Watershed

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# North Fork Crow River Watershed Lake Protection Report

Identifying management strategies to protect five high quality lakes

MINNESOTA POLLUTION CONTROL AGENCY

CLEAN WATER LAND & LEGACY AMENDMENT

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# Abbreviations

| | |
|---|---|
| 1W1P | One Watershed, One Plan |
| ac | acres |
| AgBMP | Agricultural Best Management Practices |
| AMA | Aquatic Management Area |
| AU | animal unit |
| BMP | best management practice |
| CAFO | concentrated animal feeding operation |
| chl-*a* | chlorophyll-*a* |
| CRP | Conservation Reserve Program |
| DNR | Minnesota Department of Natural Resources |
| DO | dissolved oxygen |
| EQIP | Environmental Quality Incentives Program |
| EQuIS | Environmental Quality Information System |
| ft | feet |
| HSPF | Hydrologic Simulation Program–Fortran |
| ITPHS | imminent threat to public health and safety |
| kg | kilograms |
| lb | pounds |
| LGU | local government unit |
| m | meters |
| MPCA | Minnesota Pollution Control Agency |
| NCHF | North Central Hardwood Forests |
| NFCRW | North Fork Crow River Watershed |
| NLCD | National Land Cover Database |
| NPDES | National Pollutant Discharge Elimination System |
| NRCS | Natural Resources Conservation Service |
| SAM | Scenario Application Manager |
| SDS | state disposal system |
| sq mi | square miles |
| SSTS | subsurface sewage treatment system |
| SWCD | soil and water conservation district |
| TMDL | total maximum daily load |
| TP | total phosphorus |
| WASCOB | water and sediment control basin |
| WCBP | Western Corn Belt Plains |
| WRAPS | Watershed Restoration and Protection Strategy |
| WWTP | wastewater treatment plant |
| yr | year |

| | |
|---|---|
| µg/L | micrograms per liter |

# Executive summary

The North Fork Crow River Watershed (NFCRW) in central Minnesota contains water bodies with varying water quality conditions. This report addresses five lakes that meet lake eutrophication standards established by the State of Minnesota. These lakes are a high priority for local partners to protect in order to maintain the high water quality conditions. These five lakes were selected based on a variety of factors: high recreational use, recent trends of declining transparency, water quality that is close to the state standards, and/or development pressures. This report is intended to accompany the NFCR Watershed Restoration and Protection Strategies (WRAPS) Report Update 2023 (MFCRWD and MPCA 2023) and the NFCRW Total Maximum Daily Load (TMDL) Report 2023 (HEI and MPCA 2023).

The ultimate goal is to maintain or improve water quality in the protection lakes. To achieve this, individual water quality goals for each lake are presented. The water quality goal for each lake except for Lake Koronis is a 5% reduction in total phosphorus (TP) concentration in the lake; the Lake Koronis goal is a 9% reduction in phosphorus concentration (Table 1). Minnesota Pollution Control Agency (MPCA) and local partner staff selected these modest phosphorus reduction goals to help protect the lakes from degradation. The watershed phosphorus load reductions needed to meet the lake phosphorus concentration goals and the expected corresponding lake chlorophyll-*a* (chl-*a*) concentrations and Secchi depth transparencies were estimated with a lake model (Table 2). The primary phosphorus loads to the protection lakes are from watershed runoff (mostly from agricultural lands), septic systems, internal loading, and atmospheric deposition.

**Table 1. Water quality summary and phosphorus targets.**

| | TP (µg/L) | | Chl-*a* (µg/L) | | Secchi (m) | |
|---|---|---|---|---|---|---|
| Lake | Observed | Target | Observed | Target | Observed | Target |
| Grove | 31 | 30 | 10 | 9 | 2.0 | 2.1 |
| Koronis | 33 | 30 | 17 | 16 | 2.1 | 2.2 |
| Calhoun | 27 | 26 | 10 | 9 | 1.5 | 1.5 |
| Minnie-Belle | 17 | 16 | 4 | 4 | 4.5 | 4.5 |
| Washington | 29 | 27 | 13 | 12 | 1.2 | 1.3 |

