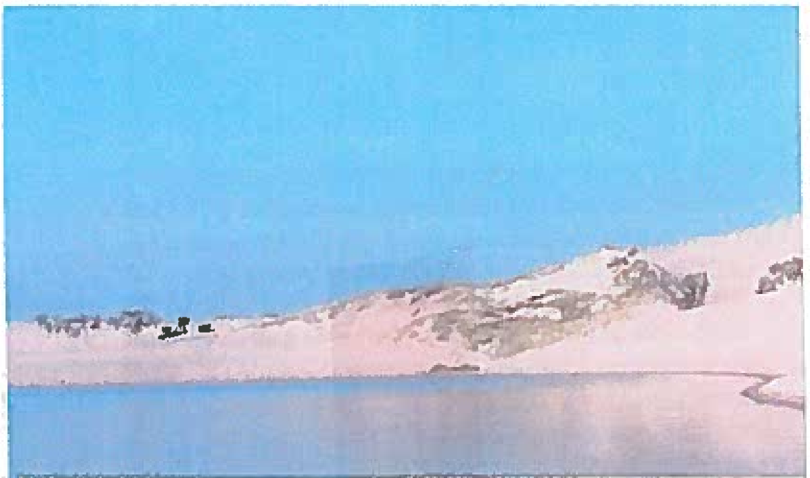

USGS Water Quality and Hydrology of Silver Lake, Oceana County, Michigan, Summary and Conclusion Scientific Investigations Report 2015-5158

Summary and Conclusions

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. Previous studies conducted indicated that Silver Lake was experiencing advanced eutrophication and more frequent algal blooms in recent years. As a result, the Silver Lake Improvement Board (SLIB) concluded that a detailed interpretive study was necessary. 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, as well as identify the 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 (well mixed) lake with a residence time of approximately 223 days.

On an annual basis, the primary contributor of water to Silver Lake is Hunter Creek, at 52.2 percent. Other water sources include groundwater (30.6 percent), direct precipitation (10.3 percent), the tributary at the State Park (4.1 percent), and the tributary at North Shore Drive (2.8 percent). During the spring season, Hunter Creek is the dominant source (62.6 percent) of water to the lake; however, in the summer the primary contributor of water to the lake becomes groundwater (43.7 percent). In the fall, both Hunter Creek and groundwater contribute similar proportions (42.8 and 36.5 percent, respectively) of the overall water budget and during winter Hunter Creek again becomes the dominant source (54.9 percent) of water to the lake. The primary component of water loss from Silver Lake is the outflow of water from Silver Lake via Silver Creek, which accounts for 91.9 percent of all water leaving Silver Lake. The remaining 8.1 percent is lost through evaporation.

Study results indicated that Silver Lake is colimited by both phosphorus and nitrogen, based on both the bioassay results and the nitrogen:phosphorus ratios in the lake. As a result, both phosphorus and nitrogen are deemed critical nutrients in the development of algal blooms and lake eutrophication. Although this colimitation indicates that both nitrogen and phosphorus are needed to produce excessive algal growth during the summer months, it does not indicate that both nutrients must be reduced to control algal blooms. Study results indicate that the largest controllable nutrient to Silver Lake is phosphorus.

Based on the average total phosphorus and total nitrogen concentrations in Silver Lake and the U.S. Environmental Protection Agency (EPA) nutrient criteria recommendation for phosphorus and nitrogen, the lake is classified as eutrophic. Silver Lake also was classified as eutrophic using Carlson's TSI approximately 63 percent of the time (five sampling events), mesotrophic to slightly eutrophic approximately 25 percent of the time (two sampling events), and oligotrophic to slightly mesotrophic about 13 percent of the time (one sampling event).

