THE RESTORATION OF SILVER LAKE,

MANITOWOC COUNTY

January 2009

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PUB-SS-____ 2009

Introduction

Silver Lake is located just west of the city of Manitowoc. Since the 1950s, the water quality of the lake was heavily degraded with frequent and large algal blooms and occasional winter and summer fish kills. Conditions were so bad that in 1998 the lake was placed on the 303(d) list, due to phosphorus pollutants resulting from agriculture, internal loading, and local landuse. This is a list of water bodies that are degraded to the point they do not meet fishable and swimmable standards.

In order to improve the lake's water quality, a number of measures were undertaken in the last 10 years. These included rerouting the incoming stream so that most of the water did not enter the lake. The fishery was eradicated and restocked. After these other measures had been completed, an alum treatment was done to reduce internal loading of phosphorus from the bottom sediments. This report documents these restorative techniques and the response of the lake to these changes.

Lake Characteristics

The surface area of Silver Lake is 69 acres with a maximum depth is 43 feet and the mean depth is 16 feet. The lake is a drainage lake with a permanent stream entering the east basin near the lake's outlet (Figure 1). An intermittent stream enters the lake's western basin. Before 2000 the lake's watershed size was 12,147 acres with 71% of the landuse in agriculture (Figure 2). The entire lake is a wildlife refuge and substantial numbers of waterfowl visit the lake in the spring and fall. No hunting is permitted. The use of outboard motors is also prohibited.

The large watershed size combined with the high level of agricultural activity resulted in high nutrient loadings to the lake. Consequently the lake experienced very high phosphorus levels resulting in large and frequent algal blooms. Phosphorus levels in the lake at times exceeded 350 $\mu g\ L^{-1}$ and were much higher than other lakes in the county (Figure 3). These high algal levels resulted in frequent winter fish kills since the 1950s as well as occasional summer fish kills. Consequently, the fish community was highly degraded. The predominant fish were carp, bullheads, and gizzard shad.

A phosphorus budget was constructed for the lake that indicated 67% of the phosphorus entering the lake came from Silver Creek (Figure 4). The other major source was internal loading, from the deep water sediments during anoxic periods as well as nutrient release from rough fish, e.g. carp.

A sediment core was taken from each basin to reconstruct the water quality history of the lake. The core from the East Basin showed that the lake began to degrade during the 1930s. It was found that when Highway 151 was rebuilt in 1935, Silver Creek was routed directly into Silver Lake. Prior to this time a wetland had separated the creek from the lake. Undoubtedly, during periods of high flow the stream would have discharged into the lake but other times most of the water would have bypassed the lake or the water would have been filtered by the wetland. After the diversion of the stream into the lake, the sedimentation rate increased (Figure 5). The rate was variable during the next 70 years depending upon the amount of runoff from the watershed. The rate was especially high during the period from 1960-1985. This was because agriculture, in general, intensified during the period with increased mechanization and switch to cash cropping. During the last 20 years, conservation practices have been instituted which has reduced sediment runoff. Unfortunately the sedimentation rate increased by an order of magnitude as a result of the stream diversion and increase in agriculture intensity during the last half of the twentieth century.

Along with the increase in the sedimentation rate was an increase in soil erosion (indicated by an increase in aluminum deposition) as well as phosphorus deposition (Figure 5). Again these increases were the result of diverting the stream into the lake as well as increased agricultural activity. With the increase in delivery of sediment and phosphorus to the lake, the inlake phosphorus levels significantly increased (Figure 5). The inlake phosphorus concentrations were estimated using changes in the diatom community. Diatoms are a type of algae that are preserved in the sediments. Different species live under differing phosphorus levels so changes in the community can be used to estimate past phosphorus levels. The phosphorus levels in the early part of the twentieth century were about 40 µg L^{-1}. Soon after the stream was diverted into the lake, levels increased to around 100 µg L^{-1}. They continued to increase and reached levels exceeding 200 µg L^{-1}in the 1960s (Figure 5).

