# Martin and Typo Lakes Carp Management Report and Future Management Feasibility Assessment

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## Preface

This in an interim report that presents carp management and a feasibility analysis of future management through July 2019. As of this date all major components of management and analysis are completed such that findings can be reported with confidence. However, new data is continuously being collected and this report will be updated accordingly from time to time.

## Purpose

The purpose of carp management in Martin and Typo Lakes is to improve aquatic habitat and water quality. The purpose of this report is to provide science-based recommendations for if and how carp management should be pursued.

## Executive Summary

Martin and Typo Lakes are located in Anoka County Minnesota and is impaired for excessive nutrients that cause algal blooms. Total maximum daily load (TMDL) and watershed restoration and protection strategies (WRAPS) have been previously prepared that identified carp an important target for lake management. This study evaluated the carp population and concluded that carp biomass indeed exceeds threshold for ecological damage by at least 3-folds and a significant portion of carp biomass would need to be removed to facilitate lake restoration.

Both lakes exceed carp biomass targets. Research at the University of Minnesota has found that lake health quickly deteriorates when carp populations exceed 100 kg/ha (89 lbs/acre, Bajer et al. 2008). Typo Lake's carp biomass was 334 kg/ha at the start of this study, and Martin Lake's was 507 kg/ha.

Carp have recruited to these lakes relatively infrequently. At Typo Lake most of the carp are ages 19-33 years and only 5% are four years old or younger. At Martin Lake most of the carp are ages 11-29 years. Moreover, as of 2016 barriers are in place at lake inlets and outlets to prevent carp from moving between overwintering and spawning areas, and this should reduce the chances of future recruitment. Use of winter aeration in Martin Lake further reduces recruitment chances by reducing the likelihood of winterkills of native predators. Infrequent recruitment suggests that carp management could have lasting benefits with minimal maintenance efforts.

Carp removals are recommended as a feasible way to improve lake health and water quality. Removals from 2017-2019 have reduced carp biomass by 40.1% in Typo Lake and 29.6% at Martin Lake. Across both lakes this is a 34.7% reduction. A reduction of 75% would reduce carp to the goal of 100 kg/ha and seems feasible.

Removal of carp might have a long-lasting effect because production of young carp in both lakes has been low in the last 20 years. Thus, we anticipate that a significant effort to reduce carp biomass might be need once every 5-15 years. Further, as cost effectiveness of carp removal increases, future removal efforts might be more affordable than those used in the past. Carp recruitment is often density-dependent and increased production of young often occurs after commercial removal, or after partial winterkills and carp die-offs and die-offs on

native predators. It is encouraging though that as of now, we see no evidence of carp recruitment despite 40% adult carp biomass reduction in Typo.

Current cost effectiveness of carp management vs. other BMPs is poorly documented and complex. In a small urban lake, Bartodziej et al. (2017) suggested that carp removal allowed for an in-lake TP management that was 2-5 times more cost effective than watershed BMPs. However, specific numbers for larger shallow lakes (e.g. Typo Lake) are difficult to quantify. In part, this is because of positive feedbacks such as macrophyte reestablishment when carp are removed. The macrophytes can reduce wind disturbance, provide refugia for zooplankton that eat algae, and provide spawning & hiding habitat game fish. All of these feedbacks can achieve phosphorus reductions far greater than the direct effects of removing carp alone.

We used TMDL and monitoring estimates of internal loading, much of which is due to carp, to estimate phosphorus removals that could be achieved in Martin and Typo Lakes from carp management. We conservatively estimate a 15% nutrient reduction could be achieved. This equates to 1,082 lbs/yr phosphorus in Martin Lake and 1,300 lbs/yr in Typo Lake. We estimate that the costs of achieving carp reductions to a biomass of 100 kg/ha (89 lbs/ac) is $180,000. Assuming a 10-year duration of benefits, the cost per pound of phosphorus removed is therefore $7.55. Any estimate such as this will need to be regularly revised with updated science. This estimate does not include additional P removed with carp biomass (0.05% of carp biomass is P), which would make the strategy even more viable economically.

Carp management is expected to increase cost-effectiveness of on-land BMPs. Shallow lakes in particular tend to settle into stable states of either algae or macrophyte dominated. Pushing a lake away to the later state often cannot be achieved without a large in-lake practice. These lakes are resistant to changing state. Watershed projects alone may yield little or no perceptible water quality change unless in-lake practices are also done to move the lake from its otherwise stable state.

TMDL studies seem to suggest that carp management is not only part of a management strategy for Martin and Typo Lakes, it is essential if goals are to be reached. WRAPS and 1W1P similarly note carp management in these lakes as a priority. Reaching water quality standards is a high priority locally because Martin Lake has become, through recent management, close to reaching state water quality standards. Typo Lake is farther from those standards, but is the upstream most lake and benefits there will benefit multiple downstream waters. Downstream waters include the Sunrise River and St. Croix River. Both Martin and Typo Lakes began a trend of improving water quality when carp management started.

## Watershed and Morphology

Martin and Typo Lakes are interconnected lakes located in northeastern Anoka County of Minnesota, generally in the Twin Cities metropolitan area. They are in watersheds that are mostly rural residential, wetland and forests. These lakes are priorities locally and regionally due to their potential for recreation, wildlife and because they are connected to other priority waterbodies including the Sunrise River and St. Croix River.

Both Martin and Typo Lakes are on the state list of impaired waters for excess phosphorus that fuels algae blooms. A TMDL study has been conducted to identify the sources of impairment and phosphorus reductions needed (Schurbon et al. 2012). Additional discussion of the severity and nature of the impairments is below in the water quality section of this report.

These lakes are hydrologically connected to other impaired waters (see Figure 1): Linwood Lake and the St. Croix River. Martin Lake outlets to the West Branch of the Sunrise River, which was listed as impaired for high pH affecting aquatic life until 2018. High pH was due to eutrophication in upstream lakes. It was recently removed from the impaired list due to improvements and a recognition that the problem will be addressed by focusing on Typo and Martin Lakes. Generally, management plans for all of these interconnected impaired waters have recognized the importance of working first on Martin and Typo Lakes, as they are the farthest upstream and work there will benefit the downstream waters.

Typo Lake is upstream of Martin Lake. It has a surface area of 280 acres and a maximum depth of 6 feet (Figure 2). All of the lake is littoral. There is little variation in depth, though the bottom composition varies from deep, loose sediment to firm sand.

Typo Lake's watershed is 11,000 acres. The three most common land uses are agriculture (38%), forested (30%) and wetland (13%). Developed land is 3.8% of all lands. The lakeshore is sparsely developed, with <35 homes on its 3.8 miles of shoreline. A DNR Wildlife Management Area occupies a large portion of the northwest shore. No areas in the water are served by municipal stormwater conveyances.

Martin Lake is a deeper recreational lake. It has a surface area of 238 acres, of which 83% is littoral (Figure 3). The maximum depth is 17 feet. The bottom sediment is generally more firm than Typo Lake.

Martin Lake's watershed includes 4,832 that drains directly to the lake, 7,486 that drain through the Linwood Lake chain and 11,289 acres that drains through Typo Lake. Residences occupy most of the lakeshore – there are approximately 146 homes on the lake's 3.13 miles of shoreline, or 1.13 homes per 100 feet of shoreline. The only areas of the Martin Lake watershed served by municipal stormwater conveyances are immediately adjacent to the lakeshore.

The lakes have moderate water residence times. The residence time at Typo Lake is 70-76 days. At Martin Lake it is 80-91 days (Schurbon et al. 2012).

