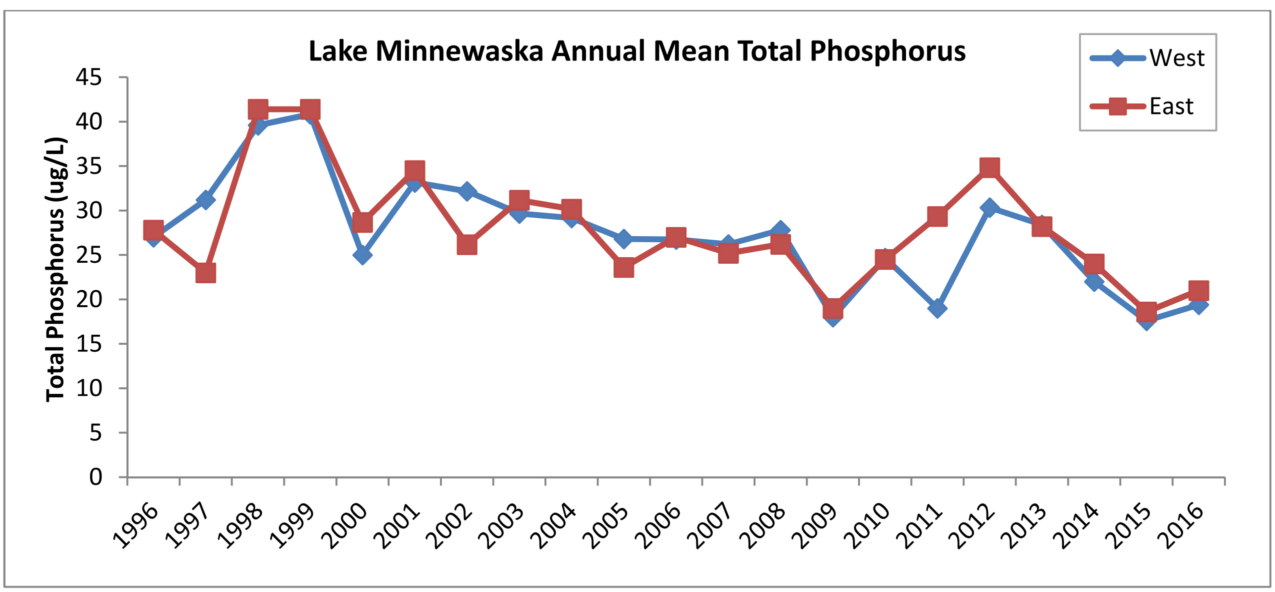
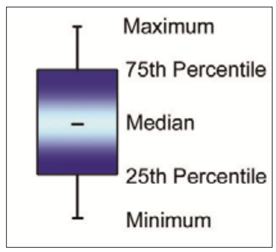


Figure 13. Annaul mean total phosphorus concentrations in Lake Minnewaska.

Ecoregion Comparisons

Minnesota is divided into 7 ecoregions based on land use, vegetation, precipitation and geology (Figure 12). The MPCA has developed a way to determine the "average range" of water quality expected for lakes in each ecoregion. From 1985-1988, the MPCA evaluated the lake water quality for reference lakes. These reference lakes are not considered pristine, but are considered to have little human impact and therefore are representative of the typical lakes within the ecoregion. The "average range" refers to the 25th - 75th percentile range for data within each ecoregion. For the purpose of this graphical representation, the means of the reference lake data sets were used.

Lake Minnewaska is in the Central Hardwood Forest Ecoregion. The mean total phosphorus, chlorophyll *a* and transparency (Secchi depth) for Lake Minnewaska are within the ecoregion ranges (Figure 13).



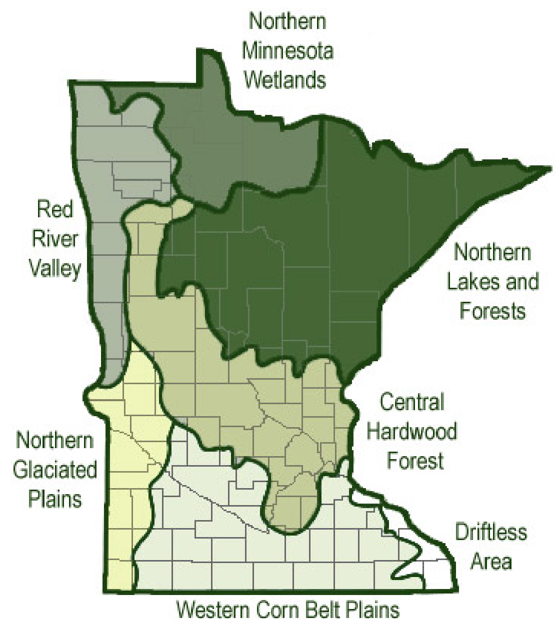


Figure 14. Minnesota Ecoregions.