The likely contribution of phosphorus and nitrogen from septic systems was computed by using a model for septic transport, because septic systems sited on the lakeshore could be important sources of the phosphorus and nitrogen observed in shallow groundwater. This septic model considers the number of residences within 200 feet (ft) of the shore of the lake or surface waters that drain to the lake. Septic systems further than 200 ft from the lake still have an expected impact, but because of the longer travel distance and larger area of diffusion from these systems, the uncertainty in the estimation of their loads is too large to produce a reliable number. Further, the model included only personal residences in the septic model estimates, not commercial facilities such as campgrounds and hotels within 200 ft of the shoreline and Hunter Creek, because the septic model was not designed to accurately represent commercial facilities. If commercial facilities were included, the estimated impact (nutrient loading) of septic systems to the lake and Hunter Creek would be higher. It should be noted, however, that commercial and residential septic sources further than 200 ft from the lake are still captured in the nutrient budget from the groundwater well monitoring that includes nearby (within 200 ft) and diffuse (further than 200 ft) septic sources. As a result of these constraints, the amounts of phosphorus and nitrogen being contributed directly to the lake or tributaries to the lake, as computed using this model, are likely a conservative estimation (an underestimation) of the actual phosphorus and nitrogen loads contributed by all of the septic systems around the lake. The septic model estimated that septic systems likely contributed 47.8 percent

(300.9 pounds [lbs]) of phosphorus and 1.1 percent (136.1 lb) of nitrogen to groundwater annually. Study findings indicate that much of the phosphorus contribution to Silver Lake via groundwater is orthophosphate, a form of phosphorus that can readily stimulate algae growth.

The mean annual input of phosphorus to Silver Lake was approximately 1,342 lb. The major pathways of phosphorus to Silver Lake were groundwater (46.9 percent), followed by Hunter Creek (28.7 percent). However, 19.5 to 73.7 percent of phosphorus in groundwater and 2.1 to 43.6 percent of phosphorus in Hunter Creek is likely derived from septic loading, indicating that septic loading is the largest potentially controllable nutrient load modeled in this study. The largest loading of phosphorus to Silver Lake occurred in the spring months, followed by the summer and fall. Of the total 1,342 lb of phosphorus that entered Silver Lake annually (mean), almost all of the phosphorus was exported out of the lake (1,340 lb), with minimal phosphorus deposition occurring in the lakebed sediment.

The mean annual input of nitrogen to Silver Lake was approximately 51,998 lb. The major sources of nitrogen to Silver Lake were Hunter Creek (56.3 percent), groundwater (24.9 percent), and atmospheric deposition (8.8 percent). The septic model loading scenarios indicate that septic systems account for 0.05 to 3.1 percent of the load to Hunter Creek, and 0.23 to 2.8 percent of the contribution of nitrogen to groundwater. The largest nitrogen loading to Silver Lake was observed during the spring, followed by the summer and fall months. About twice as much nitrogen entered Silver Lake during the spring (19,180 lb) as compared to the fall months (8,921 lb). Of the 51,998 lb of nitrogen that entered Silver Lake annually (mean), approximately 42.2 percent (21,928 lb) of nitrogen was deposited in the lakebed sediment according to the BATHTUB model.

The data collected as part of this study were used to model future nutrient loading and eutrophication scenarios using the BATHTUB model developed by the U.S. Army Corps of Engineers. Both phosphorus and nitrogen constituents were altered in the various nutrient-loading scenarios. Based on Carlson's trophic state index (TSI), the baseline calibrated dataset for the model indicated that Silver Lake was eutrophic, and thus all of the nutrient loading scenarios began with the lake being eutrophic. BATHTUB model simulations indicate that if phosphorus and nitrogen loading from groundwater were decreased by 75 percent, and all of the other nutrient inputs stayed the same, the condition of Silver Lake would most likely range from highly mesotrophic to eutrophic (the current [2014] condition of Silver Lake). This result also applies to the same scenario of nutrient loading from Hunter Creek. If nutrient loading continued to increase in groundwater or Hunter Creek, the lake would continue to remain eutrophic with more frequent algal blooms. Therefore, BATHTUB model simulations indicate that the reduction of nutrients from either Hunter Creek or groundwater alone may not be enough to effectively improve the trophic status and related water-quality issues in Silver Lake. However, if phosphorus and nitrogen from a combination of sources (groundwater, Hunter Creek, and lawn runoff) were reduced by 75 percent, then Silver Lake could be classified as mesotrophic based on Carlson's three TSI equations.