***Figure 1 – Location map.***

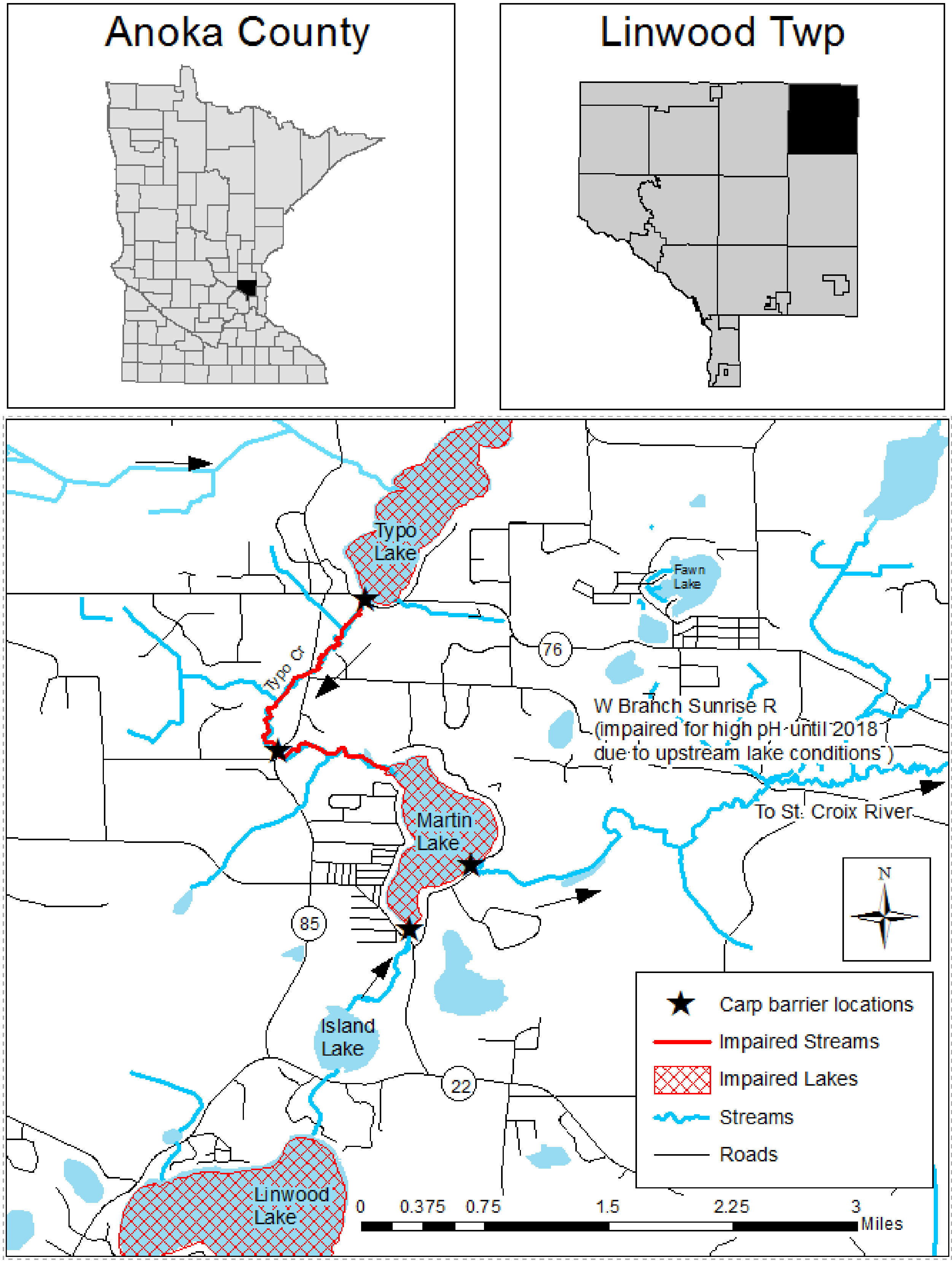


***Figure 2 – Typo Lake morphology.*** *Source: MN DNR.*

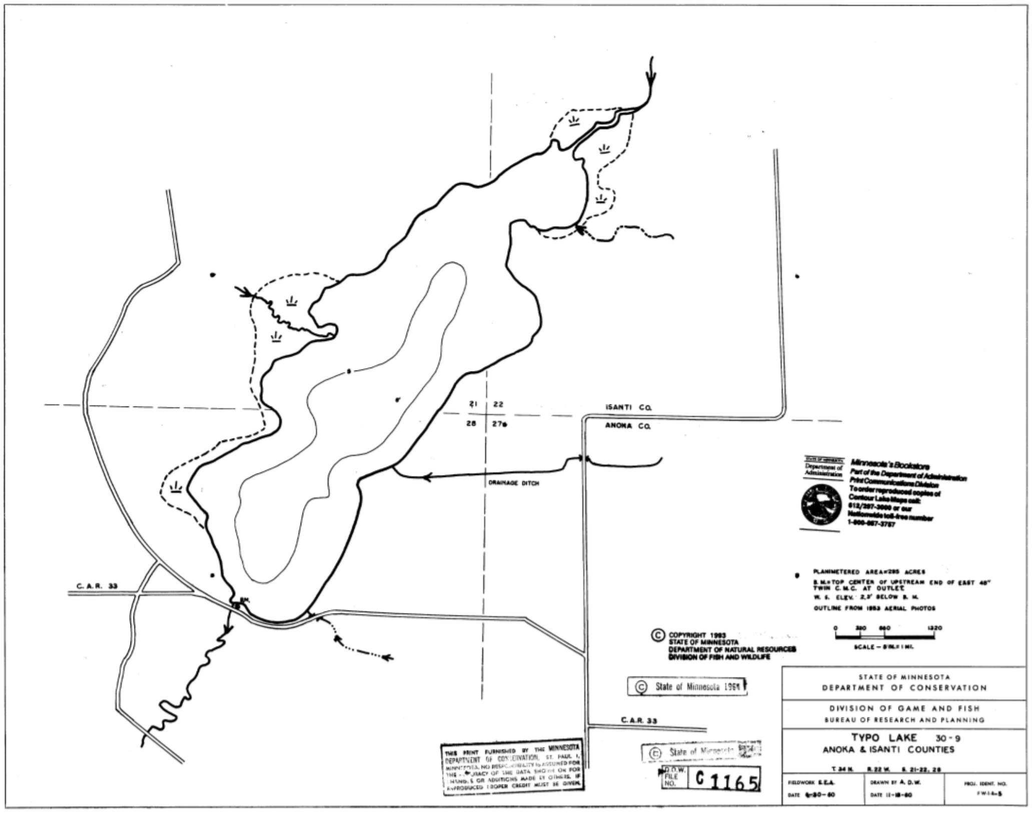
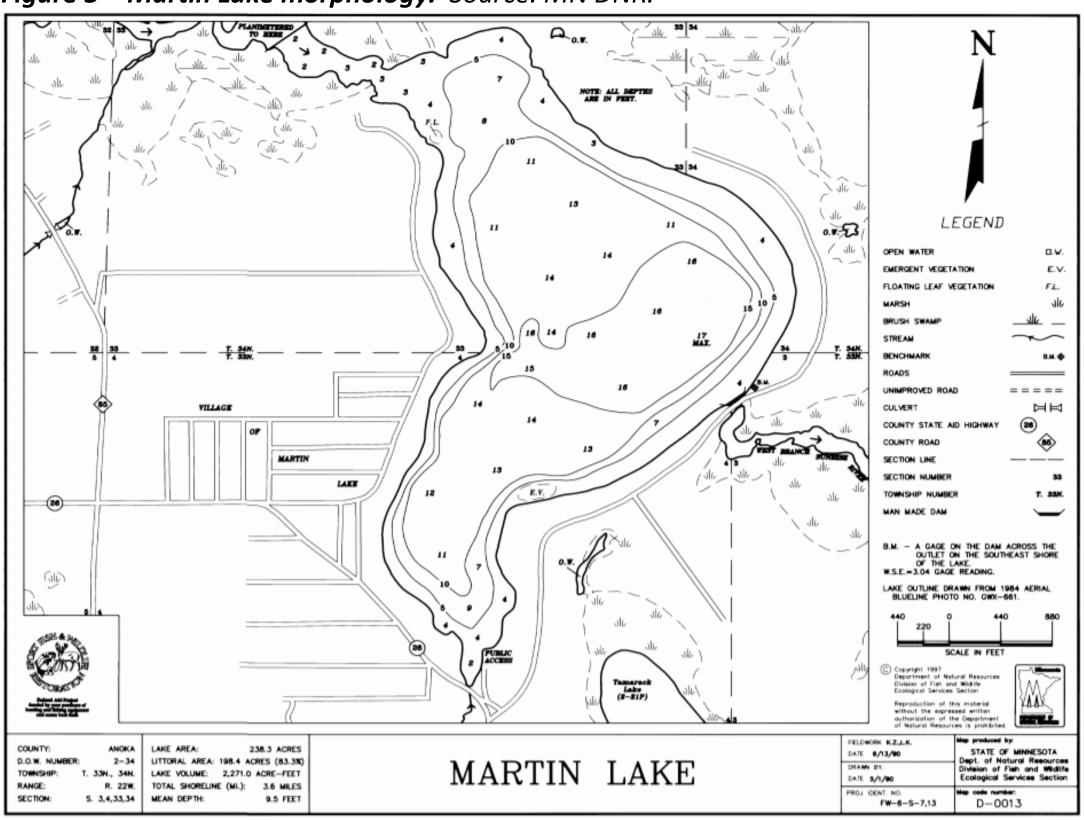



***Figure 3 – Martin Lake morphology.*** *Source: MN DNR.*



## Assessment of Aquatic Invasive Species

The lakes are not designated as "infested waters" by the state. However, it is expected that curly leaf pondweed may be present in either or both lakes because it is common in other nearby lakes. Common carp are also present.

Efforts are underway to protect these lakes against infestation by other AIS. Anoka County's AIS Prevention Program includes watercraft inspectors, outreach and education, and early detection sampling plates for zebra mussels.

## Vegetation

Aquatic vegetation is sparse in Martin and Typo Lakes. While no recent vegetative surveys have been done, surveys as long ago as 1974 by the MN DNR found "little to no aquatic vegetation" in Typo Lake. There are small areas of lily pads. In Martin Lake there is more vegetation, but it is still sparse and not diverse. Lily pads are most apparent. It is believed that carp activity and poor clarity are strongly limiting the plant community. Records indicate water quality was poor during the earliest vegetative surveys.

However, vegetation in these lakes was not always so poor. Long-time residents have communicated that Typo Lake once had dense wild rice and was full of ducks and duck hunters (V. Boettcher, personal communications, 2001 with J. Schurbon). The lake's depth, which rarely exceeds four feet, shoreline public hunting areas and relatively undeveloped shoreline make it an excellent candidate for wildlife habitat if aquatic vegetation is restored.

## Lake Water Quality

Martin and Typo Lakes are both impaired for excessive nutrients that result in algal blooms that affect aquatic recreation and habitat. Frequent water quality monitoring and a total maximum daily load (TMDL) study as well as have occurred to track and understand the nature of these impairments. In simple terms, Typo Lake has an "F" water quality letter grade while Martin Lake receives a "C" grade, but as of 2018 both lakes are showing a statistically significant trend of improvement (letter grades from the Metropolitan Council lake grading method).

**Table 1 -** Martin and Typo Lakes water quality summary. Measurements were taken at a depth of one meter.

| Water Quality Parameter | Typo Lake 2018 Average | Martin Lake 2018 Average | Applicable state water quality standard |
|---|---|---|---|
| pH | 8.99 | 8.80 | |
| Turbidity (NTU) | 82.5 | 15.8 | |
| Dissolved oxygen (mg/L) | 9.73 | 9.53 | |
| Chlorophyll-a (µg/L) | 61.9 | 25.1 | <20 |
| Total phosphorus (µg/L) | 149.0 | 54.0 | <60 |
| Secchi transparency (ft) | 1.0 | 3.0 | >3.3 |

At Typo Lake eighteen years of water quality monitoring have been conducted by the MPCA (1993, ’94, and ’95) and the Anoka Conservation District (1997-2001, ‘03, ‘05, ‘07, ‘09, ’12, 2014-2018). Overall, water quality has improved from 1993 to 2018 in a statistically significant way (repeated measures MANOVA with response variables TP, Cl-a, and Secchi depth; $F_{2, 15}=5.6$, $p=0.02$). When we tested these response variables individually with one-way ANOVAs, TP and Secchi depth still show no significant change across this time period. Cl-a, however, is showing a statistically significant decline ($p=0.001$). A superficial look at these parameters suggests that total phosphorus is generally stable between 150 µg/L and 250 µg/L (excluding high outlier years 2007 and 2009) without any sort of long-term trend. Secchi transparency in recent years is similar to averages from the early 1990s, an improvement from the late 1990s-2010. The major driver of improved water quality is decreasing Cl-a concentrations.