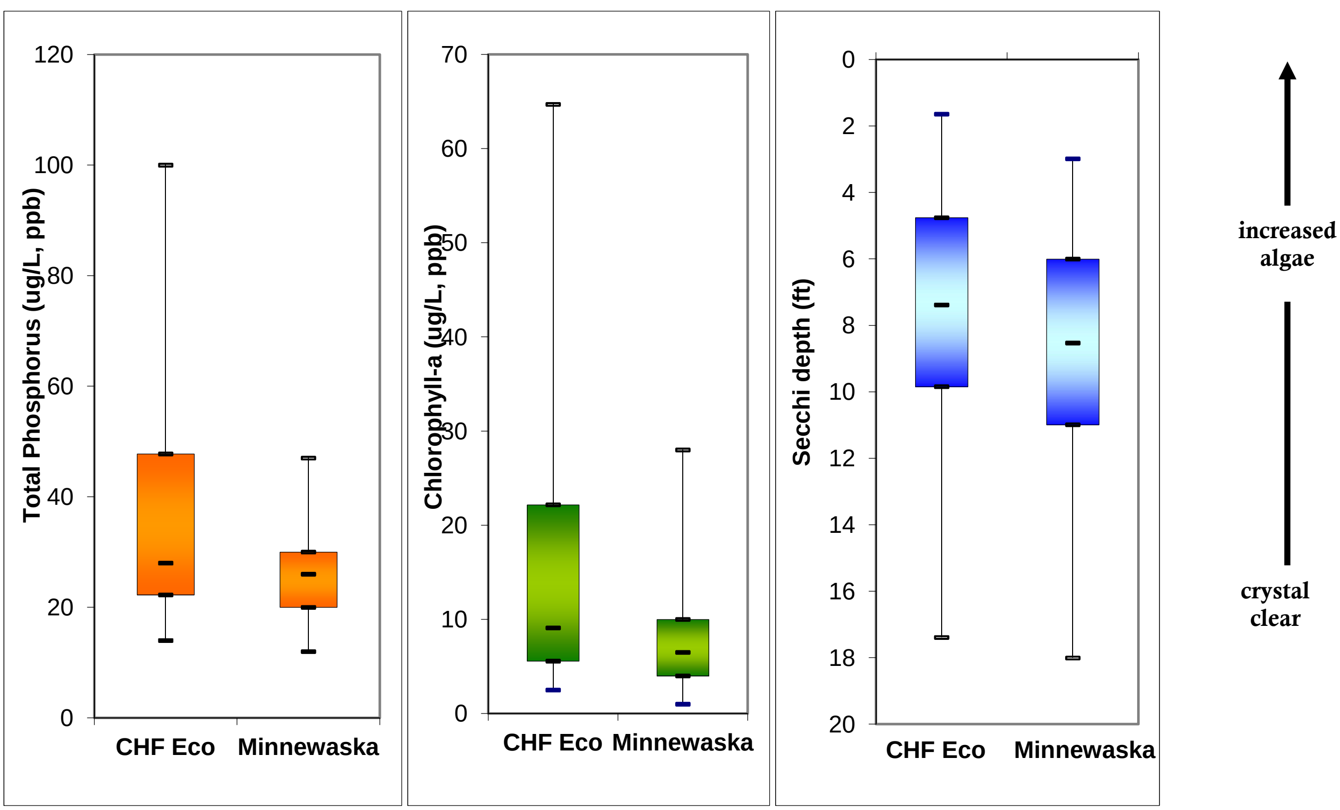


Figure 15. Lake Minnewaska ranges compared to Northern Lakes and Forest Ecoregion ranges. The Lake Minnewaska total phosphorus and chlorophyll *a* ranges are from 118 data points collected in May-September of 2004-2016. The Lake Minnewaska Secchi depth range is from 495 data points collected in May-September of 2004-2016.

Inlet/Outlet Water Quality

Water quality parameters were monitored at Lake Minnewaska's main inlets as part of the Lake Minnewaska Clean Water Partnership Project in 2014-2015 (Table 9). Results show that the water average chemistry in Trapper Run Creek and Perkins Creek fit into the expected ranges for the Central Hardwood Forest Ecoregion (Table 9). When looking at the maximum for each parameter, the data show that Perkins Creek sometimes has high nutrient concentrations (Table 10). This could be due to stormwater runoff in Glenwood during storm events. Overall, neither of the inlets appear to be contributing large amounts of water and nutrients to the lake all year long.

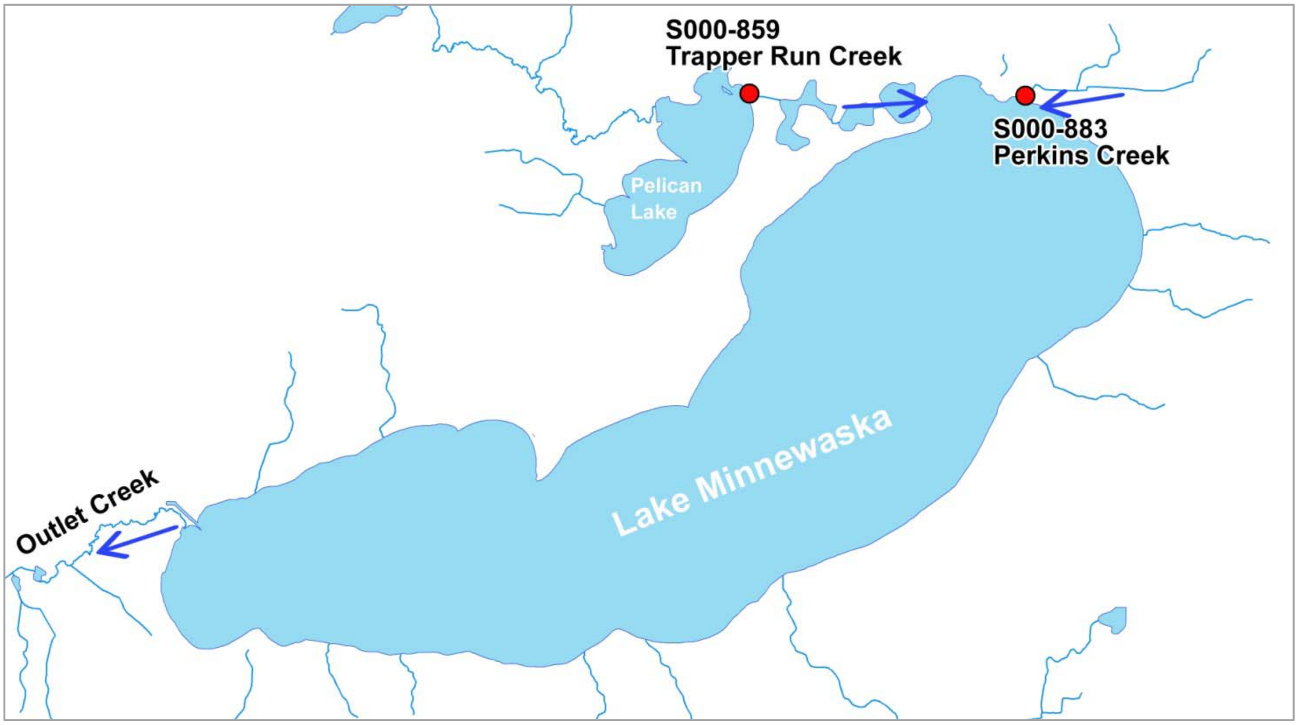


Table 9. Water quality means for inlets to Lake Minnewaska as compared to the Ecoregion Ranges.

