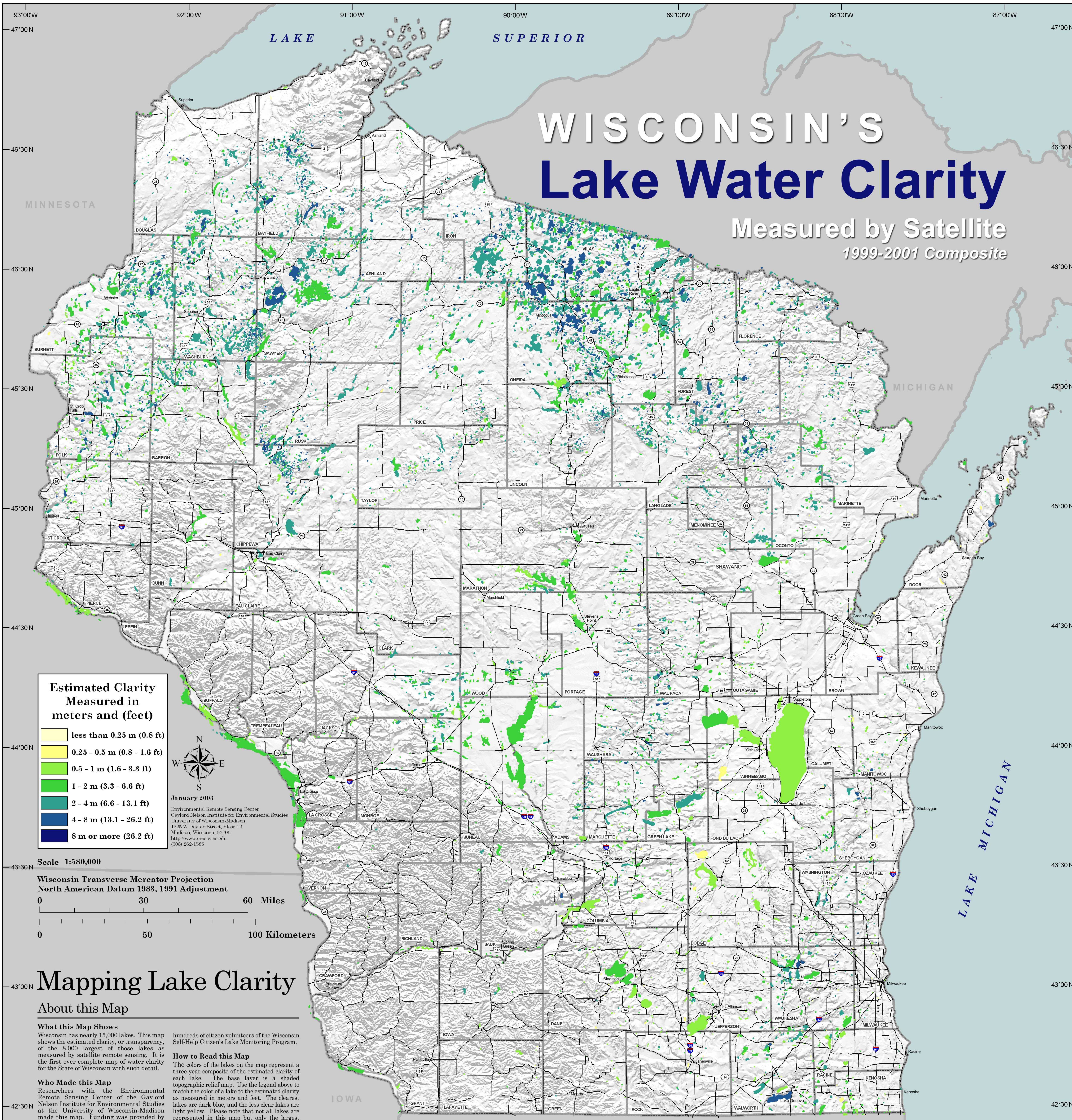

WISCONSIN'S

Lake Water Clarity

Measured by Satellite

1999-2001 Composite

Estimated Clarity Measured in meters and (feet)