Past Rehabilitation Efforts

After public access was acquired Silver Lake was treated with toxaphene in the fall of 1965 to control the rough fish population found in the lake. A total of 10,000 pounds of rough fish were removed from the lake with carp making up 40% of the harvest and bullheads the remaining 60%. Minor components of the catch were largemouth bass and northern pike. Very few panfish were observed. After treatment, the lake was restocked with 4000 legal sized brook trout to provide immediate fishing, northern pike fry, fingerlings and adults, walleye fry and fingerlings, yellow perch adults, and largemouth bass fingerlings and adults. Concurrently, a fish weir was proposed to block the upstream migration of carp from Lake Michigan into Silver Lake. Plans were dropped when revisions that allowed the structure to withstand a twenty year flood, made the cost to high for the lake association.

Carp and bullhead quickly re-entered the lake and once again dominated the fish community. An electroshocking survey in August 1967 indicated carp and bluegill were the dominant species with northern pike, walleye, and largemouth bass present in much lower numbers. A May 1974 electroshocking survey had similar results with numerous carp and white sucker seen. Sixteen yellow perch and one northern pike were also caught. Other fish observed were black bullhead, bluegill and pumpkinseed.

It is clear from earlier studies that Silver Lake experienced poor water quality conditions because of a number of sources. The primary problem was the input of nutrients and sediment from Silver Creek. Because of the input of large amounts of nutrients the lake experienced poor oxygen levels at times causing fish kills and resulting in an unbalanced fishery dominated by rough fish. Because of decades of high nutrient loading, a significant amount of internal phosphorus loading was occurring. It was clear that the primary problem was Silver Creek and agricultural landuse within the watershed. Initially, conservation practices were instituted on the landscape to reduce the runoff of sediment and nutrients to the stream. This began in 1984 with the awarding of a Wisconsin Fund Non-point Watershed Project called the Seven Mile Silver Creek project. The project ended in 1995 with the installation of 13 barnyard treatment systems, 14 restored wetlands, and 5 sediment basins to trap sediments. Three easements to install permanent grass buffers along stream channels were also installed. However, phosphorus loadings to the lake remained high.

In the mid 1990's a project was initiated to align the inlet to the lake more directly toward the outlet hoping to bypass a significant portion of the loading. The presence of deep peat deposits (> 90 ft.) and close proximity to the Hwy 151 right of way precluded a complete diversion at this time. In addition, a bridge downstream of the lake was replaced and stream obstructions were removed to provide better downstream flow. This redirection can be seen by comparing where Silver Creek enters the lake in Figure 1 with Figure 6. Also, at this time additional agricultural best management practices were installed in the lake's direct drainage area. However monitoring and a winter fish kill in 1996 and a summer kill in 1999 indicated that the improved watershed conditions and the partial diversion had not significantly improved in the lake.

Contemporary Rehabilation Efforts

In order to improve the lake's water quality and thus make the lake a more desirable environment for recreational use the restoration effort was redoubled. A team of stakeholders including Manitowoc County Land and Water Conservation Department, Wisconsin Department of Natural Resources, Silver Lake Protection and Rehabilitation District, Holy Family Convent, and area sportsman clubs was convened to set scientific and sociologic goals and facilitate the full restoration of the lake. These steps are summarized in Table 1.

Table 1. Restoration Steps.

- Design project with partners
- Set scientific and sociologic goals
- Divert stream from lake
- Eradicate fishery and replace with diverse community
- Apply alum to reduce internal loading
- Improve county park

Since the major source of nutrients was Silver Creek, it was clear that the first step should be the full diversion of the stream away from the lake, effectively reducing the lake's watershed from over 12,000 acres to 475 acres (Figure 7). This diversion was designed by the engineering firm of Foth & Van Dyke and involved placing a berm between the stream and the outlet (Figure 8). The berm was constructed of clay material that was placed on the lake bed. It was anticipated that a significant amount of organic muck would be displaced by the installation of the berm. The diversion was started in 2001. A picture of the berm under construction is shown in Figure 9. More muck was displaced than was anticipated which completely blocked access to the lake (Figure 10). Removal of the muck caused delays and additional money had to be found but the stream diversion was completed in early 2002. As part of the stream diversion, a box culvert was installed so that an existing boat ramp could be replaced. In addition the public parking lot was expanded and a foot bridge across the creek that provided access to the County Park was replaced. The lake outlet structure was constructed with a flap gate so water could leave the lake when necessary but not let water or fish from the creek enter the lake. However, to guard against downstream flooding the berm was designed with a reinforced overtopping structure so that water from the stream could enter the lake during 25 year runoff events and greater. It was believed that a fully restored Silver Lake would develop enough resiliency to withstand infrequent mixing with the creek's higher nutrient levels, sediment loads and invasive fish species.