**Table 2. Summary of existing and target loads.**

| Lake | Existing load (lb/yr) | Target load (lb/yr) | Target P load reduction (lb/yr) | Target P load reduction (%) |
|---|---|---|---|---|
| Grove | 1,248 | 1,136 | 112 | 9 |
| Koronis | 16,834 | 14,749 | 2,085 | 12 |
| Calhoun | 678 | 619 | 59 | 9 |
| Minnie-Belle | 1,520 | 1,380 | 140 | 9 |
| Washington | 5,135 | 4,699 | 436 | 8 |

For each lake, an implementation scenario was developed to illustrate an example combination of best management practices (BMPs) that collectively could achieve the phosphorus load reduction targets (Table 3). For each protection lake, local partner staff provided a set of BMPs that are most applicable to the lake watershed. The example implementation scenarios include an annual estimate of cost-share dollars needed to incentivize adoption of the practice. The costs do not take into account design and construction oversight or operation and maintenance costs. The implementation scenario illustrates the approximate level of effort needed to achieve the phosphorus reduction targets, but other combinations of BMPs may achieve the same goals. The scenarios should be adapted based on factors such as local knowledge about sources, interested landowners, available funding, etc. Information is provided for each protection lake for local partner staff to develop alternative implementation scenarios. As BMP implementation progresses and new implementation options arise, alternative implementation scenarios will allow local partner staff to evaluate progress made towards achieving the load reduction goals.

**Table 3. Example implementation scenario summaries.**

| Lake name | BMP name | Cropland area treated by BMP (ac) | TP load reduction (lb/yr) | Cost to incentivize ($/yr) |
|---|---|---|---|---|
| Grove | Alternative tile intakes | 537 | 75 | 1,252 |
| | Restore tiled wetlands | 171 | 19 | 5,249 |
| | *Total* | *708* | *94* | *6,501* |
| Koronis | Alternative tile intakes | 661 | 198 | 1,541 |
| | Restore tiled wetlands | 108 | 25 | 3,311 |
| | WASCOBs [a] | 62 | 25 | 3,058 |
| | *Total* | *831* | *248* | *7,910* |
| Calhoun | Alternative tile intakes | 356 | 32 | 828 |
| | Restore tiled wetlands | 57 | 4 | 1,755 |
| | WASCOBs | 33 | 4 | 1,644 |
| | *Total* | *446* | *40* | *4,227* |
| Minnie-Belle | Restore tiled wetlands | 22 | 14 | 661 |
| | Corn and soybeans with cover crop | 114 | 42 | 4,311 |
| | Conservation cover perennials | 13 | 14 | 1,275 |
| | *Total* | *148* | *70* | *6,247* |
| Washington | Alternative tile intakes | 262 | 171 | 611 |
| | Restore tiled wetlands | 43 | 21 | 1,308 |
| | WASCOBs | 24 | 21 | 1,208 |
| | *Total* | *329* | *213* | *3,127* |

a. WASCOB: water and sediment control basin

# 1. Overview

The NFCRW (hydrologic unit code [HUC]-8 07010204, approximately 1,485 square miles) in central Minnesota contains water bodies with varying water quality condition. This report addresses five lakes that meet lake eutrophication standards established by the State of Minnesota. These lakes are a high priority for local partners to protect in order to maintain the high water quality conditions (Table 4, Figure 1). These five lakes are referred to as "protection lakes" in this report and were selected based on a variety of factors: high recreational use, recent trends of declining transparency, water quality that is close to the state standards, and/or development pressures (Table 4).