- less than 0.25 m (0.8 ft)
- 0.25 - 0.5 m (0.8 - 1.6 ft)
- 0.5 - 1 m (1.6 - 3.3 ft)
- 1 - 2 m (3.3 - 6.6 ft)
- 2 - 4 m (6.6 - 13.1 ft)
- 4 - 8 m (13.1 - 26.2 ft)
- 8 m or more (26.2 ft)

N W E S

January 2003

Environmental Remote Sensing Center
Gaylord Nelson Institute for Environmental Studies
University of Wisconsin-Madison
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Madison, Wisconsin 53706
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(608) 262-1585

Scale 1:580,000

Wisconsin Transverse Mercator Projection
North American Datum 1983, 1991 Adjustment

0 30 60 Miles

0 50 100 Kilometers

Mapping Lake Clarity

About this Map

What this Map Shows

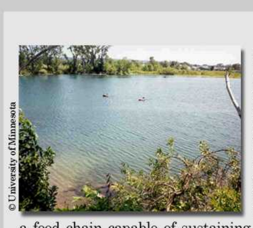
Wisconsin has nearly 15,000 lakes. This map shows the estimated clarity, or transparency, of the 8,000 largest of those lakes as measured by satellite remote sensing. It is the first ever complete map of water clarity for the State of Wisconsin with such detail.

Who Made this Map

Researchers with the Environmental Remote Sensing Center of the Gaylord Nelson Institute for Environmental Studies at the University of Wisconsin-Madison made this map. Funding was provided by the NASA Affiliated Research Center (ARC) and Regional Earth Science Applications Center (RESAC) programs, and by the North Temperate Lakes Long-Term Ecological Research program (LTER), coordinated by the UW-Madison Center for Limnology. Field data and other assistance were provided by the Wisconsin Department of Natural Resources (WDNR) and the hundreds of citizen volunteers of the Wisconsin Self-Help Citizen's Lake Monitoring Program.

How to Read this Map

The colors of the lakes on the map represent a three-year composite of the estimated clarity of each lake. The base layer is a shaded topographic relief map. Use the legend above to match the color of a lake to the estimated clarity as measured in meters and feet. The clearest lakes are dark blue, and the less clear lakes are light yellow. Please note that not all lakes are represented in this map but only the largest 8,000. Also note that "clarity" refers to the clarity of each lake as it appeared to the satellite on one late summer day in 1999, 2000, or 2001. Here's why. To generate this full statewide map, researchers needed cloud-free imagery for the whole state. This could only be accomplished by building a mosaic of the clear parts of many images. It took three summers to collect enough clear imagery to complete the "puzzle."


© University of Minnesota

This Lake is Oligotrophic
Lakes like this are generally clear, deep and free of weeds or large algae blooms. Although they are beautiful, they are low in nutrients and do not support large fish populations. However, oligotrophic lakes often develop a food chain capable of sustaining a very desirable fishery of large game fish. They are also desirable for other recreational activities such as swimming and boating.


© University of Minnesota

This Lake is Eutrophic
Lakes like this are high in nutrients and support a large biomass (all the plants and animals living in a lake). They are usually either weedy or subject to frequent algae blooms, or both. Eutrophic lakes often support large fish populations, but are also susceptible to oxygen depletion. Small, shallow, eutrophic lakes are especially vulnerable to winterkill which can reduce the number and variety of fish. Rough fish are commonly found in eutrophic lakes.

What Clarity Means

What "Clarity" Means

The clarity of lake water, or its transparency, is often related to the amount of nutrients in the water. Nutrients promote growth of plankton and algae. The more nutrients, the more plankton and algae, and the cloudier the water is.

Why Clarity Matters

In most cases, the clearer a lake is, the healthier it is. Human activities impact the quality of lakes and wetlands in many ways. Eutrophication is the most pervasive problem affecting lakes. While eutrophication itself is a slow, natural process, it is greatly accelerated when excessive nitrogen, phosphorus, and other nutrients runoff from agricultural landscapes, fertilized urban lawns, golf courses, or streets, when septic systems are defective, or when urban storm drains enter lakes. As lakes become eutrophic, their recreational and ecological quality declines.