At Martin Lake eighteen years of water quality data have been collected by the MPCA (1983), Metropolitan Council (1998, 2008), and the ACD (1997, 1999-2001, 2003, 2005, 2007, 2009, 2012-2018). Citizens monitored Secchi transparency 17 other years. Anecdotal notes from DNR fisheries data indicate poor water quality dating back to at least 1954. Although still pretty poor, water quality in Martin Lake has shown an improvement from 1983 to 2018 that is statistically significant (repeated measures MANOVA with response variables TP, Cl-a, and Secchi depth; $F_{2, 14}=5.33$, $p <0.05$). This is especially true for the last decade. Further examination of the data shows that while TP and Secchi transparency have not changed in the long-term since 1983, chlorophyll-a has shown a statistical decrease ($p <0.01$) over this time. Water quality in Martin Lake declined through the late 1990’s and reached its worst in 2007. In nine years sampled since 2007, all three parameters have improved on a statistically significant basis (TP $p <0.01$, Cl-a $p <0.05$, Secchi $p <0.01$).

At both lakes, water quality improvements appear driven by projects since 2015. Those projects have included stormwater treatment retrofits and carp management. At Martin Lake 2016, 2017 and 2018 all had new record low average total phosphorus concentrations. At Typo Lake 2018 was a record low phosphorus.

***Figure 4 – Typo Lake historic water quality.*** *TP = total phosphorus. Cl-a = Chlorophyll-a. Secchi = transparency.*

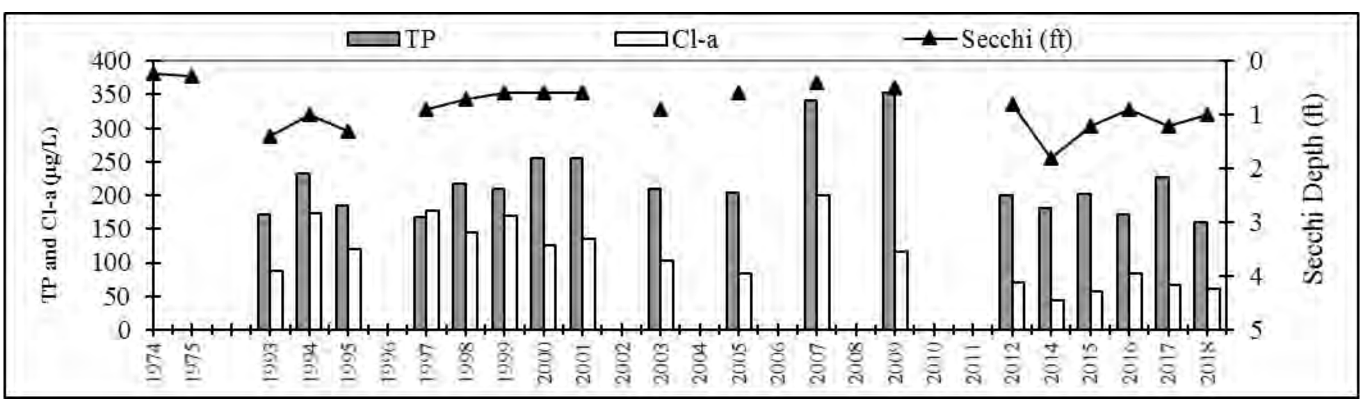
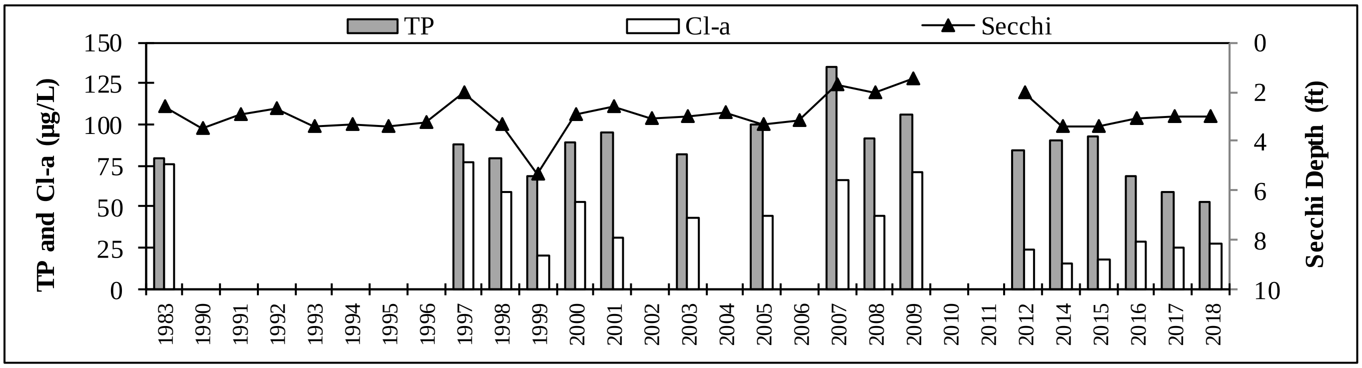


***Figure 5 – Martin Lake historic water quality.*** *TP = total phosphorus. Cl-a = Chlorophyll-a. Secchi = transparency.*




## Phosphorus Loading Sources and Reductions Needed

A total maximum daily load (TMDL) study of Martin and Typo Lakes and the creek connecting the lakes, was begun in 2009 and finalized in 2012. That study focused upon determining phosphorus sources and reductions needed. It included monitoring, modeling and professional judgement. It also recommended management approaches. It found that large pollutant reductions are needed at both lakes, those reductions are most likely to be feasible in Martin Lake, and work at both lakes is needed to achieve goals in either lake or downstream priority waterbodies.

Typo Lake is severely impaired. It is nearly always starkly brown with clarity under 1.5 feet. 81% phosphorus reductions are needed. By far the largest phosphorus sources are common carp, internal sediments and ditched wetlands upstream. Recent monitoring has found that the upstream ditched wetlands are less of a source of phosphorus than previously thought, leaving in-lake sources as the management focus. The management goals for Typo Lake, at least on 10-20 year timelines, is to reduce the severity of the impairment to a degree that delisting of downstream impairments is possible.

***Figure 6 –*** *Typo Lake watershed phosphorus source summary. From Martin and Typo Lakes TMDL study, 2012).*

| Phosphorus Source | Annual TP Load (lb/yr) | Area (ac) | Areal Load (lb/ac-yr)[1] | Percent of External TP Load (%) |
|---|---|---|---|---|
| Direct Watershed Runoff | 7,550 | 11,000 | 0.69 | 99.5% |
| SSTS | 38 | n/a | n/a | 0.5% |
| **Total** | **7,588** | **11,000** | **n/a** | **100.0%** |

[1] Annual TP load (lb/yr) divided by drainage area (ac)

Martin Lake is moderately impaired. It has periods of intense algae blooms in summer. Clarity averages 3 feet. 41% phosphorus reductions are needed. The largest phosphorus source is water from Typo Lake. The other important phosphorus sources appear to be the common carp, internal sediments, stormwater direct drainage, lakeshore erosion and shoreland septic systems.

***Figure 7 –*** *Typo Lake watershed phosphorus source summary. From Martin and Typo Lakes TMDL study, 2012).*

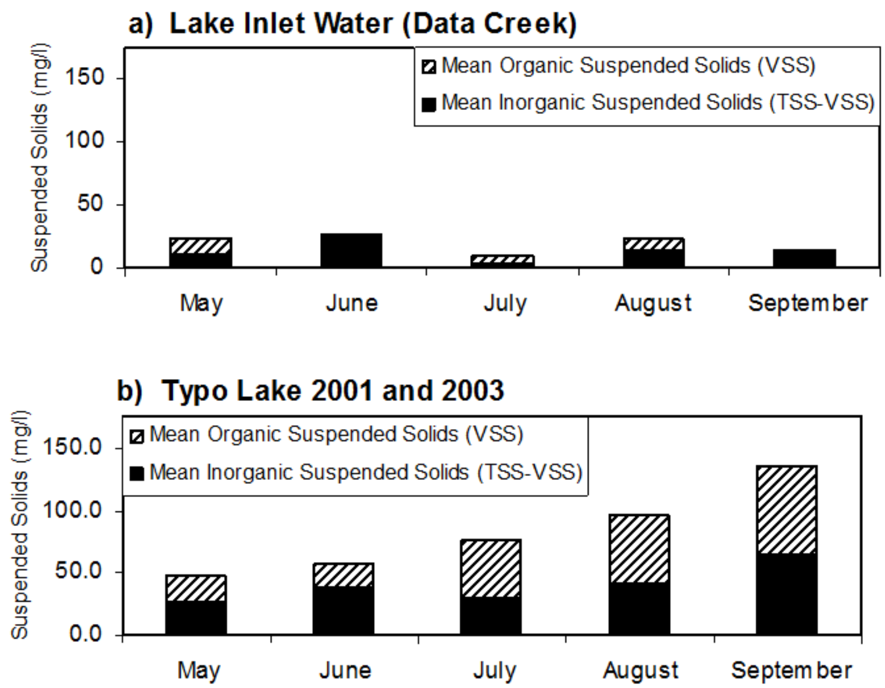
| Phosphorus Source | Annual TP Load (lb/yr) | Area (ac) | Average Areal Load (lb/ac-yr)[1] | Percent of Watershed TP Load (%) |
|---|---|---|---|---|
| Direct Watershed Runoff | 1,790 | 4,832 | 0.37 | 25% |
| SSTS | 164 | n/a | n/a | 2.3% |
| Upstream Lake Loading (Typo Lake)[2] | 4,787 | 11,290 | 0.42 | 67% |
| Upstream Lake Loading (Island Lake)[2] | 408 | 7,486 | 0.054 | 5.7% |
| **Total** | **7,149** | **23,608** | **n/a** | **100%** |

[1] Annual TP load (lb/yr) divided by drainage area (ac)
[2] Calculations are from lake outlet; includes lake area and drainage area

The phosphorus source summaries above are for *watershed* sources. The TMDL models do a poor job of quantifying internal phosphorus sources. The models estimated internal loading was 11% of the total phosphorus in Typo Lake, and no internal loading component was quantified in Martin Lake. This is because the TMDL models have no explicit internal loading component. Rather, it was assumed that any phosphorus not explained by the models is internal loading. Recognizing this, the TMDL authors explicitly state that the "actual internal load may represent…more of the total load to the lake, and evidence suggests this is the case."

