Water Quality and Hydrology of Silver Lake, Oceana County, Michigan, with Emphasis on Lake Response to Nutrient Loading, 2012–14

By Angela K. Brennan,[1] Christopher J. Hoard,[1] Joseph W. Duris,[1] Mary E. Ogdahl,[2] and Alan D. Steinman[2]

Executive Summary

Silver Lake is a 672-acre inland lake located in Oceana County, Michigan, and is a major tourist destination due to its proximity to Lake Michigan and the surrounding outdoor recreational opportunities. In recent years, Silver Lake exhibited patterns of high phosphorus concentrations, elevated chlorophyll *a* concentrations, and nuisance algal blooms. The U.S. Geological Survey (USGS), in cooperation with the Silver Lake Improvement Board and in collaboration with the Annis Water Resources Institute (AWRI) of Grand Valley State University, designed a study to assess the hydrologic and nutrient inputs to Silver Lake in order to identify the events and conditions that affect the nutrient chemistry and production of algal blooms in the lake. This information can inform water-resource managers in developing various management strategies to prevent or reduce the occurrence of future algal blooms.

USGS and AWRI scientists collected data from November 2012 to December 2014 to provide information for future management decisions for Silver Lake. Silver Lake can be classified as a polymictic lake and has a residence time of approximately 223 days. Based on the mean lake Secchi depth, total phosphorus, and total nitrogen concentrations, Silver Lake is classified as a eutrophic lake. In-situ bioassay results indicate that algal growth in Silver Lake is colimited by both nitrogen and phosphorus. The nutrient budget for Silver Lake was calculated using the BATHTUB model based on 2 years of water-quality data collection. The BATHTUB model, developed by the U.S. Army Corps of Engineers, treats the lake as a well-mixed system with multiple inputs and outlets for both water and dissolved constituents, such as nutrients.

Based on results of the BATHTUB model, which were conditioned on observed concentrations and flows, the mean annual input of phosphorus to Silver Lake was approximately 1,342 pounds (lb); the mean annual input of nitrogen to Silver Lake was approximately 51,998 lb. The major measured sources of phosphorus loading to Silver Lake were groundwater and Hunter Creek, whereas the major measured sources of nitrogen to Silver Lake were Hunter Creek, groundwater, and atmospheric deposition. The largest loading of phosphorus and nitrogen to Silver Lake occurred during the spring. Minimal phosphorus deposition (if any) occurred in the lakebed sediment; however, of the nitrogen that entered Silver Lake, approximately 42.2 percent was deposited in the lakebed sediment as simulated by the BATHTUB model.

In addition to measured sources, a septic load model was used to estimate the likely range of septic contribution to groundwater and adjacent surface waters. The likely septic loading scenario estimates that septic systems contribute 47.8 percent of the phosphorus to groundwater and 22.3 percent of phosphorus to Hunter Creek. These results indicate that septic systems are a major source of phosphorus loading to Silver Lake. The likely septic loading scenario indicated that septic systems account for 0.95 percent of the nitrogen load to Hunter Creek and 1.1 percent of the contribution of nitrogen to groundwater.

The BATHTUB model was used to estimate future nutrient loading and eutrophication scenarios based on water-quality data collected from Silver Lake, groundwater, major tributaries, and atmospheric deposition. A separate septic load model was used to estimate the septic contribution to groundwater or directly to surface water, and the nutrient load estimates were modeled using the BATHTUB model to determine subsequent water-quality changes to Silver Lake.

- BATHTUB model scenarios based on measured data:
  - The first BATHTUB scenario evaluated the condition of Silver Lake and the change to lake water quality (trophic status) as a result of changes in nutrient loading from different sources. Based on BATHTUB model simulations, if groundwater loading of phosphorus and nitrogen only were decreased by 75 percent, and all of the other nutrient inputs stayed the same, the future condition of Silver Lake would most likely remain highly mesotrophic to

[1]U.S. Geological Survey, Michigan Water Science Center, Lansing, Michigan

[2]Annis Water Resources Institute, Grand Valley State University, Muskegon, Michigan

eutrophic (the current [2014] condition of Silver Lake). If nutrient loading continued to increase in groundwater, the lake would continue to remain eutrophic with more frequent algal blooms. If nutrient loading from Hunter Creek only decreased by 50–75 percent, and all of the other nutrient inputs stayed the same as the baseline dataset, Silver Lake would remain eutrophic to highly mesotrophic. By reducing the input of manageable nutrient sources (Hunter Creek, groundwater, and lawn runoff) by 75 percent, the BATHTUB model simulation indicates that Silver Lake would be classified as mesotrophic, which is indicative of improved water quality, water clarity, and reduced algal bloom frequency.

- Simulations also were run using the BATHTUB model to evaluate the number of days Silver Lake could experience algal blooms (algal blooms are defined as modeled chlorophyll *a* in excess of 10 micrograms per liter [µg/L]) as a result of an increase/decrease in phosphorus and nitrogen loading from groundwater, Hunter Creek, and (or) a combination of sources. If the phosphorus and nitrogen loading from Hunter Creek is decreased (and all other sources are not altered), Silver Lake will continue to experience algal blooms, but less frequently than what is currently experienced. The same scenario holds true if the nutrient loading from groundwater is decreased. Another scenario was simulated using a combination of sources, which includes increases and decreases in phosphorus and nitrogen loading from sources that are the most likely to be managed, and includes groundwater (as a result of conversion of household septic to sewers), Hunter Creek (conversion of household septic to sewers), and lawn runoff. Results of the BATHTUB model indicated that a 50-percent reduction of phosphorus and nitrogen from these sources would result in a considerable decrease in algal bloom frequency (from 231 to 132 days) and severity, and a 75-percent reduction would greatly reduce algal bloom occurrence on Silver Lake (from 231 to 57 days).

- BATHTUB model scenarios based on septic load model:
  - A scenario also was conducted using the BATHTUB model to simulate the conversion of septic to sewer and included a low, high, and medium (likely) scenario of nutrient loading to Silver Lake. Simulations of the BATHTUB model indicated that, under the likely scenario, the conversion of all onsite septic treatment to sewers would result in an overall change in lake trophic status from eutrophic to mesotrophic, thereby reducing the frequency of algal blooms and algal bloom intensity on Silver Lake (chlorophyll *a* >10 µg/L, from 231 to 184 days per year, or chlorophyll *a* >20 µg/L, from 80 to 49 days per year).

Introduction

"A lake is the landscape's most beautiful and expressive feature. It is earth's eye; looking into which the beholder measures the depth of his own nature." ~Henry David Thoreau

Silver Lake is a 672-acre inland lake located along the eastern shore of Lake Michigan in Oceana County, Michigan. The lake is separated from Lake Michigan by a large dune complex of rolling sand hills that measures about 1.5 miles (mi) wide and about 3 mi long (http://www.thinkdunes.com). These dunes are considered one of the largest deposits of living dunes on the shores of Lake Michigan, as the dunes continue to grow and move, covering cabins and filling in approximately 18 acres of Silver Lake from 1950 to 2012 (Groves and others, 2013). During May–September, almost 1 million people visit Silver Lake and the surrounding sand dunes for outdoor recreation, including the 450-acre off-road vehicle (ORV) area owned by the Silver Lake State Park (SLSP). The Silver Lake sand dunes are the only dunes east of the Mississippi River where people are allowed to drive ORVs (http://www.thinkdunes.com). The recreational opportunities and the water resources of Silver Lake are considered a highly valued asset to the surrounding community and tourists alike.