When Clarity is Not a Good Indicator

Some lakes (particularly in the northern part of the state) have naturally occurring high levels of colored dissolved organic matter, tannic acid, and humic acid that can stain the water a dark brown color. These lakes may be in perfect "health" but also have a low level of clarity. The satellite assessment of water clarity shown in this map provides a reliable estimate of water clarity, but determining whether or not any given lake is suffering from degraded water quality requires additional information.

How this Map was Made

How Clarity is Measured

People traditionally measure lake water clarity with a "Secchi" disk, named after its inventor, Father Angelo Secchi, a 19th century Italian Jesuit priest and Papal scientist. A Secchi disk is a 20-centimeter (8-inch) diameter metal disk, usually painted black and white, that a researcher or lake monitoring volunteer lowers over the side of a boat with a rope at the deepest part of a lake. By using the rope as a measuring tape, the person notes the depth at which the disk is no longer visible. The clearer the lake, the deeper the Secchi measurement will be.

The Wisconsin Department of Natural Resources coordinates annual summer Secchi measurements through a network of volunteers called the Self-Help Citizen's Lake Monitoring Program. This information is extremely valuable for monitoring lake water clarity. However, Secchi measurements are only collected for approximately 800, or 10%, of the large lakes. Using new satellite remote sensing technology, the clarity of the remaining 90% of the large lakes can be accurately estimated.

How Satellite Imagery is Used

For this map, researchers at the University of Wisconsin's Environmental Remote Sensing Center derived the clarity estimates from a mosaic of satellite images collected by the Landsat-5 and -7 satellites over three summers (1999-2001). Three summers were necessary due to the limitations imposed by the satellite's orbit and cloud cover.

The Landsat satellites orbit the Earth at an altitude of 705 kilometers (438 miles) above the surface, passing over the same point once every 16 days. However, Wisconsin's humid summer climate limits the number of cloud-free images available. To ensure consistency from year to year, researchers only use images collected between mid-July and mid-September. This is the period when Wisconsin's lakes are used most intensively, and when water quality problems (such as algal blooms) are most likely to occur. The map is simply a composite "snapshot" in time, since the clarity of any given lake can change substantially over time.

To "calibrate" or "ground-truth" the satellite images, volunteers in the Self-Help Citizen's Lake Monitoring Program made water clarity (Secchi disk) measurements on hundreds of lakes, timed to coincide with the satellites' orbits over Wisconsin. The resulting database represented by this map is the most complete and up-to-date record of the clarity of Wisconsin's lakes available.

Why Some Lakes are not Mapped

Lakes under 2 hectares (5 acres) in area are not included in this database, because such small lakes do not generally completely cover many Landsat image pixels. Even lakes greater than 2 hectares may be omitted if their shape is narrow or highly irregular, such that no 30-meter Landsat pixel falls entirely within the lake's boundary. Finally, the water clarity estimates for very shallow lakes are unreliable, because the spectral radiance measured by Landsat may be coming from the lake bottom, rather than from the water itself. Thus, lakes that are known to be "optically shallow" (having a maximum depth that is less than twice the normal Secchi disk measurement), or whose depth is unknown and presumed shallow, are noted in the database.

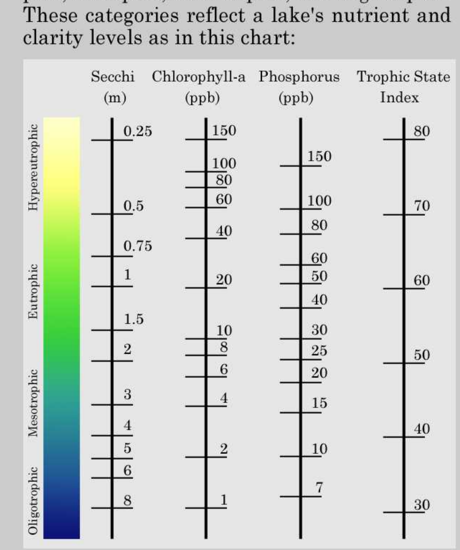
More About the Science

Clarity and Trophic State

Clarity is a common, but indirect, way to roughly estimate the "trophic" or nutritional condition of the lake. Researchers use various methods to calculate the trophic state of lakes. Common characteristics used in combination to make the determination are:

- **Secchi disk readings:** an indicator of water clarity
- **Chlorophyll-a concentration:** the amount of algae present
- **Total phosphorus concentration:** important for algae growth

Lakes can be divided into four general categories based on trophic state: hypereutrophic, eutrophic, mesotrophic, and oligotrophic. These categories reflect a lake's nutrient and clarity levels as in this chart:



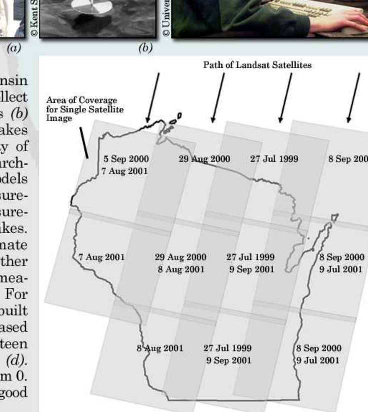
More about Satellite Remote Sensing

The instruments on Landsat-5 and -7, known as the "Thematic Mapper" (TM) and "Enhanced Thematic Mapper Plus" (ETM+), respectively, measure spectral radiance, or reflected sunlight coming from the Earth's surface, in several wavelength bands or channels. For Wisconsin's lakes, the clarity of water is indicated by the combination of spectral radiance in two Landsat bands, numbers 1 and 3 (sensitive to blue and red wavelengths of light, respectively). In these bands, the sensors are able to record features on the landscape as small as 30 by 30 meters (98 by 98 feet) in size. While very small objects such as cars and people cannot be seen by Landsat, larger features such as lakes can be readily observed. Each satellite image is a grid of millions of these 30-meter pixels. It takes 160 million such pixels to produce a mosaicked statewide image.

Researchers developed statistical models to describe the relationship between the field observations of secchi disk transparency and the digital satellite measurements of spectral radiance, for a set of 371 "training" lakes. Researchers then applied these regression models to the image data for all other lakes in the satellite's field of view, yielding estimates of water clarity for the thousands of lakes that were not sampled by volunteers. Finally, the scientists used an additional 226 volunteer-sampled lakes to check the accuracy of the satellite estimates. For this map, researchers generated a single water clarity estimate for each lake based on the average reading at the lakes' deepest basin. However, it is also possible to use the models to calculate the clarity of every 30-meter pixel, providing information on the internal variability in water clarity within each lake.


© University of Wisconsin - Madison (a) © Kent State University (b) © University of Wisconsin - Madison (c)

Putting it all Together
Volunteers and Wisconsin DNR researchers *(a)* collect the Secchi measurements *(b)* from several hundred lakes each summer. University of Wisconsin-Madison researchers build regression models that compare Secchi measurements with satellite measurements *(c)* of the same lakes. Regression models estimate the clarity for all of the other lakes large enough to be measured by the satellites. For this map, researchers built eight different models based on the dates of the seventeen satellite images needed *(d)*. The r^2 typically ranged from 0.7 to 0.9, indicating very good estimates.



(d)

Credits

This map is a product of the Environmental Remote Sensing Center of the Gaylord Nelson Institute for Environmental Studies at the University of Wisconsin-Madison 53706 created with ERDAS® Imagine®, ESRI® ArcGIS®, and Adobe® Photoshop® by Drs. Samuel A. Batzli and Jonathan W. Chipman with editorial input from Drs. Thomas M. Lillesand and Timothy P. Olsen and data assistance from Mark J. Nordheim and Jill E. Leale. Interactive web version by Dr. Peter R. Weiler available at http://www.ersc.wisc.edu

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