The reduction of phosphorus and nitrogen from either of the small tributaries was not significant enough to modify the trophic status of the lake. The model output indicated that Silver Lake would remain eutrophic, even with a 75-percent reduction of phosphorus and nitrogen from these 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. On the other hand, if nutrient loads increase from Hunter Creek, Silver Lake will experience more frequent and more intense algal blooms. If the nutrient loading from groundwater alone were decreased, the overall impact on Silver Lake would not be as effective at reducing algal bloom frequency as the reduction of nutrient loading from Hunter Creek alone. A third scenario includes an increase and decrease in phosphorus and nitrogen loading from nutrient sources that are the most likely to be managed and include groundwater (sewer installation), Hunter Creek (sewer installation and riparian best management practices [BMPs]), and lawn runoff (fertilizer BMPs). BATHTUB model simulations indicate that a 50-percent reduction of phosphorus and nitrogen from these sources would result in a considerable decrease in algal bloom frequency and severity, and a 75-percent reduction would greatly reduce algal bloom occurrence on Silver Lake.

A scenario also was conducted using the BATHTUB model to simulate the conversion of septic to sewer and included a high, low, and medium (most likely) scenario for both phosphorus and nitrogen loading to Silver Lake. The BATHTUB model simulation indicated that the conversion of onsite septic treatment to sewers would result in an overall change in lake trophic status from eutrophic to mesotrophic, and greatly reduce the frequency of algal blooms and algal bloom intensity on Silver Lake. According to the BATHTUB model, the installation of a sewer system may eliminate the largest phosphorus load modeled in the study and thus improve the trophic status of Silver Lake.

It is important to note that the reduction of the productivity in lakes by decreasing nutrient loading can be very effective; however, the rate at which the productivity of the lake will revert toward conditions existing prior to increased loading is variable. In other words, it took time for Silver Lake to become eutrophic, and it will take time for the lake to begin to recover after phosphorus and nitrogen loading from the lake's major nutrient sources is addressed. The local residents and businesses, as well as local government agencies, will need to determine the best management strategy or strategies to address the major nutrient contributions to Silver Lake.

A Summary of Nutrients

Nutrients can come from natural sources such as eroding soils, decomposing plant material, and wildlife wastes; however, excess nutrients enter surface waters from point-source discharges (a discrete pipe) as well as nonpoint sources (overland runoff).

"In Michigan, nutrient control has focused on phosphorus since the majority of surface waters are limited in this nutrient. Nitrogen reductions have been necessary when this nutrient was considered the limiting factor for plant productivity or has been the direct cause of water quality impairment"(Michigan Department of Environmental Quality, 2013).

Phosphorus

Phosphorus plays a major role in biological metabolism, and is an essential nutrient used by all organisms for the basic processes of life. Its natural source is the weathering and leaching of phosphate-rich geological formations. However, phosphorus is used extensively in agricultural and residential fertilizers, and is a component of domestic sewage (wastewater discharge, failing septic systems). Phosphorus also can enter the system through wet and dry atmospheric deposition, waterfowl feces, and plant decomposition. Phosphorus is considered a limiting nutrient in most Midwestern lakes, as phosphorus typically "limits" macrophyte and algal growth because it is less available for uptake than other nutrients, such as nitrogen (Wetzel, 1983). Aquatic plants may struggle to grow in lakes with little to no phosphorus, but may grow rapidly in systems with excessive amounts of phosphorus.

Nutrient loading in lakes can come from outside the lake (for example, atmospheric, tributaries, waterfowl), which is referred to as external loading, or from the sediments within the lake, which is referred to as internal loading. In the case of phosphorus, internal loading is often a function of sediment redox state, as anoxic conditions will cause the reduction of ferric iron (Fe^{3+}) to ferrous iron (Fe^{2+}), liberating phosphorus that is bound to ferric oxyhydroxides, resulting in phosphorus flux from the sediment to the overlying water column (fig. 4).