	Dissolved oxygen (mg/L)	Ortho-phosphate (ug/L)	Total Phosphorus (ug/L)	Nitrate + Nitrite (mg/L)	Total suspended solids	Turbidity
Perkins Creek (S000-883)	9.8	42.0	86.0	3.3	15.3	11.2
Trapper Run Creek (S001-859)	9.8	7.0	42.0	0.1	10.6	8.4
Ecoregion Ranges	NA	NA	60-150	0.04-0.26	4.8-16	3-8.5

Table 10. Water quality maximums for inlets to Lake Minnewaska as compared to the Ecoregion Ranges.

	Dissolved oxygen (mg/L)	Ortho-phosphate (ug/L)	Total Phosphorus (ug/L)	Nitrate + Nitrite (mg/L)	Total suspended solids	Turbidity
Perkins Creek (S000-883)	15.16	5.17	78.0	301.0	128	120
Trapper Run Creek (S001-859)	13.84	0.2	20.0	80.0	56	37
Ecoregion Ranges	NA	NA	60-150	0.04-0.26	4.8-16	3-8.5

Lakeshed Data and Interpretations

Lakeshed

Understanding a lakeshed requires an understanding of basic hydrology. A watershed is defined as all land and water surface area that contribute excess water to a defined point. The MN DNR has delineated three basic scales of watersheds (from large to small): 1) basins, 2) major watersheds, and 3) minor watersheds.

The Chippewa River Major Watershed is one of the watersheds that make up the Minnesota River Basin, which drains south to the Mississippi River and eventually the Gulf of Mexico (Figure 14). Lake Minnewaska is located in minor watershed 26097 (Figure 15).

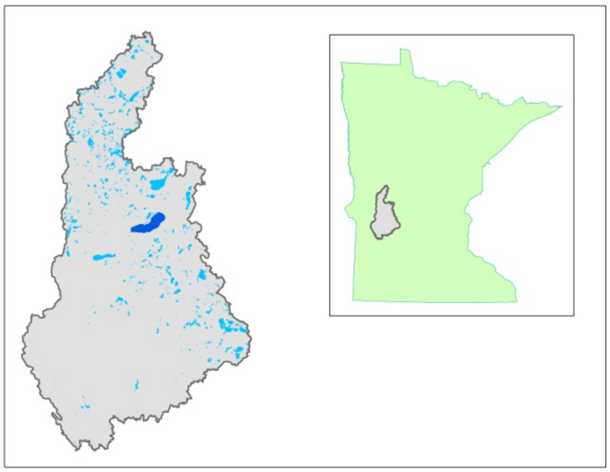


Figure 16. Major Watershed.

Figure 17. Minor Watershed.

The MN DNR also has evaluated catchments for each individual lake with greater than 100 acres surface area. These lakesheds (catchments) are the "building blocks" for the larger scale watersheds. Lake Minnewaska falls within lakeshed 2609700 (Figure 16). Though very useful for displaying the land and water that contribute directly to a lake, lakesheds are not always true watersheds because they may not show the water flowing into a lake from upstream streams or rivers. While some lakes

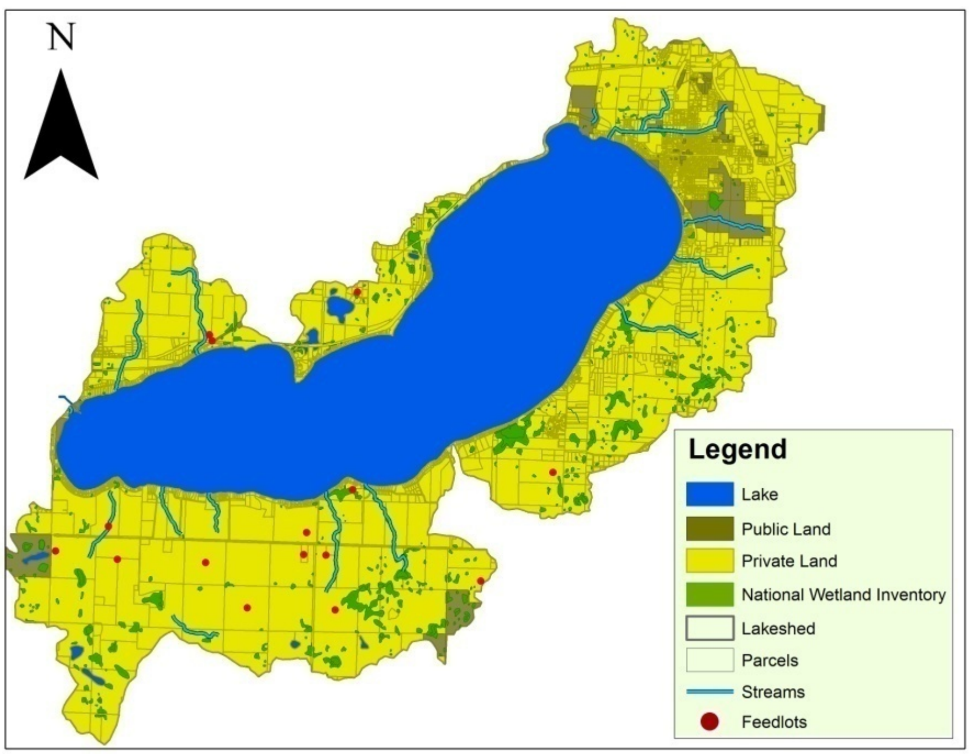


Figure 18. Lake Minnewaska lakeshed (2609700) with land ownership, lakes, wetlands, and rivers illustrated.

may have only one or two upstream lakesheds draining into them, others may be connected to a large number of lakesheds, reflecting a larger drainage area via stream or river networks. For further discussion of Lake Minnewaska 's watershed, containing all the lakesheds upstream of the Lake Minnewaska lakeshed, see page 17. The data interpretation of the Lake Minnewaska lakeshed includes only the immediate lakeshed as this area is the land surface that flows directly into Lake Minnewaska.