The next step was to eradicate the lake's fishery and restock it. The eradication was accomplished in the fall of 2003 using rotenone. Most of the fish that were found to be present in the lake were gizzard shad, carp, and bullheads. Very few gamefish were recovered.

Since the rotenone treatment, the lake has been stocked with a variety of fish species that would promote self-sustaining populations, be desired by anglers and help maintain the water quality goals of the restoration project. To date, six species and over 180,000 individual fish have been stocked (Table 2).

Table 2. Fish stocked into Silver Lake since the 2003 rotenone treatment.

	2004	2005	2006	2007	Total
Largemouth Bass	10,000 (small fingerling)	1,000 (small fingerling)	--	--	11,000
Walleye	1,000 (small fingerling)	1,400 (large fingerling)	1,360 (small fingerling)	1,358 (small fingerling)	5,118
Northern Pike	2,000 (small fingerling)	6,800 (small fingerling)	--	--	8,800
Northern Pike	100 (large fingerling)	--	3,000 (large fingerling)	--	3,100
Yellow Perch	4,000 (small fingerling)	1,000 (small fingerling)	--	--	5,000
Fathead Minnow	150,000 (adult)	--	--	--	150,000
White Sucker	250 (adult)	250 (adult)	322 (adult)	--	822
Total	167,350	10,450	4,682	1,358	183,840

In addition to fish stocked by the State, several species of fish, most notably bluegill and pumpkinseed were found in the lake during surveys since 2004. It is suspected that these fish were illegally stocked into the lake following the rotenone treatment. Following an overtopping event in the spring of 2004, it was feared that alewives had also re-entered the lake. This species targets and feeds upon large zooplankton. Since the water quality goals of the project hinged on maintaining a fishery that would not feed on large zooplankton to a significant extent, additional study was done to find out how many of these fish were present. This study was conducted by Dr. Tom Hrabick of U. of Minnesota-Duluth. Using acoustical survey techniques, he found no alewives. His report can be found in Appendix A.

The next step was to add aluminum sulfate (alum). The purpose of this treatment was to reduce internal loading of phosphorus from the deep water sediments. When the bottom waters become devoid of oxygen, phosphorus that is bound with iron in the sediments is released into the overlying water. In the presence of oxygen iron is in the ferric form which is insoluble. When oxygen levels are very low the ferric iron is converted into the ferrous form which is soluble in water. Since a large portion of the phosphorus in the sediments is bound with iron, when the iron diffuses from the sediments into the overlying water, the phosphorus associated with it also enters the water column. Applying alum results in the iron bound phosphorus becoming bound with aluminum instead. Aluminum and the associated phosphorus is insoluble and remains so in the absence of oxygen. There phosphorus is not released from the deep water sediments even when the overlying water becomes anoxic.

In the spring of 2004 alum was applied at a rate of about 50 g m^2 over the lake at water depths greater than 10 feet. This treatment occurred over a 2 day period. Figure 11 is a picture of the barge applying the alum. In June 2008, the Silver Lake area experienced a large amount of rain over several days resulting in an extreme runoff event and discharge of Silver Creek into the lake. This discharge would simulate how the lake and stream related prior to the diversion in 2002. Figure 12 shows pictures of the stream discharging into the lake. Beyond assessing the success of the restoration, this project was able to assess the resiliency of the lake to a major perturbation.

Lake response to restoration efforts

Various parameters were sampled in Silver Lake to assess the success of this project. These measurements include the trophic variables, phosphorus, chlorophyll, and water clarity; zooplankton community, fish community, and macrophyte community.