**Table 4. List of high priority protection lakes in NFCRW.**

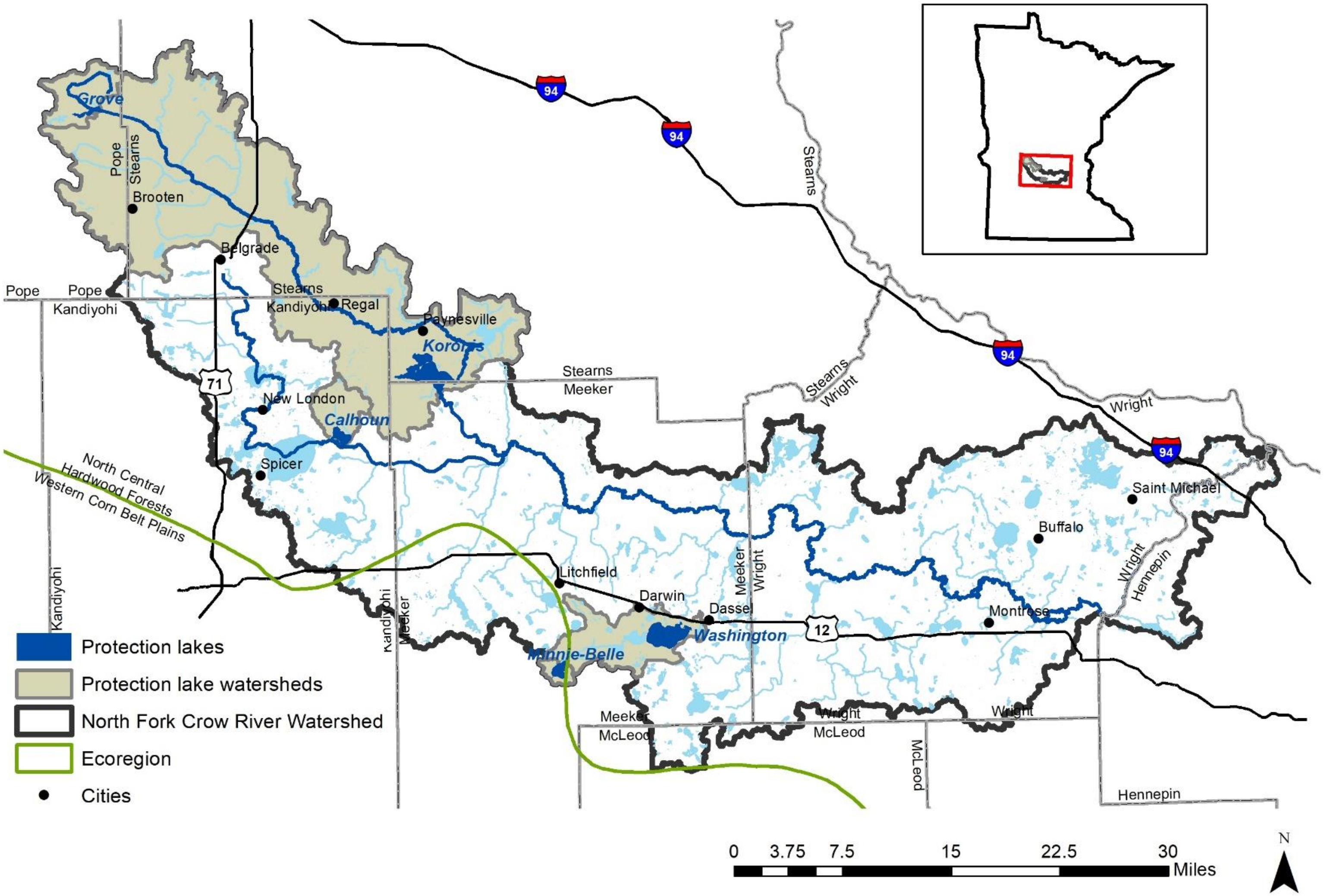
| Lake name | Lake ID | County | Designated use class | Reason for high protection priority |
|---|---|---|---|---|
| Grove | 61-0023-00 | Pope | 2B, 3C | Trend of declining transparency<br>Headwaters of the North Fork Crow River |
| Koronis | 73-0200-02 | Stearns | 2B, 3C | Fluctuating water quality<br>Fish assemblage impairment (see Section 3.2.2)<br>Significant community and economic importance in the area; high recreational use |
| Calhoun [a] | 34-0062-00 | Kandiyohi | 2B, 3C | Fluctuating water quality<br>Planned housing development |
| Minnie-Belle | 47-0119-00 | Meeker | 2B, 3C | Vulnerable fish communities [b]<br>Headwaters of Lake Washington, another protection lake |
| Washington | 47-0046-00 | Meeker | 2B, 3C | Significant community and economic importance to the cities of Darwin and Dassel |

a. Lake Calhoun has an aquatic consumption impairment due to high levels of mercury in fish tissue. The mercury TMDL for Lake Calhoun was approved as part of the Minnesota Statewide Mercury TMDL (MPCA 2007).