The lakeshed vitals table identifies where to focus organizational and management efforts for each lake (Table 11). Criteria were developed using limnological concepts to determine the effect to lake water quality.

KEY

● Possibly detrimental to the lake
◍ Warrants attention
○ Beneficial to the lake

Table 11. Lake Minnewaska lakeshed vitals table.

Lakeshed Vitals		**Rating**
Lake Area (acres)	8,050.3	descriptive
Littoral Zone Area (acres)	944.8	descriptive
Lake Max Depth (feet)	32	descriptive
Lake Mean Depth (feet)	15.0	○
Water Residence Time	NA	NA
Miles of Stream	13.4	descriptive
Inlets	9	◍
Outlets	1	○
Major Watershed	26 Chippewa River	descriptive
Minor Watershed	26097	descriptive
Lakeshed	2601001	descriptive
Ecoregion	North Central Hardwood Forest	descriptive
Total Lakeshed to Lake Area Ratio (total lakeshed includes lake area)	3:1	○
Standard Watershed to Lake Basin Ratio (standard watershed includes lake areas)	7:1	○
Wetland Coverage (NWI) (acres)	728.9	○
Aquatic Invasive Species	Eurasian Water Milfoil, Zebra Mussels	●
Public Drainage Ditches	0	○
Public Lake Accesses	3	◍
Miles of Shoreline	19.9	descriptive
Shoreline Development Index	1.6	○
Public Land to Private Land Ratio	1:19.7	◍
Development Classification	General Development	●
Miles of Road	89.1	descriptive
Municipalities in lakeshed	Starbuck, Long Beach and Glenwood	●
Forestry Practices	None	○
Feedlots	16	●
Sewage Management	Individual Waste Treatment Systems (septic systems and holding tanks)	◍
Lake Management Plan	None	◍
Lake Vegetation Survey/Plan	None	◍

Land Cover / Land Use

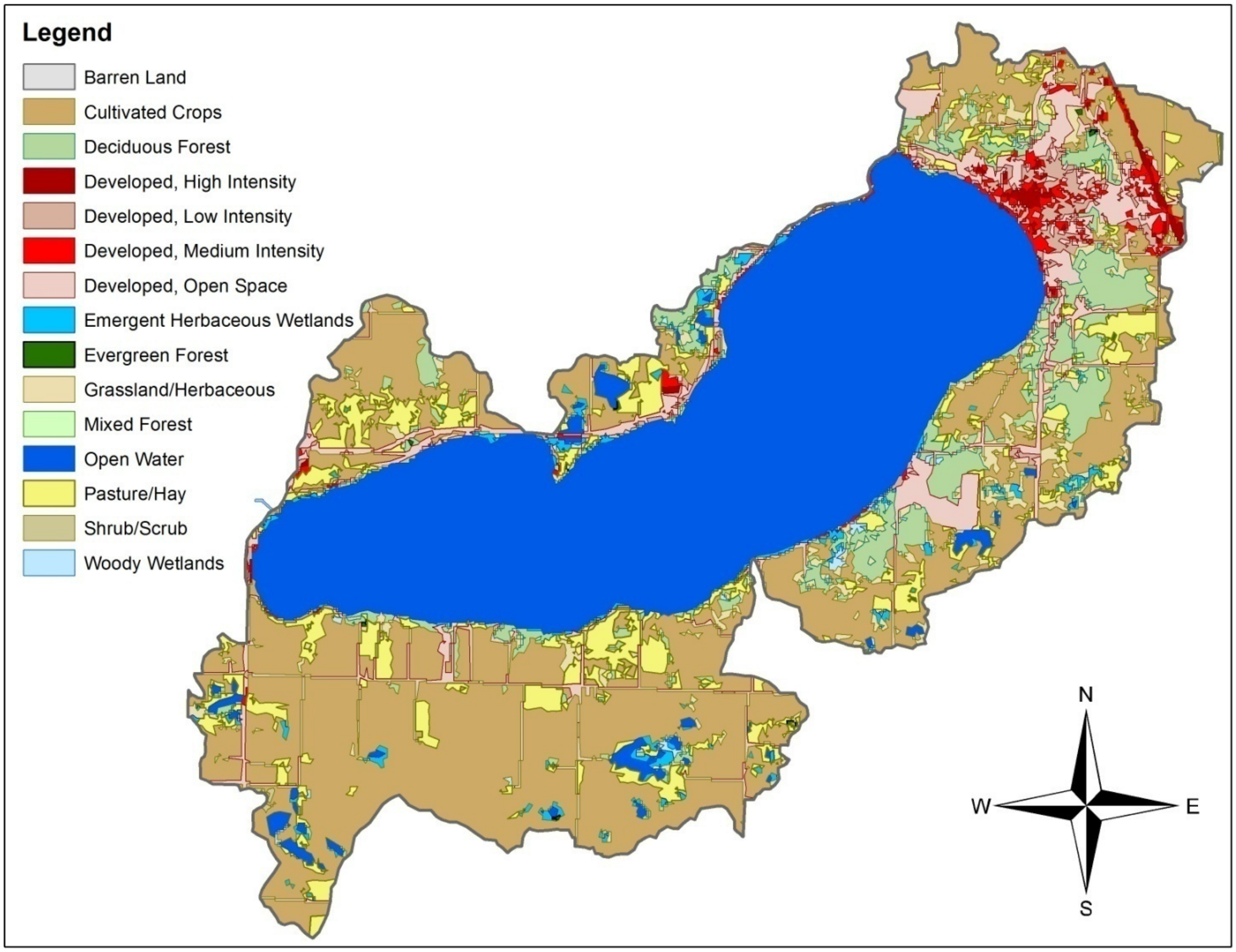


Figure 19. Lake Minnewaska lakeshed (2609700) land cover (NLCD 2011).

The activities that occur on the land within the lakeshed can greatly impact a lake. Land use planning helps ensure the use of land resources in an organized fashion so that the needs of the present and future generations can be best addressed. The basic purpose of land use planning is to ensure that each area of land will be used in a manner that provides maximum social benefits without degradation of the land resource.