Trophic Variables

Prior to the stream diversion, phosphorus levels in both basins were extremely high. Maximum levels were variable between years depending upon how much runoff occurred from Silver Creek. Summer mean phosphorus levels often exceeded 200 µg L^{-1} (Figures 3, 13a, 14a) placing the lake in the hypereutrophic category. Following the stream diversion, phosphorus levels were much lower but they were still high enough to cause frequent nuisance algal blooms. The mean concentration in 2003, the first year following diversion, was 106 µg L^{-1}. Following the fish eradication and alum treatments, the phosphorus levels dropped even more to a summer mean of 34 µg L^{-1} in the East Basin and 35 µg L^{-1} in the West Basin in 2004 (Figures 13a, 14a). For 3 years (2005-07) the summer mean phosphorus concentrations was less than 30 µg L^{-1}. This places Silver Lake in the mesotrophic range and the concentration was close to levels present in the lake prior to 1900. With the overtopping of the berm in 2008, phosphorus levels were the highest they had been since the completion of the restoration effort. The summer mean increased to 44 and 45 µg L^{-1} in the East and West basins, respectively. The higher levels in 2008 were undoubtedly the result of the heavy rains in June as concentrations were higher in the surface waters the rest of the summer compared with 2007 (Figure 15).

As with phosphorus, chlorophyll concentrations were very high prior to the stream diversion (Figure 13b, 14b, Table 3). Values were around 100 µg L^{-1} which are levels expected in hypereutrophic lakes. After the diversion, chlorophyll levels were reduced to near 40 µg L^{-1} which are still high. The first year after the alum treatment and fish restocking the values were still somewhat elevated, especially in August when levels exceeded 35 µg L^{-1}. During the period 2005-07, the mean summer chlorophyll concentrations were below 10 µg L^{-1}, which place the lake in the mesotrophic range. In 2008 the higher phosphorus levels following the heavy June rains resulted in higher chlorophyll levels (Table 3).

Water clarity was measured using a 20 cm black and white Secchi disc. Generally, clarity was measured at least monthly during the summer. Some years it was measured twice per month. Secchi depth prior to the diversion was very poor, being about 0.7 meters. After the diversion the water clarity did not improve much. However after the alum treatment and fish eradication and restocking it greatly improved. During the period 2005-07, water clarity was much better than prior to the restoration work and was at its highest level in 2007. The improving water clarity is partially in response to the changing zooplankton community. As will be discussed later, in 2007 there was more large zooplankton which help reduce the algal levels and thus improve water clarity. Even though phosphorus and algal levels were higher in 2008 compared with the previous 3 years, this was not reflected in the water clarity. The mean summer Secchi in both basins was better than in 2005 or 2006 (Table 3). This was primarily due to exceptional water clarity in May and early June. Water clarity in late July and August was less than 1 meter.

Table 3. Summer mean concentrations of the trophic variables. The stream was diverted in 2002 and fish eradication and alum treatment occurred between the summers of 2003 and 2004. The stream overtopped its banks and discharged into the lake during June 2008.

	Total Phosphorus (µg L^{-1})	**Chlorophyll** (µg L^{-1})	**Secchi Depth** (m)
	EAST BASIN		
1996	186	91	2.1
1997	268	167	2.3

2003	107	38	1.3
2004	34	19	1.9
2005	27	8	1.1
2006	27	10	1.4
2007	28	8	2.1
2008	45	13	1.7
WEST BASIN			
1996	182	95	2.1
1997	276	200	1.6
2003	107	42	1.3
2004	35	18	1.7
2005	ND	ND	ND
2006	31	11	1.4
2007	23	8	2.3
2008	44	12	1.9

The purpose of the alum treatment was to reduce the migration of phosphorus from the bottom sediments when the bottom waters lack oxygen. Without oxygen, iron and its associated phosphorus is released from the sediments into the overlying water. The aluminum in alum binds with the phosphorus that is associated with iron. Since aluminum, unlike iron, does not be become soluble when the oxygen disappears, the phosphorus remains in the sediments.

Phosphorus profiles were collected from both basins near the end of stratification annually in 2003 through 2007. The purpose of this sampling was to measure the effectiveness of the alum treatment. Prior to the alum treatment phosphorus concentrations in the bottom waters of the East Basin exceeded 2.0 mg L^{-1} (Figure 16) and the increase in phosphorus mass from internal loading was 212 kg. The three years following the alum treatment (2004-06), the phosphorus levels in the bottom waters were significantly less, never exceeding 250 µg L^{-1}. More importantly, the increase in the mass of phosphorus was about 1 kg. In 2008 the stream overtopped its banks in June of a significant amount of water entered the lake. In 2008 the phosphorus levels in the bottom waters were much higher in mid-September, with concentrations approaching 1 mg L^{-1} just above the sediments. Although phosphorus levels were not as high as prior to the alum treatment (2003) they were much higher than at any time during the period 2004-2006).