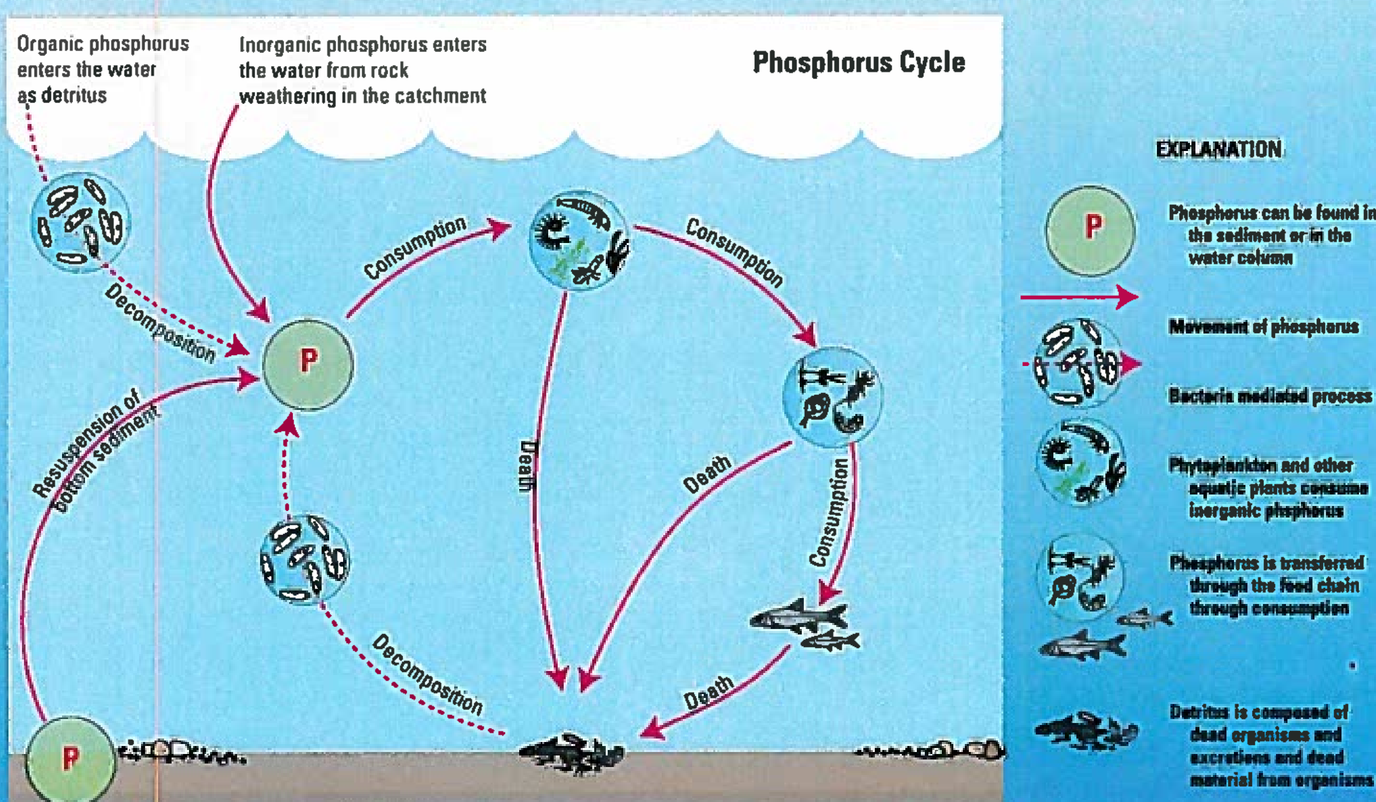

Figure 4. Phosphorus cycle in lakes. (Used with permission of the Queensland Government, Department of Environment and Heritage Protection.)

Nitrogen

All organisms require the nutrient nitrogen to live and grow; it is a building block of cellular proteins. Many of the same sources that contribute phosphorus to the system also contribute nitrogen, and nitrogen is a major nutrient that affects the productivity of fresh waters. The nitrogen cycle is a complex biochemical process in which nitrogen in various forms is altered by nitrogen fixation, assimilation, and denitrification (Wetzel, 1983) (fig. 5).

"Although nitrogen is abundant naturally in the environment, it is also introduced through sewage and fertilizers. Some nitrate enters water from the atmosphere, which carries nitrogen-containing compounds derived from automobiles and other sources. Ammonia and organic nitrogen can enter water through sewage effluent and runoff from land where manure has been applied or stored" (U.S. Geological Survey, 2015b).