Monitoring data does a better job of explaining the magnitude of internal loading that is occurring in these lakes. At Typo Lake paired measurements of total suspended solids (TSS) and volatile suspended solids (VSS) were taken in Typo Creek (Figure 8). Suspended solids in the lake are four times greater than in the lake inlet stream. Both algal (VSS) and inorganic (TSS-VSS) components were substantially greater in the lake. In other words, the lake's water quality is multi-fold poorer than water entering the lake. Internal lake processes are a large part of the water quality problem.

***Figure 8*** *– Comparison of suspended solids in Typo Lake's inlet and Typo Lake. From Martin and Typo Lakes TMDL study, 2012).*




Fisheries surveys provide further insight into the role of rough fish in internal pollutant loading. The TMDL study examined DNR fisheries surveys and found that in Typo Lake black bullheads were 68% of fish biomass in 1999 and about half that much in 2004. At Martin Lake carp and black bullheads were 37% of biomass in 1999 and 18% in 2004.

More recent fisheries data also found abundant rough fish. DNR fisheries surveys have not been analyzed, but electrofishing carp surveys have been done in 2017. Those surveys estimated 15,300 carp in Typo Lake and 13,409 in Martin Lake. These preliminary estimates placed carp biomass at 384 kg/ha in Typo Lake and 408 kg/ha at Martin Lake. Mark-recapture studies in 2017-2019 further narrowed down those estimates to 334 kg/ha in Typo Lake and 507 kg/ha in Martin Lake. This is substantially greater than the 100 kg/ha above which carp have been found to be detrimental to lake health or the 200 kg/ha above which almost no rooted vegetation survives in a lake (Bajer et al. 2018).

## History of Water Quality Projects

The TMDL study provided a work prioritization for improving these lakes, which is presented below. Following each management priority is a description of recent work completed and upcoming work in the Sunrise River Watershed Management Organization's plan. Both lakes began a trend of statistically improving water quality in about 2015 when these projects launched.

<u>TMDL Priorities and Projects Accomplished or Upcoming:</u>

1. **Direct drainage to Typo Lake (Data Creek)**
    - **2018 - A feasibility study of restoring ditched wetlands** was completed. While landowners were not willing to proceed at that time, the Sunrise River Watershed Management Organization will re-approach them every two years.
    - **2018 - Additional water monitoring** was conducted and found this area had much lower phosphorus concentrations compared to the TMDL study findings, and therefore this project type has become a lower priority.

2. **Typo Lake internal loading**
    - **2014-2016 - Carp barriers** were constructed at four strategic locations throughout Martin and Typo Lakes. The purpose was to prevent seasonal migrations between deeper Martin Lake where carp could most successfully overwinter and shallower Typo Lake and other waters where carp could most successfully spawn.
    - **2017-2019 – Carp management feasibly study**. The feasibility study included population surveys, aging, surveys of spawning areas, radio telemetry, modeling, and this report of findings.
    - **2017-2019 - Carp removals using box netting**. As of August 2019, 36.9% of carp have been removed from Typo Lake and 37.6% removed from Martin Lake. Preliminarily the study found 74% and 75.5% carp removals were needed from each lake to reach 100 kg/ha carp biomass goals.
    - **Upcoming** – Continued carp management in Martin and Typo Lakes to the goals stated above. This work is dependent upon grant funding, but local matching funds are already committed.
3. **SSTS's around Martin Lake**
    - **2018-ongoing – Grants to repair noncompliant septic systems** were begun county-wide, with special outreach to Martin Lake residents. In 2018 one septic system in the Martin Lake shoreland zone was replaced. The Sunrise River
    - **2018-2019 - Enhanced township outreach and enforcement** has begun under the leadership of the building inspector, who has special expertise in designing septic system solutions for difficult locations.
    - **Upcoming in 2022 – Additional regulatory triggers** to identify and update failing septic systems will be pursued by the Sunrise River Watershed Management Organization and its member communities. Specifically, funding to develop point of sale inspections will be pursued.
4. **Direct drainage to Martin lake**

- **2012 – Subwatershed retrofit study** was completed that identified opportunities to improve stormwater runoff treatment, and ranked those opportunities by cost effectiveness.
- **2012 – Installed three stormwater retrofits** that reduced phosphorus loading to the lake by 1.9 lbs/year and solids by 603 lbs/year.
- **Upcoming 2019-2020 – Install two stormwater retrofits** (redesign and rehabilitation of existing stormwater basins) that will reduce phosphorus loading to the lake by 1.6 lbs/year and solids by 622 lbs/year.

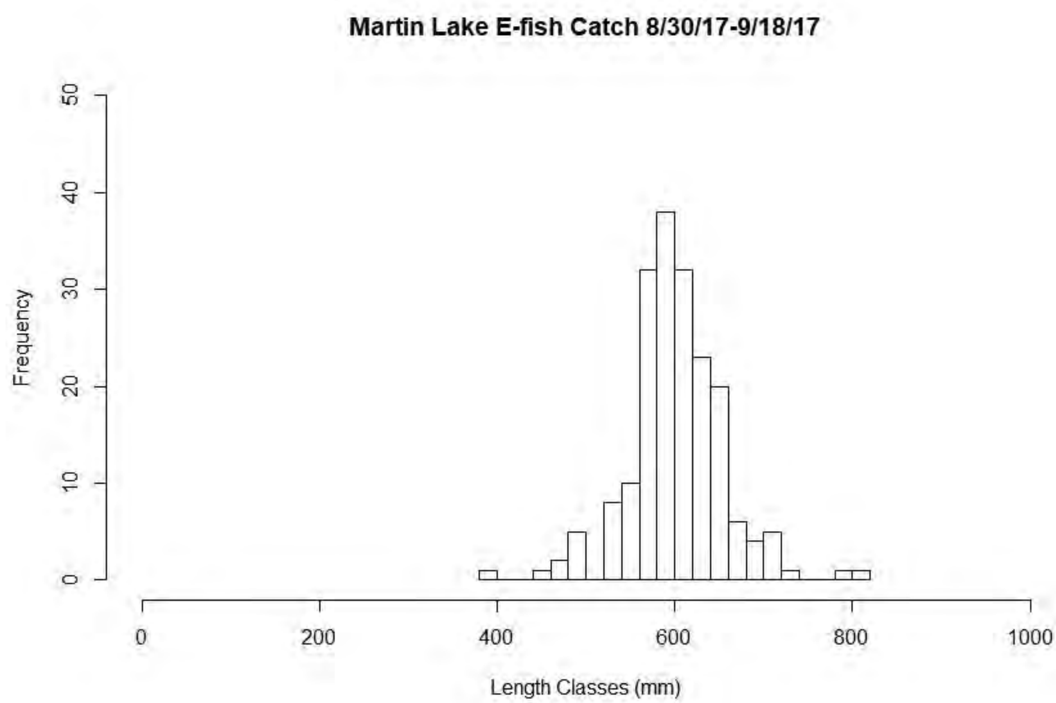
**5. Others**

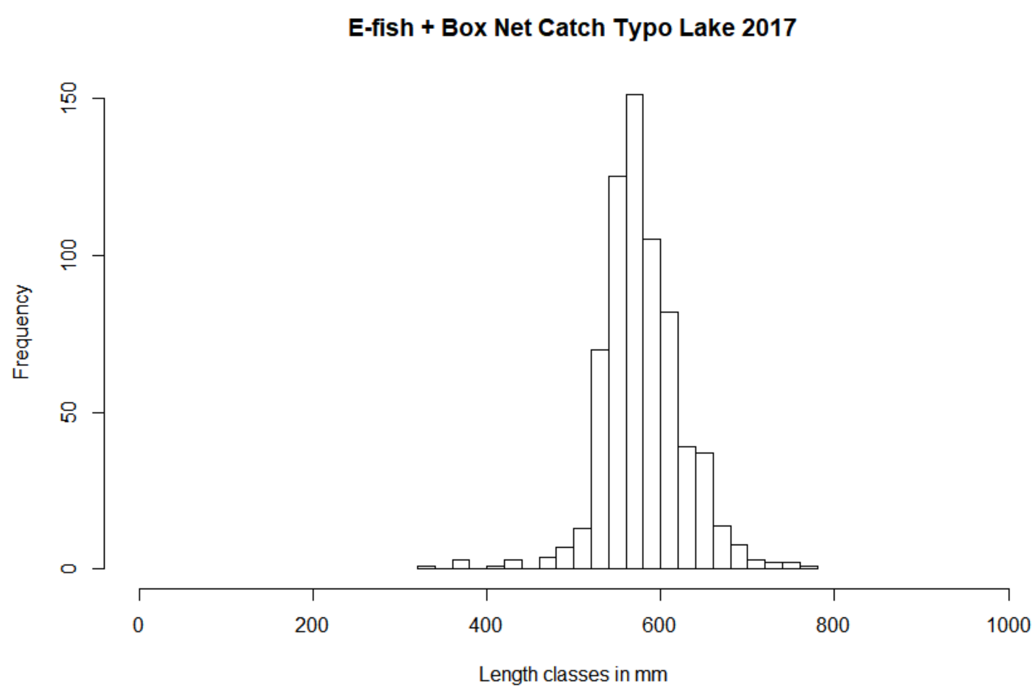
- **2012-Ongoing** – Three lakeshore restorations using bioengineering techniques have been completed to correct shore erosion.
- **2022 and beyond – A new incentive program** will be created for lakeshore restorations, to be run as a collaborative between the lake association and Sunrise River Watershed Management Organization.
- **2012-Ongoing – Outreach and education** including direct communications with residents about management of their own property.
- **2025-2026- Demonstration projects** on Anoka County Parks property adjacent to the lake.