Table 4. Amount of internal loading (kg) in each basin from the bottom sediments. The year 2003 was prior to the alum treatment while 2008 was the year of the flood.

	East Basin	West Basin
2003	212	79
2004	0	0
2005	0	0
2006	1	6
2008	63	41

Macrophytes

Macrophytes (submerged aquatic plants) are an important component of the lake's ecosystem. They provide habitat for fish and insects as well as stabilize sediments. The water clarity goal that was set for the lake (7.2 ft) was established to provide sufficient clarity to allow macrophyte growth to 11 feet, covering 30-49% of the lakebed.

Only one macrophyte survey (1979) was conducted prior to the stream diversion. Surveys have been conducted each year following the completion of the restoration work. The 1979 survey found no submerged species and the emergent species (cattails, sedges, and rushes) were very sparse. It was felt this was the result of low water clarity and the disruptive behavior of carp and bullheads.

In 2004 there were a few submerged species but they were relatively sparse in coverage. The two submerged species were *Potamogeton foliosus* (leafy pondweed) and *Stuckenia pectinata* (sago pondweed). The lone emergent species was *Nuphar variegata* (spatterdock). In 2005 only three species were present. As in 2004 they were *P. foliosus* and *N. variegata* but S. pectinata had been replaced by *Chara* (musk grass) which is actually an alga but grows like a macrophyte. In 2006 the distribution of plants had expanded from 3 to 9 sites and there was further expansion in coverage in 2007. In 2007 three new species were also found. They were *Vallisneria americana* (wild celery), *Utricularia minor* (small bladderwort), and *Lemna minor* (duckweed). Three additional emergent species were also encountered in 2007. A complete list of macrophytes found in 2007 is given in Table 5.

The amount of littoral zone that is inhabited by macrophytes and their diversity is disappointing but it does seem to be expanding. In 2007 the percentage of littoral zone with plants had increased to 21 percent and the maximum depth of growth was the greatest recorded at 11.5 feet. The 2007 macrophyte report is included in Appendix B.

Table 5. Silver Lake 2007 Aquatic Plant Species List

Common Name	Scientific Name	Growth Form
Muskgrass	*Chara* sp.	Submergent
Leafy pondweed	*Potamogeton foliosus*	Submergent
Spatterdock	*Nuphar variegate*	Emergent
Filamentous algae	*Unknown species*	Submergent
Swamp loosestrife	*Decodon verticillatus*	Emergent
Hardstem bulrush	*Schoenoplectus acutus*	Emergent
Wild celery	*Vallisneria americana*	Submergent
Duckweed	*Lemna minor*	Submergent
Small bladderwort	*Utricularia minor*	Submergent
Cattail	*Typha* sp.	Emergent

Zooplankton

One of the goals of the project was to structure the fish community such that large zooplankton would be abundant during much of the year. This was done by stocking many piscivorous fish so the number of plantivorous (plankton eating) fish would be relatively low. Since zooplankton eat algae and larger species eat more, it was hoped that if enough large zooplankton were present, algal levels would be lower than would be expected given the phosphorus concentration. This process is called biomanipulation. The zooplankter that is most desirable is *Daphnia* (water flea), particularly the larger species of this genera. An example of a large Daphnia is shown in Figure 17.

Unfortunately there is not any zooplankton data for the lake prior to the stream diversion. The first year that zooplankton samples were taken was in 2005. The biomass of the zooplankton for most of the summer was equally divided between the most desirable zooplankter, *Daphnia*, and other small cladocera (Figure 18a). The dominant *Daphnia* were *D. pulicaria* and *D. galeata mendotae*. The most common small Cladocerans were *Bosmina longirostris* and *Diaphanosoma birgei*. While the most common *Daphnia* was the taxa most desired because of its large size, the overall numbers of the zooplankton were much lower than what was hoped for.

In 2006, zooplankton numbers were higher in mid-June compared with 2005 but the biomass was much lower the rest of the summer (Figure 18b). The same *Daphnia* were present as were found in the previous year. Unfortunately most of the cladocerans were small species that eat less algae than the desired larger *Daphnia*.