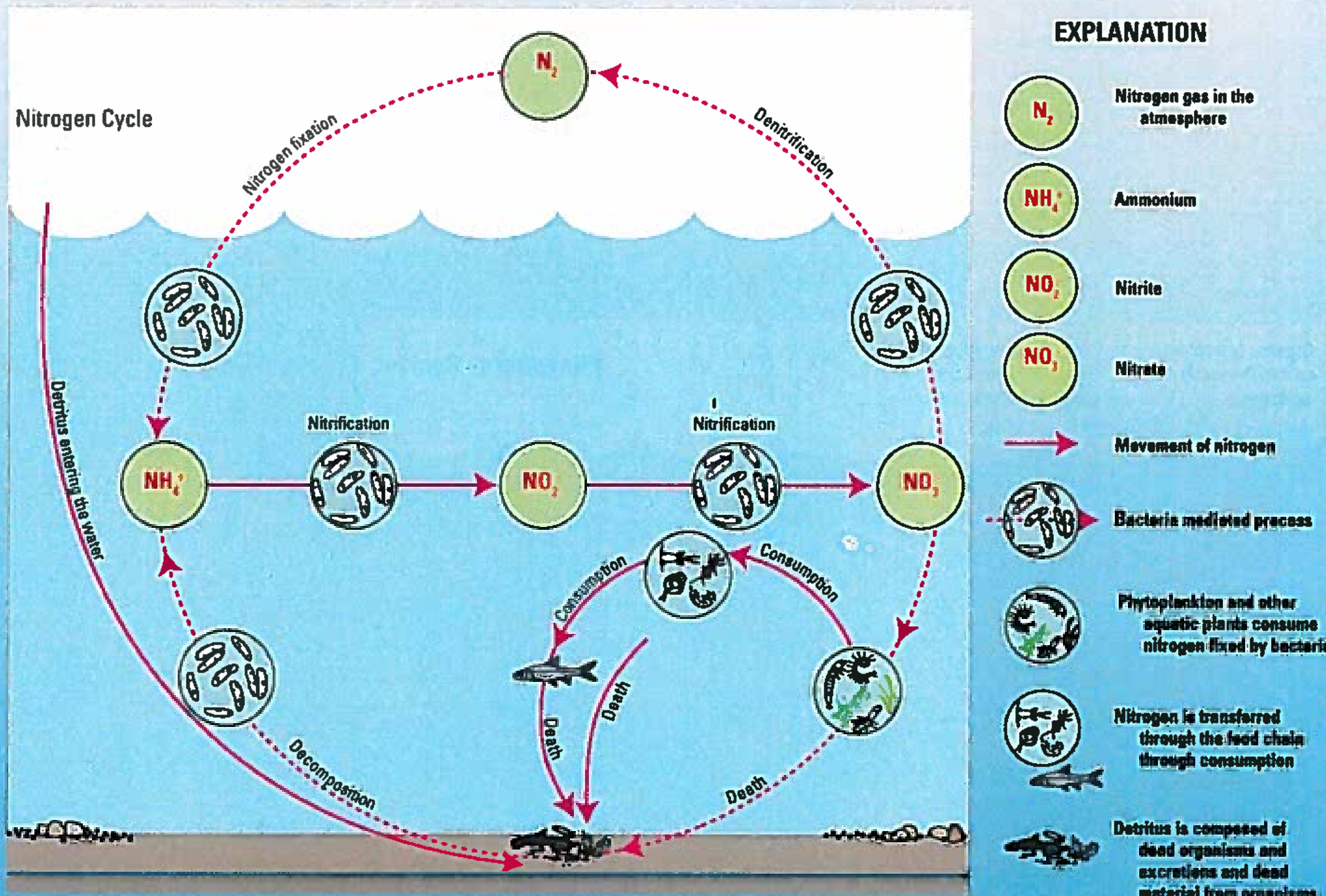

Figure 5. Nitrogen cycle in lakes. (Used with permission of the Queensland Government, Department of Environment and Heritage Protection.)