## Carp Population Assessment

The abundance, biomass and size structure of carp populations in Lake Typo and Martin were assessed during 2017-2019. Three boat electrofishing surveys were performed in each lake during August and September 2017. All carp were counted and measured for length (mm). Mean catch per hour was calculated to provide preliminary biomass estimate (Bajer and Sorensen 2012). Catch rates of carp in electrofishing surveys were relatively high in both lakes. Mean catch per hour was 22.0 in Typo and 29.6 in Martin. Both populations were dominated by relatively large carp (~400 mm to 800 mm; Figure 9). Mean length was 580 mm (2.8 kg) in Typo and 601 mm (2.9 kg) in Martin. Observed catch rates suggested that the biomass in both lakes significantly exceeded 100 kg/ha, which is considered a benchmark value for shallow lake restoration (Bajer et al. 2008). Based on electrofishing surveys and subsequent mark-recapture studies, the estimated biomass in Typo Lake was 334 kg/ha and in Martin Lake 507 kg/ha.

**Figure 9. Length structure of common carp in lakes Martin and Typo in 2017.**



We corroborated our biomass estimates by conducting mark-recapture analyses, in combination with assessing the feasibility of box-netting to remove carp from both lakes.

In Typo Lake, we installed three box nets in the summer of 2017. Each box net was 30' x 60'. The nets were baited with cracked corn for several days and lifted at night to catch carp that aggregate at the bait. Overall, nets were lifted on six occasions catching a total of 2,658 adult carp. 200 of these fish were clipped with fin clips and released back to the lake, to allow for mark-recapture estimate in 2018. In 2018, we installed 4 box nets in Typo and lifted them on five different occasions in the summer and fall. Overall, we captured 3,523 adult carp, including 45 of the ones marked and released in 2017. Mark recapture analyses (45 of 200 carp recaptured among 3,523 captured) suggested that in 2017, Typo was inhabited by 15,397 carp. Over the two years, we removed 6,181 carp, or 40.1% of the initial population. The initial biomass of carp in 2017 was 334 kg/ha and it was reduced to 200 kg/ha at the end of 2018.

In Martin Lake, we installed 4 box nets in the fall of 2018. The nets were lifted on two occasions catching a total of 3,184 carp, which were removed from the lake. In 2019, we installed 5 box nets in late spring. At that time, we also marked and released 158 carp. Those carp were captured throughout the lake using with boat electrofishing to randomly distribute marked individuals within the population. To date, the box nets were lifted on three occasions in 2019 catching a total of 1,685 carp, including 20 of the marked carp. These recapture rates suggested that Martin Lake was inhabited by 13,312 carp in the spring of 2019, and 16,469 carp in the fall of 2018. Biomass of carp in Lake Martin was reduced from 507 kg/ha in the fall of 2018 to 357 kg/ha in August 2019 (the removal is ongoing).

**Table 2. Summary of Carp removal with Box Nets in Lakes Typo and Martin.**

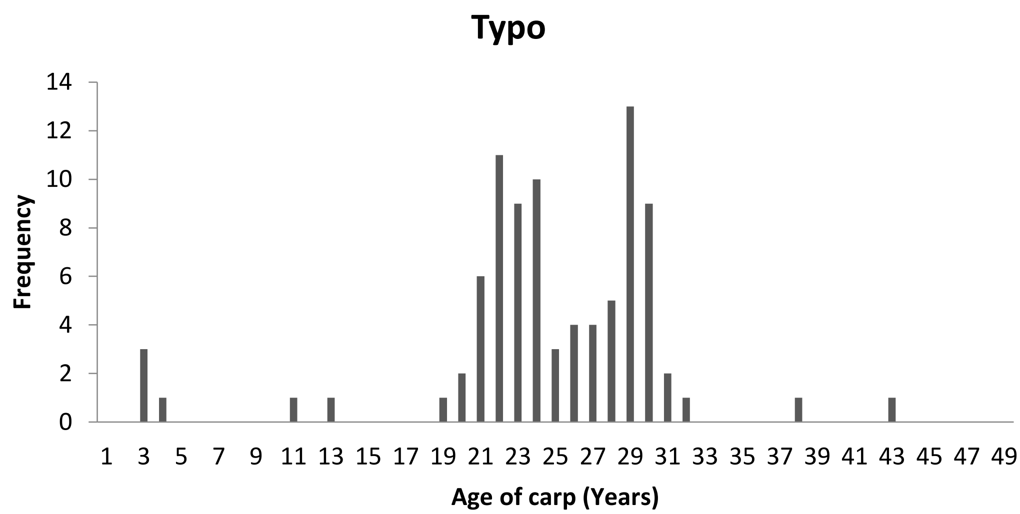
| Lake | Year | N (in lake) | N (caught and removed) | % Removed |
|---|---|---|---|---|
| Typo | 2017 | 15,397 | 2,658 | 17.3% |
| Typo | 2018 | 12,739 | 3,523 | 27.6% |
| Martin | 2018 | 16,469 | 3,184 | 19.3% |
| Martin | 2019 | 13,312 | 1,685 | 12.7% |

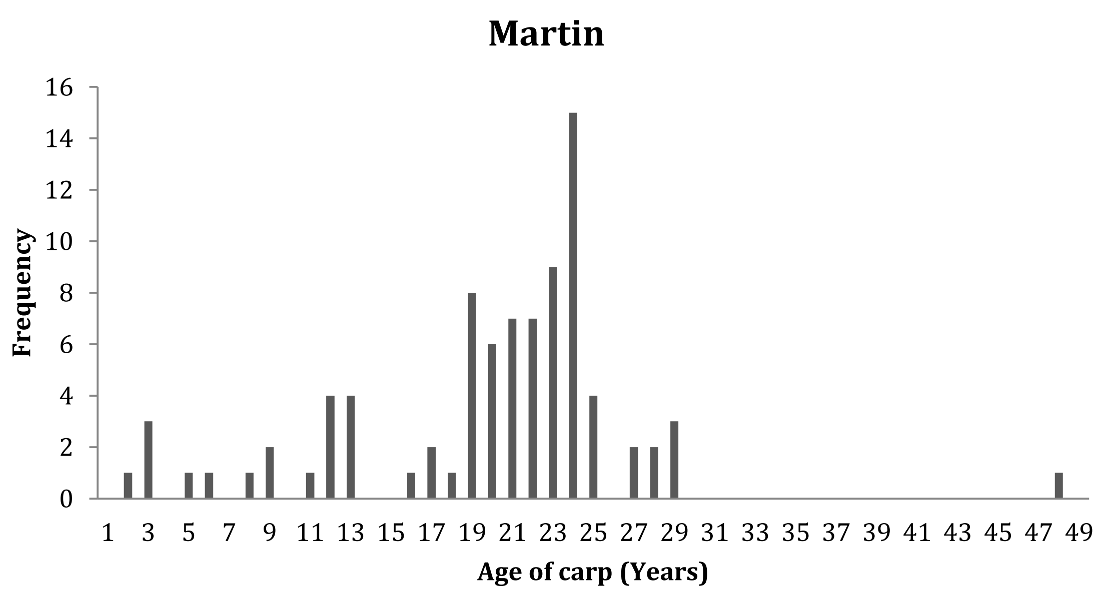
## Carp Ages and Recruitment History

One hundred carp collected from each lake during the 2017 boat electrofishing surveys were used for ageing analyses. The fish were euthanized, their asterisci otoliths were extracted, mounted in epoxy, sectioned on isomet saw and examined under a microscope.

The ageing analysis showed that the carp were relatively old. In Typo, the majority of carp were 19-33 years old with only 5% of the population being comprised of young 3 and 4-year old carp. The oldest carp in Typo was 43 years old. In Martin, most carp were between 11 and 29 years old, however, multiple age classes of carp between 2 and 9 years of age were also present in low abundance (Figure 10). Overall, ageing results suggest limited production of young carp in both lakes in the last decade.

**Figure 10. Age structure of common carp population in Typo (top) and Martin (bottom) lakes.**




## Nursery Area Identification

We used small mesh trap nets to survey for young-of-year (YOY) carp in Typo, Martin and surrounding waters such as the Sunrise River and Island Lake. The surveys were conducted on multiple days in summer and fall 2017 and 2018 as shown in Table 3. Five nets were used on each date and at each location. Overall, no YOY carp were captured at any location (Table 3).

This corroborates ageing analysis, which suggested that the population was dominated by relatively old individuals.

**Table 3. Results of trap net surveys.**

| Location | Year | Date | Species | Mean catch per trap net |
|---|---|---|---|---|
| SUNRISE | 2018 | 10/4/18 | BLB | 51.750000 |
| ISLAND | 2017 | 9/15/17 | BLB | 3.500000 |
| ISLAND | 2018 | 9/27/18 | BLB | 2.500000 |
| SUNRISE | 2018 | 10/4/18 | BLC | 1.750000 |
| TYPO | 2017 | 8/31/17 | BLC | 3.500000 |
| MARTIN | 2017 | 9/1/17 | BLC | 4.000000 |
| ISLAND | 2017 | 9/15/17 | BLC | 3.000000 |
| ISLAND | 2018 | 9/27/18 | BLC | 1.000000 |
| MARTIN | 2018 | 9/28/18 | BLC | 1.666667 |
| SUNRISE | 2018 | 10/4/18 | BLG | 10.800000 |
| TYPO | 2017 | 8/31/17 | BLG | 1.666667 |
| MARTIN | 2017 | 9/1/17 | BLG | 2.400000 |
| ISLAND | 2017 | 9/15/17 | BLG | 16.000000 |
| ISLAND | 2018 | 9/27/18 | BLG | 8.000000 |
| MARTIN | 2018 | 9/28/18 | BLG | 10.200000 |
| TYPO | 2017 | 8/31/17 | BOF | 1.000000 |
| MARTIN | 2017 | 9/1/17 | BOF | 1.000000 |
| MARTIN | 2018 | 9/28/18 | BRB | 1.000000 |
| MARTIN | 2017 | 9/1/17 | CAP (adult) | 1.000000 |
| SUNRISE | 2018 | 10/4/18 | GOS | 1.000000 |
| TYPO | 2017 | 8/31/17 | GSF | 2.000000 |
| MARTIN | 2017 | 9/1/17 | GSF | 1.000000 |
| ISLAND | 2018 | 9/27/18 | GSF | 3.000000 |

| Location | Year | Date | Species | Mean catch per trap net |
|---|---|---|---|---|
| MARTIN | 2018 | 9/28/18 | GSF | 2.000000 |
| SUNRISE | 2018 | 10/4/18 | LMB | 1.500000 |
| ISLAND | 2018 | 9/27/18 | LMB | 1.000000 |
| ISLAND | 2017 | 9/15/17 | NOP | 1.000000 |
| SUNRISE | 2018 | 10/4/18 | PMK | 1.000000 |
| ISLAND | 2017 | 9/15/17 | PMK | 1.000000 |
| ISLAND | 2018 | 9/27/18 | PMK | 1.000000 |
| TYPO | 2017 | 8/31/17 | SMB | 1.000000 |
| MARTIN | 2018 | 9/28/18 | STS | 3.000000 |
| ISLAND | 2018 | 9/27/18 | WAE | 1.000000 |
| TYPO | 2017 | 8/31/17 | WAL | 1.000000 |
| TYPO | 2017 | 8/31/17 | WHC | 3.500000 |
| MARTIN | 2017 | 9/1/17 | WHC | 2.000000 |
| MARTIN | 2018 | 9/28/18 | WHC | 2.000000 |
| SUNRISE | 2018 | 10/4/18 | WHS | 1.000000 |
| SUNRISE | 2018 | 10/4/18 | YEB | 24.333333 |
| TYPO | 2017 | 8/31/17 | YEB | 1.000000 |
| MARTIN | 2017 | 9/1/17 | YEB | 1.000000 |
| ISLAND | 2017 | 9/15/17 | YEB | 1.000000 |
| ISLAND | 2018 | 9/27/18 | YEB | 3.500000 |
| MARTIN | 2018 | 9/28/18 | YEB | 2.250000 |
| SUNRISE | 2018 | 10/4/18 | YEP | 1.000000 |