In 2007, for the first time the zooplankton community was found in higher numbers for much of the summer (Figure 18c). The dominant taxa were the larger *Daphnia* which eat the most algae. Unlike the previous years, the dominant *Daphnia* was *D. galeata mendotae*. In 2007 it appears that the zooplankton community was finally reaching the level that was hoped for, altahough the *Daphnia* were not as large as desired. The mean length was about 0.8 mm. It would be better if their length was over 1.0 mm but at least they were present in relatively high numbers for most of the summer (Figure 19).

In 2008 the zooplankton community was much different than it was in 2007 (Figure 18d). At the end of May there was a large bloom of large bodied *D. pulicaria* in both basins. The biomass was higher by an order of magnitude than anything measured in the previous years. Part of the reason for the large biomass was the larger size of the *Daphnia*. While *D. galeata mendotae* had been the dominant *Daphnia* in previous years, in early 2008 *D. pulicaria* was dominant. The *Daphnia* finally achieved the desired length of over 1 mm (Figure 19). The length was similar to that in Lake Delevan which was a lake with a successful biomanipulation in the 1990s.

Unfortunately the overtopping of the stream banks in June apparently had an adverse effect on the zooplankton community. In July and the rest of the summer *Daphnia* were absent from the community and the cladocerans present were the small taxa *B. longirostris* and *Ceriodaphnia lacustris*. The length of these small cladocerans was smaller than measured in previous years (Figure 19). *D. birgei*, which was an important late summer component of the cladoceran community in previous years was not present in 2008.

The copepod community was also different in 2008 compared with previous years. While calanoid zooplankton were common in 2006 and more so in 2007 (Figure 20), they were found in low numbers in 2008. These zooplankton are largely herbivorous and are large enough to consume a significant amount of algae. The cyclopoid copepods were not found in large numbers prior to 2008 but they was very common in late summer 2008. The most common cyclopoid was *Tropocyclops prasinus*. This is one of the smallest planktonic cyclopoids and therefore it is not able to consume large amounts of algae.

The much smaller size of the zooplankton community in 2008 compared with previous years, especially 2007, indicates fish predation is likely having an adverse affect on the zoplankton community. Since fish feed on the larger zooplankton, only the small species are able to survive under heavy predation. It appears that with the overtopping of the stream banks, planktivorous fish in large numbers entered the lake. Part of the restoration techiques used in this lake were to maintain a large bodied zooplankton community which would help reduce algal levels, even if phosphorus concentrations were elevated. It appears this part of the restoration effort has failed.

Fish Community

Following the fish eradication in the fall of 2003 a variety of fish species have been stocked in the lake. Through 2007, six species and over 180,000 individual fish have been stocked (Table 2). In general most of the stocked fish are doing well. The fish community has been sampled in the fall using electrofishing. Catch rates and average lengths have improved each year for most species. The most abundant species in 2007 were bluegill and yellow perch. Largemouth bass numbers are relatively low and it appears there is limited natural reproduction. Northern pike are doing well and have exhibited good growth. A number of these fish have been harvested through the ice. Walleye are doing well but there is little evidence of natural reproduction. The complete report of about the sampling of the fish community in 2007 is found in Appendix 2.

A few alewife were noted in the lake in 2004. These fish are highly undesirable as their primary diet are zooplankton. Consequently their presence would greatly reduce the size of the zooplankters and thus the ability of the zooplankton to reduce the amount of algae present in the lake. Alewives were not found in succeeding years. The fall electrofishing sampling is not the best method of collecting alewives because these fish are primarily found in the open water of the lake while electrofishing is done close to the lakeshore. In July 2006, Dr. Thomas Hrabik conducted a detailed survey of the lake using gillnets and acoutical techniques. This study confirmed the absence of alewives but did find that the dominant fish in the pelagic area was black bullheads. The complete report on this study is found in Appendix 3.