Changes in land use, and ultimately land cover, impact the hydrology of a lakeshed. Land cover is also directly related to the land's ability to absorb and store water rather than cause it to flow overland (gathering nutrients and sediment as it moves) towards the lowest point, typically the lake. Impervious intensity describes the land's inability to absorb water, the higher the % impervious intensity the more area that water cannot penetrate in to the soils. Monitoring the changes in land use can assist in future planning procedures to address the needs of future generations.

Phosphorus export, which is the main cause of lake eutrophication, depends on the type of land cover occurring in the lakeshed. Figure 17 depicts the land cover in Lake Minnewaska's lakeshed.

Developed land cover (Table 12) mostly describes impervious surface. In impervious areas, such as roads and houses, the land is unable to absorb water and it runs off the landscape carrying with it any nutrients or sediment in its path. The higher the impervious intensity the more area that water cannot penetrate in to the soils. Impervious areas can contribute 0.45 – 1.5 pounds of phosphorus per year in runoff. Lake Minnewaska has 6.5% of its lakeshed classified as developed (Table 12). This doesn't sound like much area, but if it is mainly concentrated on the lakeshore, the runoff from impervious areas can run directly into the lake.

Table 12. Land cover in the Lake Minnewaskashed.

Runoff Potential	Category	Specific Landcover	Acres	Percent
High	Agriculture	**Cultivated Crops**	2,0222.5	57.7%
High	Urban	**Developed, High**	95.8	0.27%
High	Urban	**Developed, Low**	413.7	1.2%
High	Urban	**Developed, Medium**	273.2	0.78%
High	Urban	**Developed, Open**	1,484.0	4.2%
High	Barren	**Barren Land**	6.1	0.02%
Low	Forest	**Deciduous Forest**	1,359.8	3.9%
Low	Forest	**Mixed Forest**	2.0	0.01%
Low	Forest	**Evergreen Forest**	14.1	0.04%
Low	Water	**Water**	8321.2	23.8%
Low	Agriculture	**Grassland/Herbaceous**	752.1	2.2%
Low	Wetlands	**Herbaceous Wetlands**	287.4	0.82%
Low	Wetlands	**Woody Wetlands**	63.2	0.18%
Low	Agriculture	**Pasture/Hay**	1,713.7	4.9%
Low	Grass/Shrub	**Shrub/Scrub**	11.6	0.03%
Total area with low runoff potential			12,525.1	35.9%
Total area with high runoff potential			22,495.3	64.2%
Total			35,020.4	100.0%

Agricultural land use has the potential to contribute nutrients to a lake through runoff, but the amount of phosphorus runoff depends on the type of agricultural land use. Generally, the highest concentration of agricultural nutrient runoff comes from animal feedlots. There are 16 animal feedlots in the Lake Minnewaska lakeshed (Table 11). The second highest agricultural runoff generally comes from row crops. A little over half (57.7%) of the lake shed is covered with cultivated crops (Figure 17). Pasture land has less nutrient runoff, and most likely doesn't impact the lake as much as other agricultural uses. Therefore, the statistics in Table 10 are valuable for evaluating runoff in the lakeshed. Overall, 64% of the Lake Minnewaska lakeshed is classified in high nutrient runoff land uses (Table 12).

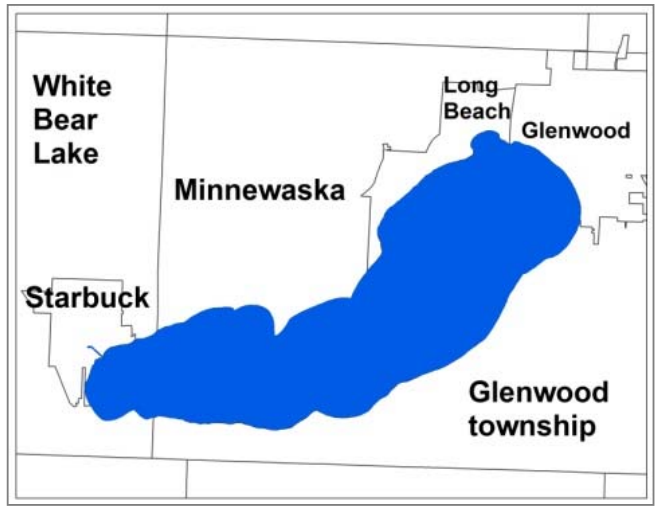
The University of Minnesota has online records of land cover statistics from years 1990 and 2000 (http://land.umn.edu). Although this data is 16 years old, it is the only data set that is comparable over a decade's time. In addition, a lot of lake development occurred from 1990 to 2000 when the US economy was booming. Table 13 describes Minnewaska's lakeshed land cover statistics related to development and percent change from 1990 to 2000. Due to the many factors that influence demographics, one cannot determine with certainty the projected statistics over the next 10, 20, 30+ years, but one can see the impervious area has increased, which has implications for storm water runoff into the lake. The increase in impervious area is consistent with the increase in urban acreage.

Table 13. Lake Minnewaska development area and % change from 1990-2000 (Data Source: UMN Landsat).

Category	1990 Acres	Percent	2000 Acres	Percent	Change 1990 to 2000
Total Impervious Area	400	2.69	737	4.97	+337 acres
Urban Acreage	1,053	4.57	1,952	8.47	+899 acres

Demographics

Lake Minnewaska is classified as a General Development lake. General Development lakes usually have more than 225 acres of water per mile of shoreline and 25 dwellings per mile of shoreline, and are more than 15 feet deep.