## Carp Movements and Tracking

Telemetry was conducted to document movement of carp between the two lakes and to determine areas of winter aggregations that could be potentially targeted with winter seining by commercial fishermen. Twenty adult common carp were implanted with radiotransmitters in Typo and another 20 in Martin in the fall of 2017 (Figure 11).

**Figure 11. Implanting a radio-transmitter in carp.**

Telemetry surveys were conducted between October 2017 and May 2019. Relatively loose winter aggregations were found. No tagged carp migrated between lakes Typo and Martin. The man-made physical barriers separating the two lakes appear effective.

## Waterbody Interconnectedness and Barriers

Martin and Typo Lakes are part of an interconnected hydrologic system that should be managed as one (Figure 1). That system includes Martin and Typo Lakes and their connecting creek. It also includes Island and Linwood Lakes and the downstream waters of the West Branch of the Sunrise River.

Martin and Typo Lakes are connected by approximately two stream miles of Typo Creek. That creek is likely an important path by which carp can move between the shallow waters of Typo Lake for spawning and the deeper waters of Martin Lake for overwintering. Moreover, the creek is shallow with a mucky bottom, and offers further spawning habitat.

The four mechanical carp barriers currently in place around these lakes. Locations are shown in Figure 1. Purposes of the barriers are to:

- Prevent movements between overwintering and spawning habitats to lower overall survival and spawning.
- Allow more effective carp population reductions by compartmentalizing the populations.
- Prevent recolonization of locations where carp reduction goals are met.

Barriers are owned and operated by Linwood Township. The barriers consist of either removable screens with horizontal bars spaced at 1.5 inches (northern two barriers) or permanently attached vertical bars with 1.5 inch spacing. The screens are removed during the periods when ice forms, and in a way that attempts to allow early spring spawning northern pike to pass.

## Carp Management to Date

Carp management at these lakes has been a priority at these lakes for decades. Brief, seemingly successful, attempts have been made. Only recently has carp management begun in a sustained, intense way that is backed by scientific methodologies. The lakes are responding with improving water quality.

MN DNR Fisheries records, which begin in the 1940's, were reviewed in 2010 to assemble a brief history of rough fish management at these lakes in the TMDL report. After that period, this report's authors have led carp management at these lakes and provided a summary of management.

Brief History of Carp Management at Martin and Typo Lakes

- **1940's –** MN DNR removed about 10,000 bullheads and 15,000 carp from Martin Lake.
- **1970's –** Martin Lake hoop netting of bullheads.
- **1974 and 1984** – Martin Lake fish winter kill. Prompts installation of aeration system in 1993.
- **1978 –** MN DNR found black bullhead abundance was about 22 times greater than other species except common carp and black crappie which were 14 and 10 times more abundant than any other species, respectively.
- **1987 –** Rough fish removal. Method and results unknown.
- **1993 –** Regular Typo Lake water quality monitoring begins. Martin Lake aeration system installed to prevent game fish winter kills.
- **1997** – Regular Martin Lake water quality monitoring begins.
- **1998 and 1999 – Successful winter Martin Lake commercial carp seining** removes perhaps thousands of carp. this amount is not confirmed, and is based on the fisherman's recollection 15 years later). In 1999 clar
- **Approximately 1970's or 1980's** – Carp trap in place at the outlet of Typo Lake. Believed to have been managed by the MN DNR. Residents report is caught "lots" of carp and suggested movement between the lakes was common.
- **1998-1999** – Martin Lake commercial carp harvest. The commercial fisherman recollected 15 years later that he caught about 200,000 pounds, however that amount is not verified. Lake clarity improved briefly from 2-3 feet in previous years to 5.3 feet in 1999.
- **2005 or 2006** – Martin Lake commercial carp removal attempt. About 6,000 pounds were removed according to the commercial fisherman's recollection.
- **2008** – Bullheads hoop netted at Martin Lake. Few bullheads were captured, but incidental capture of carp was relatively high, suggesting a large carp population.
- **2014-2016 – Four carp barriers** were constructed.
- **2017-2019 – Carp management feasibly study**. The feasibility study included population surveys, aging, surveys of spawning areas, radio telemetry, modeling, and this report of findings.

- **2017** – Typo Lake box netting.  2,322 carp removed.
- **2018** – Typo Lake box netting.  3,552 carp removed.  Martin Lake box netting. 3,369 carp removed.
- **2019** – Martin Lake box netting. 1,680 carp removed and more harvests planned. Typo Lake box netting planned but not yet started.

## Measures of Carp Management Success

Several measures of success can be used to evaluate  carp management from 2014 to August 2019 at Martin and Typo Lakes, including:

1. **Carp removals toward goals**
   Carp management goals of 100 kg/ha carp biomass were preliminarily established for these lakes based on Bajer 2018.  This is the density at which carp impacts on lakes generally become detrimental to lake health.  Table 4 below compared carp biomass in the lakes before carp removals began to present biomass.

***Table 4-*** *Carp biomass and progress toward goals.*

| Lake | 2017 Carp Biomass Est (kg/ha) | Goal (kg/ha)* | Biomass Reduction Needed | Reduction Achieved as of Aug. 7, 2019 |
|---|---|---|---|---|
| Typo Lake | 384 | 100 | 74.0% | **36.9%** |
| Martin Lake | 408 | 100 | 75.5% | **37.6%** |

*Goal is based on Bajer 2018, the biomass at which carp impacts on lakes generally become detrimental.

2. **Number of radio tracked fish that have crossed the carp barriers**
   Twenty carp were implanted with radio telemetry in 2017.  None have crossed the carp barriers, suggesting the carp barriers have been effective.

3. **Lake water quality**
   Water quality, as measured by total phosphorus, chlorophyll-a and Secchi transparency is statistically improving (see the water quality portion of this report for more detail). 2016, 2017 and 2018 have each been new record low summertime average phosphorus concentrations in Martin Lake.  2018 was a record low in Typo Lake.

4. **Habitat and vegetative improvements**
   A critical goal is habitat and vegetative improvements.  Unfortunately, no lake vegetation surveys were done prior to carp management by the DNR or anyone else. Therefore, no effective measurement of success exists.  Vegetative surveys are among the management recommendations in this report.

5. **Community and political support**

The community is strongly behind carp management, and it has been a springboard to pollutant reduction projects throughout the watershed. Linwood Township owns and operates the carp barriers, and is a significant financial contributor through the Sunrise River Watershed Management Organization (SRWMO). The Township has also provided staffing and equipment for carp harvests. Additionally, the Martin Lakers Association and SRWMO are strong partners financially, contributing over $40,000.

6. **Volunteer support**
   Approximately 15 citizen volunteers have contributed more than 400 hours so far toward carp harvests. Countless other hours have been contributed during planning, securing funds and rallying political support. The Martin Lakers Association and residents at Typo Lake have contributed the vast majority of these hours.

## Carp Management Recommendations

The goal is to reduce carp biomass below 100 kg/ha in Typo and Martin. This should allow for recovery of aquatic macrophytes and switching shallow lakes to a clear water state. To date, we have reduced carp biomass from 334 kg/ha to 200 kg/ha in Typo Lake and from 507 kg/ha to 357 kg/ha in Martin.The removal is ongoing.

Available methods to remove adult carp include:
**1) Baited box nets** that remove carp in the summer (used in 2017, 2018 and 2019). This method uses volunteers to engage local community and reduce cost. Baited box nets exploit the fact that carp can be selectively trained with food and removed. Native fish bycatch is <1%. The nets are not impacted by debris on the bottom. Recent advancements in this method include the use of PIT tags to precisely monitor carp social behaviors and the presence of carp at the bait to remove them when aggregations peak.
**2) Commercial seines** that can be pulled under the ice. This method is augmented by telemetry to locate winter aggregations of carp.
**3) Use of stream traps and electric guidance systems** to remove carp during spawning migrations. One such method is being pioneered in Rice Creek (Bajer et al. 2018).

While all three options remain on the table, we will focus primarily on box netting because this method has been shown to be relatively effective and easy to coordinate. Further, using this method we can employ volunteers who help with baiting the nets, which will substantially reduce the cost. However, we will modify the use of box nets using data on carp behavior we collected in 2017 -2019. Instead of using 2-3 nets and running them multiple times through the season, we will use more nets and use them less frequently. This should increase catch rates and increase cost effectiveness. The other two methods will be used opportunistically as conditions allow. The use of stream traps might be especially feasible if ongoing pilot projects in Rice Creek (U of M) result in an implementable technology.

Management methods to reduce carp recruitment include winter aeration to prevent winterkills to maintain abundant populations of native gamefish that forage on carp larvae and eggs (occurring at Martin Lake), and barriers to isolate nursery sites (occurring at Martin and Typo Lakes). Unlike removal of adults, prevention of carp recruitment is not always feasible. In such cases, removal of adults needs to be especially aggressive and systematic.