Trophic State Index

The concept of trophic status is based on the fact that changes in nutrient levels (phosphorus) causes changes in algal biomass (chlorophyll *a*) which in turn causes changes in lake clarity (Secchi disk transparency). A trophic state index (TSI) is a convenient way to quantify this relationship. Theoretically the TSI should be similar for all three measurements. If they differ this indicates that conditions in the lake are not balanced. Following the eradication of the fish community, it was hoped that the fish community would minimally feed on the zooplankton community. Towards this end, planktivores, such as black crappies, were not introduced into the lake. It was hoped that by having a low ratio of planktivores to piscivores, the zooplankton community would reduce the size of the algal community beyond what would be expected at the phosphorus concentration found in the lake.

Figure 21 shows the three trophic state indices for the years 2003-08. For the years 2003-06 the TSI for phosphorus and chlorophyll were similar in both basins. This indicates that the biomanipulation that was hoped for from the zooplankton was not successful. In 2007 both Secchi and chlorophyll were better than for phosphorus indicating that the biomanipulation may be starting to take effect. In 2007 the zooplankton community was larger and more numerous than in previous years. This may be due to the change in the structure of the fish community with less planktivores being present. Another reason for the improvement may be the increase in the amount of macrophytes. These plants provide some protection for the zooplankters from fish predation. In 2008 the summer mean TSI values for chlorophyll and Secchi was better than those for phosphorus indicating that less phosphorus was going into algal biomass than would be expected. This is another sign that the biomanipulation is working. This is unexpected as the zooplankton community size structure was small after mid-June. In fact the mean length of cladocerans was as small as it was in 2005 (Figure 19). Although the summer mean TSI for 2008 indicates that the biomanipulation is working this is an artifact of the high success of the biomanipulation prior to the flood. Figure 22 shows that after mid-July that the trophic variables had similar TSI values until early September when chlorophyll concentrations were less than expected.

Discussion

Silver Lake responded well to the restoration effort that was performed on the lake. The stream diversion had significant impact on reducing the phosphorus levels in the lake. Phosphorus levels were reduced from over 200 to 100 µg L^{-1}. These levels were still unacceptably high so a fish eradication was performed and the lake treated with alum to reduce the internal loading of phosphorus. These efforts were also successful with phosphorus concentrations being further reduced to below 30 µg L^{-1} through 2007. Algal levels were similarly reduced and water clarity also improved. Part of the restoration effort was structuring of the fish community to reduce predation on the zooplankton community to allow it to reduce algal levels below what would be expected, given the phosphorus concentration. The zooplankton community was slow to respond but by 2007 was present throughout most of the summer although they were not as large as was desired. In 2008 it appeared success was finally achieved. Very high numbers were present during the first part of the summer and the mean body length was over 1 mm. This all changed after the stream overtopped its banks in June 2008 The size structure of the zooplankton community became small and *Daphnia* were not present the rest of the summer.

The one part of the lake ecosystem that has not responded to date as hoped is the macrophyte community. Plants have been slow to become established and their diversity is low. It is not clear why this community has not responded as hoped. It may be that this lake was abused for such a long time period that sediment conditions are not conducive for plant growth and there may be a very low seed bank.

Impact of stream overtopping in June 2008

In June 2008 part of Wisconsin, including the area around Silver Lake, experienced an unusually high amount of rainfall. This resulted in much flooding including Silver Creek. For a few days a significant amount of flow from Silver Creek discharged into the lake (Figure 12). This had happened for a few hours in 2006 but much more water entered the lake in 2008. What was the impact of this on the restoration efforts of the lake?

Phosphorus and other trophic variables were higher the rest of the summer compared to the years 2004-07. However the levels of all three variables was better than prior to fish eradication and alum treatment (2003). The input from the stream may have had a more significant impact on the internal loading of phosphorus from the deep water sediments. While phosphorus levels in the bottom waters were much higher in 2008 than they had been since the alum treatment they were not as high as in 2003. It appears the high sediment load from the stream may have buried the alum layer and reduced its effectiveness. This would mean the lifespan of the treatment will be much less than was orginally hoped.

The zooplankton community also appears to have been impacted by the flooding. The size structure of the community was much smaller compared with the previous 3 years. It is likely that a significant number of planktivorous fish entered the lake.

While the flooding of Silver Creek had an adverse impact on Silver Lake, it did not destroy all of the restoration efforts. The biomanipulation part of the effort may have been negated and the life span of the alum treatment may have been shortened but the external loading is still much less than it was prior to the diversion. Even though phosphorus levels were elevated in 2008, they are still much lower than they were prior to 2004.