The Minnesota Department of Administration Geographic and Demographic Analysis Division extrapolated future population in 5-year increments out to 2035. Compared to Pope County as a whole, many of the townships around the lake have projected population growth over the next 20 years (Figure 20).
(source: http://www.demography.state.mn.us)

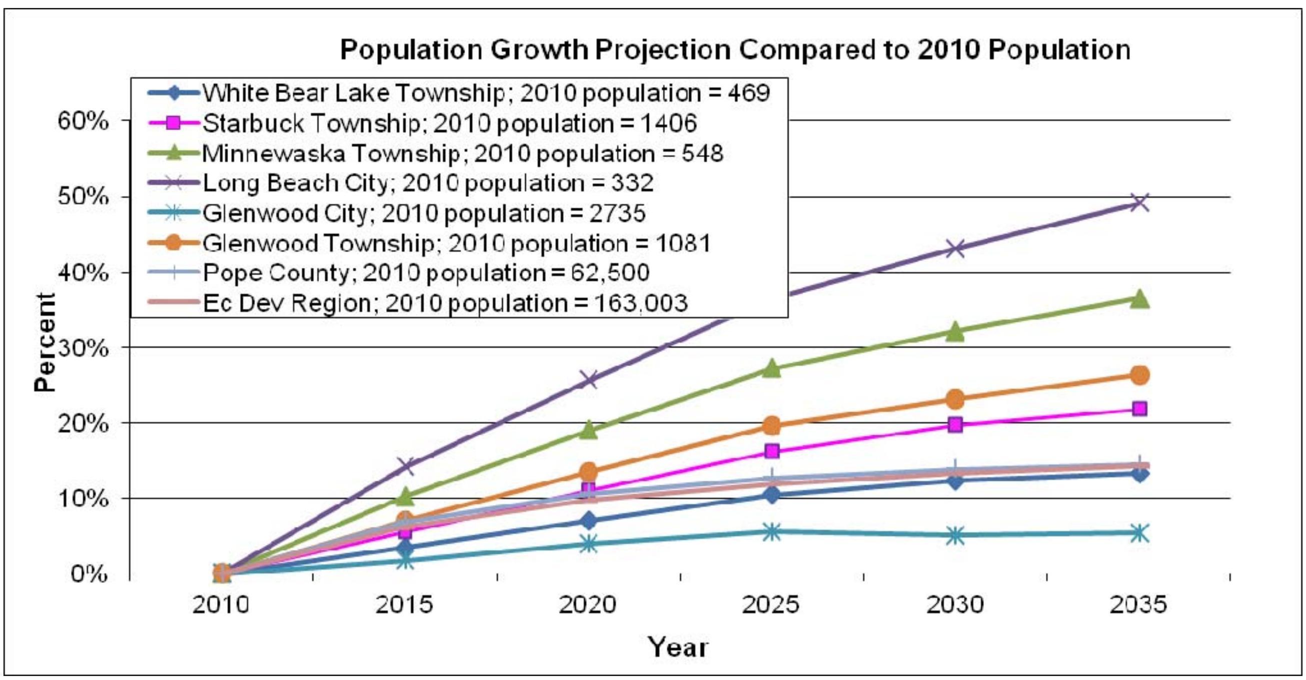


Figure 20. Population growth projection for adjacent townships and Pope County.

Lakeshed Water Quality Protection Strategy

Each lakeshed has a different makeup of public and private lands. Looking in more detail at the makeup of these lands can give insight on where to focus protection efforts. The protected lands (easements, wetlands, public land) are the future water quality infrastructure for the lake. Developed land and agriculture have the highest phosphorus runoff coefficients, so this land should be minimized for water quality protection.

The majority of the land within Lake Minnewaska's lakeshed is privately owned (Table 14). This land can be the focus of development and protection efforts in the lakeshed.

Table 14. Land ownership, land use/land cover, estimated phosphorus loading, and ideas for protection and restoration in the lakeshed (Sources: County parcel data and the 2011 National Land Cover Dataset).

	Private (60.5%)					**36.5%**	**Public (3.0%)**		
	Developed	**Agriculture**	**Forested Uplands**	**Other**	**Wetlands**	**Open Water**	**City**	**State**	**Federal**
Land Use (%)	9.23	33.27	5.23	10.39	2.36	36.48	1.57	0.41	1.02
Runoff Coefficient Lbs of phosphorus/acre/ year	0.45 – 1.5	0.26 – 0.9	0.09		0.09		0.09	0.09	0.09
Estimated Phosphorus Loading Acreage x runoff coefficient	930.8-3,102.8	1,937.38-6,708	105.5		47.6		31.6	8.2	20.5
Description	Focused on Shoreland	Cropland	Focus of development and protection efforts	Open, pasture, grassland, shrubland	Protected				
Protection and Restoration Ideas	Shoreline restoration	Restore wetlands; CRP	Forest stewardship planning, 3rd party certification, SFIA, local woodland cooperatives		Protected by Wetland Conservation Act			State Forest	National Forest

DNR Fisheries approach for lake protection and restoration

Credit: Peter Jacobson and Michael Duval, Minnesota DNR Fisheries

In an effort to prioritize protection and restoration efforts of fishery lakes, the MN DNR has developed a ranking system by separating lakes into two categories, those needing protection and those needing restoration. Modeling by the DNR Fisheries Research Unit suggests that total phosphorus concentrations increase significantly over natural concentrations in lakes that have watershed with disturbance greater than 25%. Therefore, lakes with watersheds that have less than 25% disturbance need protection and lakes with more than 25% disturbance need restoration (Table 15). Watershed disturbance was defined as having urban, agricultural and mining land uses. Watershed protection is defined as publicly owned land or conservation easement.

Table 15. Suggested approaches for watershed protection and restoration of DNR-managed fish lakes in Minnesota.

Watershed Disturbance (%)	Watershed Protected (%)	Management Type	Comments
< 25%	> 75%	Vigilance	Sufficiently protected -- Water quality supports healthy and diverse native fish communities. Keep public lands protected.
	< 75%	Protection	Excellent candidates for protection -- Water quality can be maintained in a range that supports healthy and diverse native fish communities. Disturbed lands should be limited to less than 25%.
25-60%	n/a	Full Restoration	Realistic chance for full restoration of water quality and improve quality of fish communities. Disturbed land percentage should be reduced and BMPs implemented.
> 60%	n/a	Partial Restoration	Restoration will be very expensive and probably will not achieve water quality conditions necessary to sustain healthy fish communities. Restoration opportunities must be critically evaluated to assure feasible positive outcomes.

The next step was to prioritize lakes within each of these management categories. DNR Fisheries identified high value fishery lakes, such as cisco refuge lakes. Ciscos (*Coregonus artedi)* can be an early indicator of eutrophication in a lake because they require cold hypolimnetic temperatures and high dissolved oxygen levels. These watersheds with low disturbance and high value fishery lakes are excellent candidates for priority protection measures, especially those that are related to forestry and minimizing the effects of landscape disturbance. Forest stewardship planning, harvest coordination to reduce hydrology impacts and forest conservation easements are some potential tools that can protect these high value resources for the long term.