We expect that reaching management goals via removal of adult carp can be accomplished within two years using box nets and/or commercial seining. Suppression of recruitment is difficult to assess at this point because no recruitment has been observed in recent years. We will monitor if recruitment increases in response to adult removal. So far, this has not happened. If recruitment occurs, removal of carp will need to resume to bring the population back below the threshold of 100 kg/ha.

Routine carp population assessments can be accomplished quickly by using boat electrofishing. This method allows for relatively accurate low-effort estimate of carp biomass and size structure. We recommend electrofishing surveys annually.

## Cost-Benefit Analysis of Water Quality Improvement Options

A number of projects that could improve lake water quality have been scrutinized through subwatershed assessment studies or feasibility studies. Each provides an estimate of the phosphorus reductions the project would achieve, costs, and overall cost-effectiveness. Additionally, we have used the best available information to create similar estimates for carp management. Table 5 provides a complete listing to date of the cost effectiveness of various management options.

Interpreting the list of potential projects requires recognizing:

- Projects from different studies were examined with different models.
- The wetland restoration projects have the lowest cost per pound of phosphorus removed, but the uncertainty of these outcomes is much lower. In fact, these projects may increase phosphorus due to wetland hydrology and complex soil chemistry.
- Calculating the pollutant reductions achieved by carp management is new and includes considerations of the phosphorus content of the carp themselves, direct effects of carp through sediment disturbance, indirect effects of carp removing vegetation or displacing native fish, and more.

It's noteworthy that the projects in Table 5 only consider pollutant reductions to the lake that the project area directly drains into. Benefits to other downstream waterbodies, habitat restoration and other secondary benefits should also be considered. Managers may wish to more favorably consider projects that:

- Benefit Typo Lake, thereby also providing benefits to downstream waters which most immediately include Martin Lake.
- Benefit the whole chain of lakes at once, as carp management does.
- Benefit habitat.

**We calculated pollutant reductions and cost effectiveness for carp management as follows.**

Carp management can achieve direct and indirect phosphorus removals. Direct removals are the phosphorus contained within carp that are removed from the lake. 0.05% of carp biomass is phosphorus. So, if remove 11,000 carp weighing 6.5 lbs each are removed, then we are directly reducing phosphorus by 35.75 lbs.

Indirect phosphorus removals and positive feedbacks are larger than direct benefits. By removing carp we remove phosphorus introduced into the water column by their feeding, spawning and defecating. Moreover, carp removal allows greater macrophyte establishment which has positive feedbacks within the lake such as reducing wind disturbance, providing refugia for zooplankton that eat algae, providing spawning & hiding habitat game fish, & providing waterfowl habitat. All of these multiply the phosphorus reduction.

The science on calculating indirect phosphorus reductions from carp management is developing. For the purpose of this report, we are providing the best estimate currently available. We expect the estimate will be refined in the future.

In other waterbodies where carp management has occurred with a science-based approach all the way to a goal of 100 kg/ha, phosphorus concentrations have reduced by up to 30-50% (

Table **7**). The TMDL for Typo Lake estimated internal loading was only 11% and was minimal in Martin Lake, however the authors of the TMDLs caution that their models were poor at estimating internal loading and field measurements supported their assertion that is it larger. Using a modest 15% internal loading, and assuming carp management might reduce it by half (based on Table 7) we might expect phosphorus reductions of 541 lbs/yr in Martin Lake and 650 lbs/yr in Typo Lake. Assuming a 10-year duration of benefits, reductions are 5,410 at Typo Lake and 6,500 lb P at Martin Lake for a total of 11,910 lbs of phosphorus. Martin and Typo Lake are responding to carp management with reduced phosphorus concentrations so far, an observation that lends confidence to the rather large phosphorus reduction estimates presented here.

The cost of removing carp from 2015 levels to 100 kg/ha is approximated at $180,000 (some of which has already been spent and achieved). Dividing this cost by the estimated phosphorus reduction, cost per pound of phosphorus removed is $15.11. This is exceptionally low. Watershed projects under $500/lb phosphorus are considered highly cost effective.

***Table 5*** *– Comparison of cost effectiveness of water quality improvement options.*

| ID | Description | Location | **TP Reduction** (lb/yr) | **TSS Reduction** (lb/yr) | **Volume Reduction** (ac-ft/yr) | **Estimated Cost** inc. 30-yr maintenance | **Estimated cost/lb-TP/year** (30-year) | **Info source***** | **Certainty of TP reductions** |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Wetland restoration - Ditch 20 public ditch block without bypass* | 2A – see Figure 12 | 114.57 | | | $50,391 | $14.66 | a | Low-Mod |
| 2 | Reduce carp biomass to 100 kg/ha (89 lbs/ac) | In both Martin and Typo Lakes | 2,382 | NA | 0 | $180,000 (10 yr) | $15.11 | c | High |
| 3 | Wetland restoration - Ditch 20 lateral ditch block without bypass* | 1B – see Figure 12 | 103.62 | | | $48,887 | $15.73 | a | Low-Mod |
| 4 | Wetland restoration - Ditch 20 lateral ditch block without bypass* | 1C – see Figure 12 | 86.96 | | | $48,887 | $18.74 | a | Low-Mod |
| 5 | Wetland restoration - Ditch 20 lateral ditch block with bypass* | 1B – see Figure 12 | 103.62 | | | $75,903 | $24.42 | a | Low |
| 6 | Wetland restoration - Ditch 20 lateral ditch block with bypass* | 1C – see Figure 12 | 86.96 | | | $71,899 | $27.56 | a | Low |
| 7 | Wetland restoration - Ditch 20 public ditch block with bypass* | 2A – see Figure 12 | 114.57 | | | $131,241 | $38.18 | a | Low |
| 8 | Settling pond in line with public ditch* | 3A – see Figure 12 | 117.58 | | | $213,047 | $60.40 | a | Mod |
| 9✓ | Pond reconstruct | East of 228th Pl. NE and W Martin Lake Dr. intersection | 1.1 | 435 | 0.0 | $3,930 - $5,990 | $245 - $374 | b | High |

| ID | Description | Location | TP Reduction (lb/yr) | TSS Reduction (lb/yr) | Volume Reduction (ac-ft/yr) | Estimated Cost inc. 30-yr maintenance | Estimated cost/lb-TP/year (30-year) | Info source* ** | Certainty of TP reductions |
|---|---|---|---|---|---|---|---|---|---|
| 10✓ | Pond reconstruct | East of 230th Ave. and W Martin Lake Dr. intersection | 0.5 | 187 | 0.0 | $2,696 - $3,940 | $385 - $563 | b | High |
| 11✓✓ | Curb-cut rain garden | 22529 W Martin Lake Dr. | 0.7 | 225 | 0.4 | $6,460 | $437 | b | High |
| 12✓✓ | Curb-cut rain garden | 22514 W Martin Lake Dr. | 0.6 | 215 | 0.4 | $6,460 | $458 | b | High |
| 3 | Curb-cut rain garden | 23003 W Martin Lake Dr. | 0.5 | 156 | 0.4 | $6,460 | $570 | b | High |
| 14✓✓ | Curb-cut rain garden | 22908 W Martin Lake Dr. | 0.8 | 235 | 0.6 | $10,960 | $577 | b | High |
| 15 | Curb-cut rain garden | 22964 W Martin Lake Dr. | 0.5 | 144 | 0.4 | $6,460 | $616 | b | High |
| 16 | Curb-cut rain garden | Public parcel between 228th Pl. NE and 229th Ave. NE | 0.5 | 141 | 0.4 | $6,460 | $638 | b | High |
| 17 | Curb-cut rain garden | 23154 E Martin Lake Dr. | 0.3 | 103 | 0.2 | $6,460 | $882 | b | High |
| 18 | Curb-cut rain garden | 23136 E Martin Lake Dr. | 0.3 | 78 | 0.2 | $6,460 | $1,159 | b | High |
| 19 | Curb-cut rain garden | 23140 W Martin Lake Dr. | 0.2 | 75 | 0.2 | $6,460 | $1,200 | b | High |
| 20 | Biofiltration swale | Public parcel N of 23131 W Martin Lake Dr. | 0.2 | 67 | 0.2 | $6,460 | $1,358 | b | High |
| 21✓ | Vacuum assisted street sweeping (1 spring/1 fall) | Catchments ML-1, ML-2, ML-3, ML-4, ML-5, and ML-6 | 1.8 | 803 | 0.0 | $2570/year | $1,390 | b | High |

| ID | Description | Location | TP Reduction (lb/yr) | TSS Reduction (lb/yr) | Volume Reduction (ac-ft/yr) | Estimated Cost inc. 30-yr maintenance | Estimated cost/lb-TP/year (30-year) | Info source*** | Certainty of TP reductions |
|---|---|---|---|---|---|---|---|---|---|
| 22 | Biofiltration swale | Feather St. NE | 0.1 | 22 | 0.1 | $4,787 | $6,127 | b | High |
| 23** | Lakeshore restorations | Catchments ML-9, ML-10, and ML-11 | 0.2 - 0.6 | 26 - 77 | 0.05 - 0.14 | $63,710 - $186,510 | $13,992 - $14,271 | b | High |

✓ Indicates projects with secured funding to be installed by 2021.
✓✓ Indicates projects already installed. Additionally several lakeshore restorations have been completed.
* Project being actively pursued, but landowner not willing at this time.
**Three lakeshore restorations have been completed. More are being actively pursued.
***Information sources:

a. Anoka Conservation District. 2018. Ditch 20 Wetland Restoration and Feasiblity Study to Benefit Downstream Water Quality.
b. Anoka Conservation District . 2011. Martin Lake Stormwater Retrofit Assessment.
c. Dr. Przemek Bajer and Anoka Conservation District.

There is no conceivable way to reach TMDL goals at these lakes without carp management. Table 6 summarizes pollutant reductions that could be achieved it all of the projects in Table 5 are installed. Those projects, despite being the noted of highest importance in the TMDL management recommendations, fall far short of TMDL goals. Carp management, which is also a TMDL management recommendation, seems to be the only project type that creates large enough phosphorus reductions, plus has secondary benefits like improving in-lake macrophytes that further contribute to water quality and ecological improvements. Management is other lakes has similarly shown how critical carp management is to reaching water quality goals ( Table **7**).

