

EXHIBIT E



U.S. Environmental Protection Agency

Aquatic Biodiversity

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Carlson's Trophic State Index

The cloudiness of lake water and how far down you can see is often related to the amount of nutrients in the water. Nutrients promote growth of microscopic plant cells (phytoplankton) that are feed upon by microscopic animals (zooplankton). The more the nutrients, the more the plants and animals and the cloudier the water is. This is a common, but indirect, way to roughly estimate the condition of the lake. This condition, called eutrophication, is a natural aging process of lakes, but which is unnaturally accelerated by too many nutrients.

A Secchi disk is commonly used to measure the depth to which you can easily see through the water, also called its transparency. Secchi disk transparency, chlorophyll a (an indirect measure of phytoplankton), and total phosphorus (an important nutrient and potential pollutant) are often used to define the degree of eutrophication, or trophic status of a lake.

The concept of trophic status is based on the fact that changes in nutrient levels (measured by total phosphorus) causes changes in algal biomass (measured by chlorophyll a) which in turn causes changes in lake clarity (measured by Secchi disk transparency). A trophic state index is a convenient way to quantify this relationship. One popular index was developed by [Dr. Robert Carlson](#) of Kent State University.

Trophic State Index

[Carlson's index](#) uses a log transformation of Secchi disk values as a measure of algal biomass on a scale from 0 - 110. Each increase of ten units on the scale represents a doubling of algal biomass. Because chlorophyll a and total phosphorus are usually closely correlated to Secchi disk measurements, these parameters can also be assigned trophic state index values. The Carlson trophic state index is useful for comparing lakes within a region and for assessing changes in trophic status over time. Thus it is often valuable to include an analysis of trophic state index values in summary reports of a [volunteer monitoring program](#). The program manager must be aware, however, that the Carlson trophic state index was developed for use with lakes that have few rooted aquatic plants and little non-algal turbidity. Use of the index with lakes that do not have these characteristics is not appropriate.

$$\begin{aligned} \text{TSI} &= 60 - 14.41 \ln \text{Secchi disk (meters)} \\ \text{TSI} &= 9.81 \ln \text{Chlorophyll a (ug/L)} + 30.6 \\ \text{TSI} &= 14.42 \ln \text{Total phosphorus (ug/L)} + 4.15 \end{aligned}$$

where:

$$\begin{aligned} \text{TSI} &= \text{Carlson trophic state index} \\ \ln &= \text{natural logarithm} \end{aligned}$$

The formulas for calculating the [Carlson Trophic State Index](#) values for Secchi disk, chlorophyll a, and total phosphorus are presented below. Also presented is a table that lists the trophic state values and the corresponding measurements of the three parameters. Ranges of trophic state index values are often grouped into trophic state classifications. The range between 40 and 50 is usually associated with mesotrophy (moderate productivity). Index values greater than 50 are associated with eutrophy (high productivity). Values less than 40 are associated with oligotrophy (low productivity).

Presented below are Carlson trophic state index values for "Volunteer" Lake. Summer averages (June 15 - September 1) are used in the calculations. As seen from the TSI values, Volunteer Lake can be classified somewhere near the border of mesotrophy and eutrophy.

Secchi Disk Calculations

Average Summer Secchi disk = 5.9 feet = 1.8 meters

$TSI = 60 - 14.41$ (In Secchi disk (meters))

$TSI = 60 - (14.41) (0.59)$

$TSI = 51.5$

Total Phosphorus

Average Summer Surface Total Phosphorus = 19.6 ug/L

$TSI = 14.42$ (In Total phosphorus (ug/L)) + 4.15

$TSI = (14.42) (2.98) + 4.15$

$TSI = 47.1$

Chlorophyll *a*

Average Summer Chlorophyll *a* = 17.2 g/L

$TSI = (9.81)$ (In Chlorophyll *a* (ug/L)) + 30.6

$TSI = (9.81) (2.84) + 30.6$

$TSI = 58.5$

More Resources: [EXIT disclaimer](#)

- [The Great North American Secchi Dip In](#) by Dr. Carlson with detailed explanation of the TSI (a must see!)
- Please also see the [Lake Assessment Process and Methods](#) for Minnesota Lakes and their "indicator for the month" - [water transparency](#).

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