Lake Minnewaska's lakeshed is classified with having 43% of the watershed protected and 52% of the watershed disturbed (Figure 21). Therefore, this lakeshed should have a full restoration focus. Goals for the lake should be to decrease the disturbed land use. There are other lakesheds that flow into Lake Minnewaska's lakeshed (Figure 22).

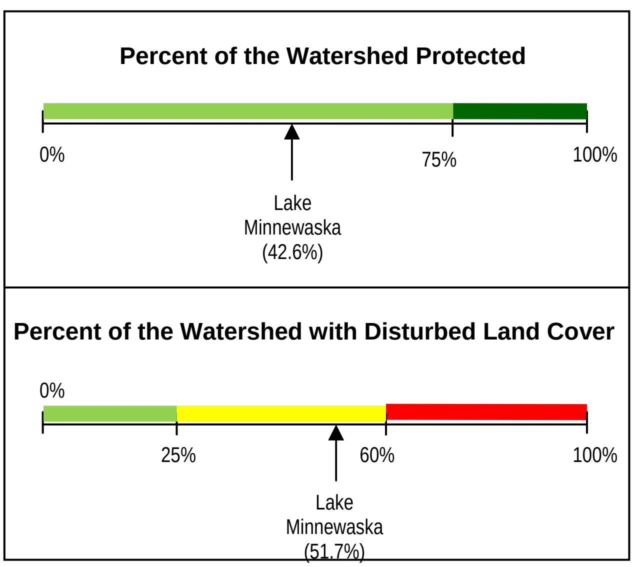


Figure 21. Lake Minnewaska's lakeshed percentage of watershed protected and disturbed.

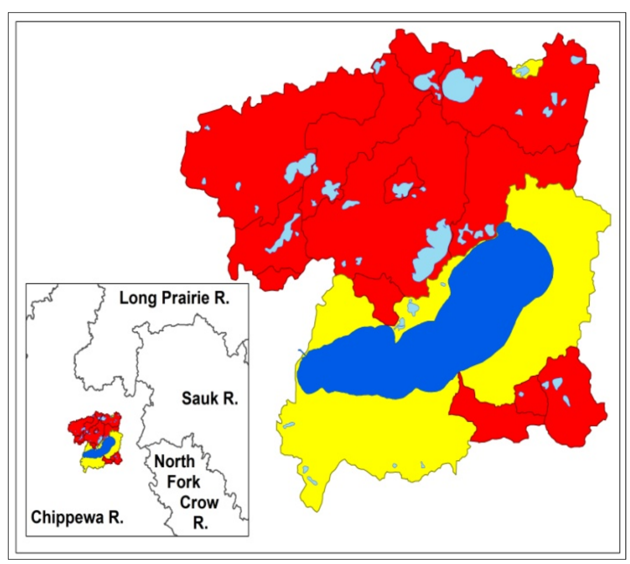


Figure 22. Lakesheds that contribute water to the Lake Minnewaska lakeshed. Color-coded based on management focus (Table 13).

Status of the Fishery (DNR, as of 06/21/2010)

Lake Minnewaska is a 7,110-acre lake located in central Pope County between Glenwood and Starbuck. For its size, Minnewaska is relatively shallow. Maximum depth is just 32.0 feet. It is the largest lake in the county and is a popular destination for anglers and recreational boaters. Swimming is also a popular activity during summer months. Municipal swimming beaches are located in Glenwood and Starbuck. Three public accesses are available. Two occur on the northeast side of the lake near Glenwood. The third access is located within the Starbuck Marina. Residential development occurs around the entire shoreline.

Lake Minnewaska supports a diverse fish community and offers a wide range of fishing opportunities. The lake is managed for walleye. Largemouth bass and other sunfishes are also important to the fishery. Although walleye abundance has decreased in recent years, gillnet catches remained above expected rates. Catches averaged 6.9-walleye/gill net in 2010. Mean size of captured walleye was 16.5 inches and 1.8 pounds. Walleye growth rates are relatively fast with fish usually exceeding 16.0 inches in length after their fourth growing season. Typical of most large walleye fisheries, natural reproduction accounts for much of the population abundance. However, walleye fry and fingerlings are routinely stocked to supplement and increase walleye numbers. The DNR stocks fry on an annual basis. Fingerling stockings are prescribed following documentation of two consecutive poor year classes. Walleye fingerlings are also stocked by the Lake Minnewaska Association.

Other gamefishes targeted by anglers include largemouth and smallmouth bass, bluegill, black crappie, northern pike, and yellow perch. Largemouth and smallmouth bass populations have expanded in recent years. Anglers can expect good catch rates of medium- to large-sized fish. Lake Minnewaska has become a popular choice for organized bass tournaments. Bluegill are also abundant and size structure of this population should prove attractive to panfish anglers. Mean size of 2010 captures was 6.2 inches and 0.2 pounds. Record-high black crappie abundance was documented in 2010 due to an extremely strong 2007 year class. Crappie fishing, in terms of both numbers and size, should greatly improve in the near future as this dominant year class recruits to a harvestable size. Northern pike abundance continues to increase. In fact, pike numbers have not been this high since the mid 1990s. Gillnet catch rate exceeded levels expected for this type of lake. Mean length of the 2010 capture sample was only 19.7 inches but large pike were recorded in the pike catch. Numerous pike exceeding 30.0 inches in length were captured. The largest pike measured was nearly 36.0 inches. Yellow perch catches averaged 31.5-fish/gill net. Harvestable-size perch are present, but the greatest proportion of the population is comprised of smaller fish.

Other fish sampled in the 2010 survey included bigmouth buffalo, black, brown, and yellow bullhead, bowfin (dogfish), common carp, freshwater drum (sheepshead), hybrid sunfish, pumpkinseed sunfish, tullibee (cisco), and white sucker.