***Table 6*** *– Comparison of pollutant reductions possible from all possible projects versus TMDL pollutant reduction goals.*

| Lake | Total Phosphorus Reductions if all Table 5 were installed, *excluding carp management** | Total Phosphorus Reductions from carp management | TMDL Phosphorus Reductions Needed |
|---|---|---|---|
| **Martin Lake** | 431.43 | 541 lbs/yr* | 2,973 lbs |
| **Typo Lake** | 422.73 | 650 lbs/yr | 7,041 lbs |

*Pollutant reductions listed for Martin Lake are only reductions within Martin Lake. In reality, reductions to Typo Lake should be added because Typo Lake provides pollutant loading to Martin Lake downstream.

***Table 7*** *- Mean concentrations of total phosphorus (May through October) before and after carp management. Carp were either eradicated using water drawdown, rotenone (ROT), or their abundance was reduced using physical removal.*

| Lake | Area (ha) | Max Depth (m) | TP before | TP after | Change |
|---|---|---|---|---|---|
| Casey[1] | <5 | <1 | 216.1 (22.03) | 117 (68.9) | -45.8% |
| Markham[1] | <5 | <1 | 148.2 (44.4) | 90.5 (6.4) | -38.9% |
| Kohlman Basin[1] | <5 | ~1.5 | 129.4 (28.1) | 84.8 | -34.5% |
| Ventura Marsh[2] | 76 | 0.8 | 391.0 | 276 | -29.4% |
| Pickerel[3] | 237 | 1.0 | 345.0 (42.1) | 99.8 (35.9) | -71.1% |
| Howard[4] | 172 | 1.6 | 117.9 (57.4) | 37.8 (13.4) | -67.9% |
| Managed Lakes[5] | -- | -- | 180.9 | 74.3 | -58.9% |
| Mean | | | | | -49.5% |

*[1]Bartodziej et al. in prep, [2] Schrage and Downing 2004, [3] Andy Schenkel, Shell Rock River Watershed District, unpublished, [4] Matt Kocian Rice Creek Watershed District, unpublished data, [5]Hanson et al. 2017*
*[1] represent mean values for eight shallow lakes in which benthic fishes were removed using toxins (rotenone) and/or water draw-downs and 19 turbid lakes (reference lakes) in which benthic fishes were not removed in southern Minnesota [11]. From Bajer et al. 2019 in preparation.*

***Figure 12*** *– Modeled wetland restoration water quality projects upstream of Typo Lake. From the 2018 study by the Anoka Conservation District entitled "Ditch 20 Wetland Restoration Feasibility Study To Benefit Downstream Water Quality."*

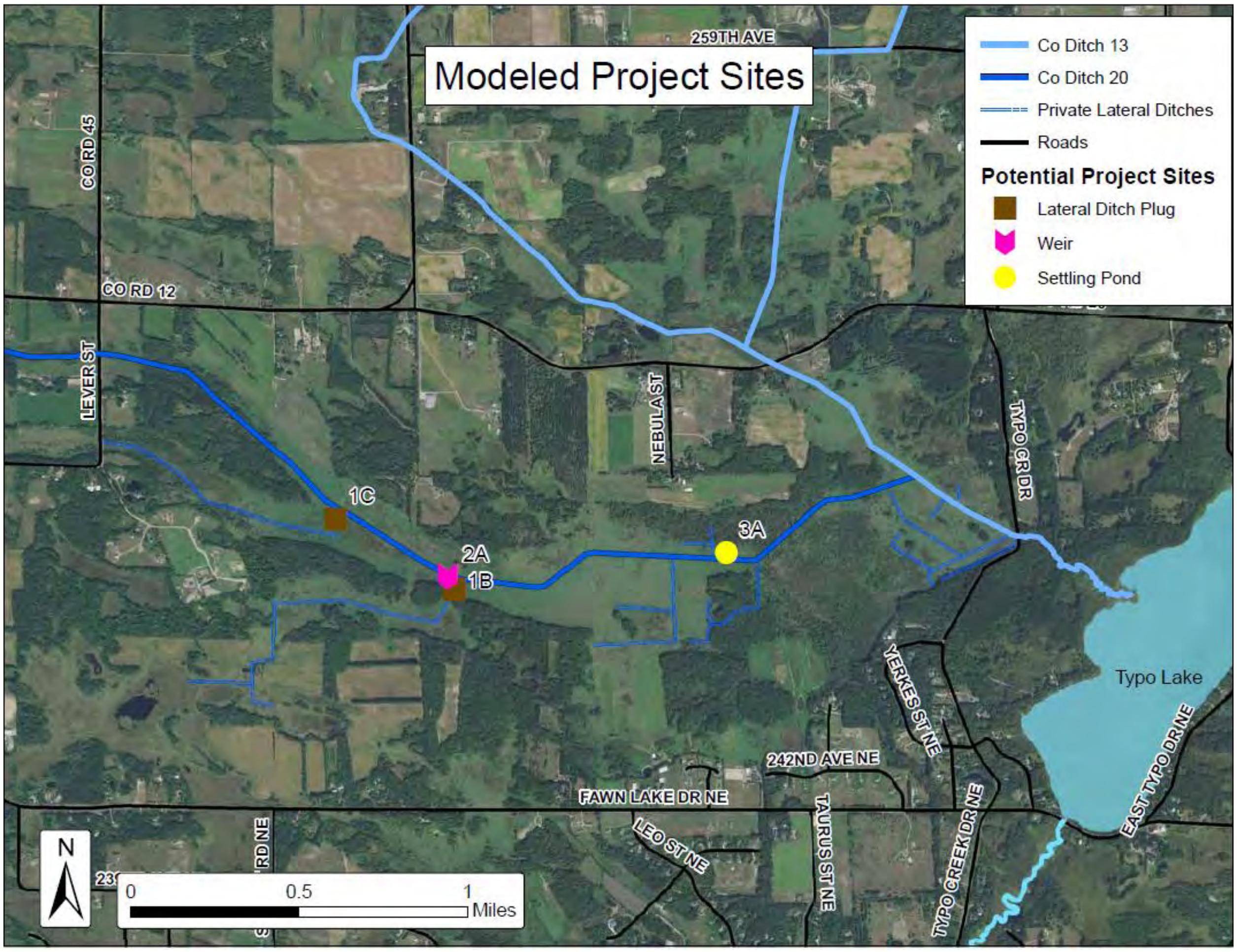
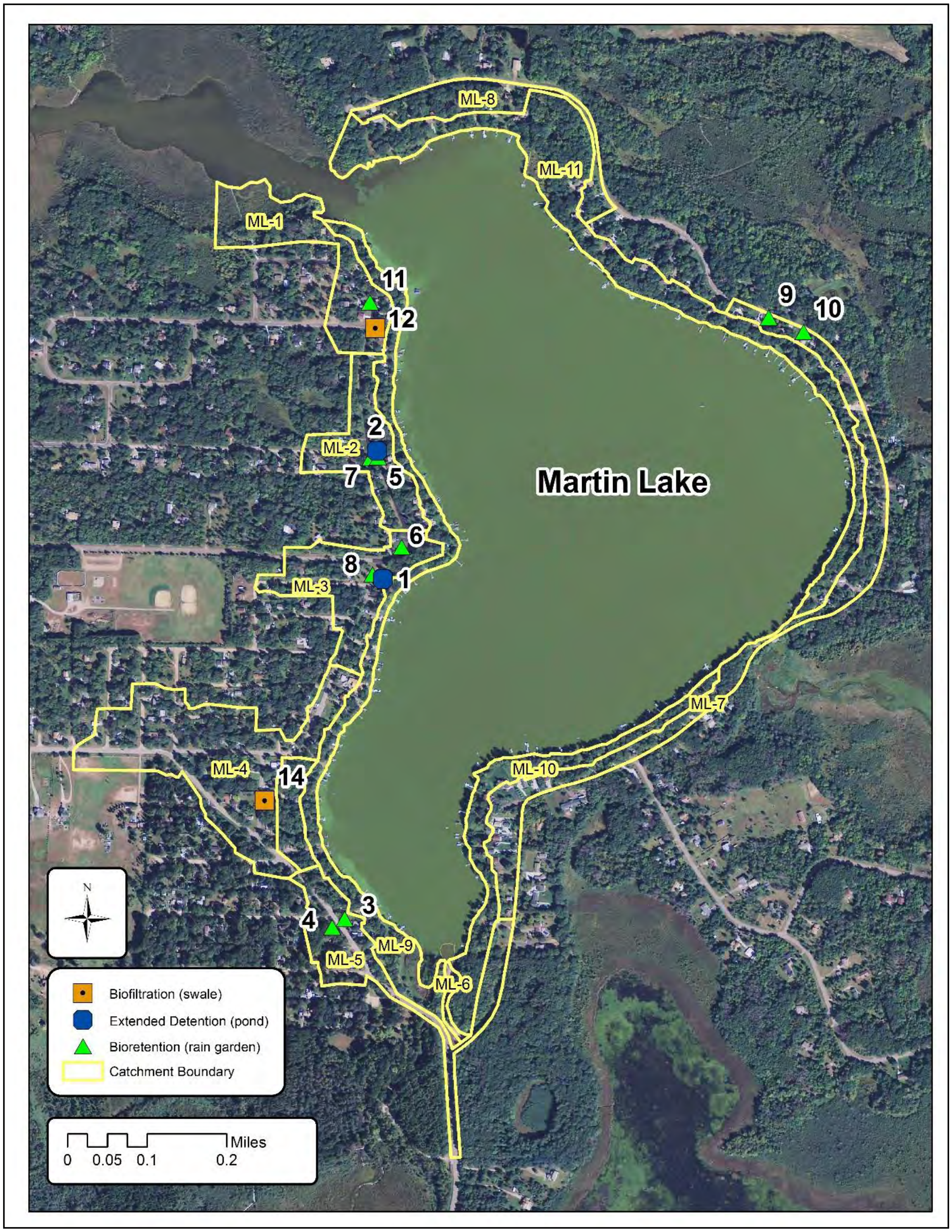


***Figure 13*** *- Modeled stormwater retrofit water quality projects near Martin Lake. From the 2011 study by the Anoka Conservation District entitled "Martin Lake Stormwater Retrofit Assessment."*



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