Fishing pressure on Lake Minnewaska can be heavy at times, during both open water and winter seasons. To help maintain fishing quality, anglers are encouraged to practice selective harvest. The selective harvest concept promotes release of larger fish and harvest of more abundant smaller fish for eating. Releasing medium to large fish will ensure the lake will sustain enough spawning age fish and provide anglers with opportunities to catch more large fish in the future. See the link below for specific information on gillnet surveys, stocking information, and fish consumption guidelines. http://www.dnr.state.mn.us/lakefind/showreport.html?downum=61013000

Key Findings / Recommendations

Monitoring Recommendations
Transparency monitoring at sites 201 and 205 should be continued annually. It is important to continue transparency monitoring weekly or at least bimonthly every year to enable year-to-year comparisons and trend analyses. Especially with the introduction of Zebra mussels in 2012, it is important to track transparency to see how Zebra mussels are affecting it.

Total Phosphorus and chlorophyll *a* monitoring should continue, as the budget allows, to track trends in water quality. Chlorophyll a concentrations are showing a decrease that could be attributed to Zebra mussels.

The inlets to Lake Minnewaska appear to be minor, but past monitoring shows that Perkins Creek could be contributing nutrients and sediment to the lake during storm events (Table 10). Further monitoring of Perkins Creek would help better understand it's loading to the lake and show the efficacy of any mitigation projects.

Overall Summary
Lake Minnewaska is a mildly eutrophic lake (TSI = 50) and the total phosphorus, chlorophyll *a* and transparency ranges are within the ecoregion ranges for expected water quality conditions. Trend analysis shows that there was a declining trend in transparency in the lake from 1996 - 2013, and since then the transparency has improved. This could be due to the establishment of zebra mussels in the lake in 2012. Zebra mussels filter large quantities of water and eat the small algal particles. Algae concentrations (chlorophyll a) are lower in 2015-2016 as well, which could be due to zebra mussel feeding (Figure 12).

Forty-two percent (42%) of Lake Minnewaska lakeshed is disturbed by development and agriculture (Figure 19). The threshold of disturbance where water quality tends to decline is 25%. Lake Minnewaska is over this threshold. Even if zebra mussels are decreasing the algae concentration and improving the lake's transparency, it is important to still consider the lake's phosphorus concentration.

Lake Minnewaska has the advantage of a fairly small watershed (watershed to lake area ratio of 7:1). The lake does not have any major river inlets, which means that the main potential impacts to the lake are likely from land practices directly around the shoreline and within the lakeshed (the land area draining directly towards the lake, Figure 19).

Priority Impacts
Lake Minnewaska is heavily developed (Figure 16). There are three cities on Lake Minnewaska's shores (Glenwood, Long Beach and Starbuck), which can potentially impact the lake by stormwater runoff. Impervious surface and urban development areas increased 337 and 899 acres respectively within the lakeshed between 1990 and 2000 (Table 13). Looking at population growth projections, the population of the cities and townships around the lake are projected to grow in the next 20 years. The conversion of small lake cabins to year-round family homes increases the impervious surface and runoff from the lake lots as well. Additional development within the lakeshed will likely be the main impact affecting the water quality of Lake Minnewaska.

In addition, because Lake Minnewaska is a fairly shallow lake (max depth = 32 feet), it could be subject to internal loading. Internal loading is when the phosphorus that is in the lake sediment re-suspends into the water column, feeding algae and plants. Phosphorus re-suspends when large boat motors churn up the sediment, and when the lake has a few calm days which allows it to loosely stratify, and then windy days, which mixes the water back up.

Best Management Practices Recommendations
The management focus for Lake Minnewaska should be to protect the current water quality and restore the lakeshed. ***Efforts should be focused on managing and/or decreasing the impact of the impervious surface in the lakeshed.*** Although it may not be possible to decrease the impervious area in the lakeshed, it is possible to reduce the impact of the impervious surface by retaining stormwater instead of allowing it to runoff into the lake. Project ideas include shoreline restorations on lakeshore property, rain gardens in the city and around the lake, and enforcement of county shoreline ordinances that limit impervious surface.

Native aquatic plants stabilize the lake's sediments and tie up phosphorus in their tissues. When aquatic plants are uprooted from a shallow lake, the lake bottom is disturbed, and the phosphorus in the water column gets used by algae instead of plants. This contributes to "greener" water and more algae blooms. Protecting native aquatic plant beds will ensure a healthy lake and healthy fishery. If a swimming area is necessary in front of people's docks, clear only a small area of plants. Clearing a whole 100 foot frontage is not necessary and can contribute to additional algae blooms.

Project Implementation
The best management practices above can be implemented by a variety of entities. Some possibilities are listed below.

Individual property owners
- Shoreline restoration
- Rain gardens
- Aquatic plant bed protection (only remove a small area for swimming)
- Conservation easements

Lake Associations
- Lake condition monitoring
- Ground truthing – visual inspection upstream on stream inlets
- Watershed runoff mapping by a consultant
- Shoreline inventory study by a consultant
- Conservation easements

Soil and Water Conservation District (SWCD) and Natural Resources Conservation Service (NRCS)
- Shoreline restoration
- Stream buffers
- Wetland restoration
- Forest stewardship planning
- Work with farmers to
    - Restore wetlands
    - Implement conservation farming practices
    - Land retirement programs such as Conservation Reserve Program

Organizational contacts and reference sites

Lake Association	Minnewaska Lake Association http://mlalake.org/main/
Pope County Environmental Services Department	130 East Minnesota Avenue, Glenwood, MN 56334 (320) 634-7791 https://www.co.pope.mn.us
Pope Soil and Water Conservation District	1680 Franklin Street North, Glenwood, MN 56334 (320) 634-5327 http://popeswcd.org
DNR Fisheries Office	10 First Ave SW Glenwood, MN 56334 (320) 634-7322 http://www.dnr.state.mn.us/areas/fisheries/glenwood/index.html
Regional Minnesota Pollution Control Agency Office	714 Lake Ave., Suite 220, Detroit Lakes, MN 56501 (218) 847-1519 http://www.pca.state.mn.us
Regional Board of Soil and Water Resources Office	520 Lafayette Road North, St Paul, MN 55155 (651) 297-2906 http://www.bwsr.state.mn.us