b. Reference: NFCRW Water Assessment and Trends Update (MPCA 2020)

This report is intended to accompany the NFCRW WRAPS Report Update 2023 (MFCRWD and MPCA 2023) and the NFCRW TMDL Report 2023 (HEI and MPCA 2023; referred to as the "TMDL Report" herein). For each of the five protection lakes, this report provides a summary of the lake and watershed conditions, a phosphorus source assessment, lake water quality targets, phosphorus loading goals, implementation options, and an example implementation scenario.

**Figure 1. Location of protection lakes and protection lake watersheds in the North Fork Crow River Watershed.**



# 2. Data assessment methods

## 2.1 Water quality standards and water quality data

Water quality in the protection lakes is evaluated in this report against Minnesota's lake eutrophication standards for the North Central Hardwood Forests (NCHF) and the Western Corn Belt Plains (WCBP) ecoregions (Table 5). Lake Minnie-Belle is in the WCBP ecoregion, and the rest of the protection lakes are in the NCHF ecoregion (Figure 1). For more information about lake water quality standards, see the TMDL Report (HEI and MPCA 2023).

**Table 5. Lake eutrophication standards.**

| Parameter | NCHF Lakes and reservoirs | NCHF Shallow lakes | WCBP Lakes and reservoirs |
|---|---|---|---|
| Total phosphorus (µg/L) | ≤ 40 | ≤ 60 | ≤ 65 |
| Chlorophyll-a (µg/L) | ≤ 14 | ≤ 20 | ≤ 22 |
| Secchi transparency (m) | ≥ 1.4 | ≥ 1.0 | ≥ 0.9 |
| Applicable protection lake | Grove, Koronis | Calhoun, Washington | Minnie-Belle [a] |

c. A portion of the Lake Minnie-Belle Watershed is in the NCHF ecoregion (Figure 1).

Water quality data from the MPCA's Environmental Quality Information System (EQuIS) were used for the lake and watershed water quality analyses, with a focus on monitoring sites located in the deepest part of the lake, with longer data records, and with larger sample sizes. Water quality data from 2000 through 2019 were evaluated and used in the water quality graphs. Data from the last 10 years (2010 through 2019) were used to summarize the existing conditions in the water quality summary tables. Years with fewer than three samples were not used in the graphs or summary tables. Data from 2020 became available during the course of this study and were added to water quality graphs; however, the 10-year averages were not updated with the 2020 data.

The data summaries provided in this report were calculated for this study and may differ slightly from the summaries provided on the MPCA's water quality dashboard.

## 2.2 Phosphorus sources

Phosphorus is an essential nutrient for aquatic and terrestrial life and is found naturally throughout a watershed. There are several potential sources of phosphorus to the protection lakes, including watershed runoff, feedlots, wastewater, internal loading, and atmospheric deposition. Some of the sources require a National Pollutant Discharge Elimination System (NPDES)/State Disposal System (SDS) permit and some are nonpermitted. The phrase "nonpermitted" does not indicate that the pollutants are illegal, but rather that they do not require an NPDES permit.

A description of phosphorus sources is provided below. More detailed information of the phosphorus sources to each of the protection lakes can be found in the report sections for the individual lakes (Section 3).

### 2.2.1 Watershed runoff

Precipitation that falls in a watershed drains across the land surface, and a portion of it eventually reaches lakes and streams. Phosphorus is carried with the runoff water and delivered to surface water bodies. The phosphorus sources in watershed runoff may include soils, fertilizer, vegetation, release from wetlands, and livestock, pet, and wildlife waste. A portion of the phosphorus in watershed runoff can be considered natural background sources, which are inputs that would be expected under natural, undisturbed conditions.

Much of the watershed phosphorus loading data is derived from the MPCA's Hydrologic Simulation Program–Fortran (HSPF) model application of the NFCRW (RESPEC 2016, Tetra Tech 2017 and references within). Please see the TMDL Report (Section 3.6.5.2 in HEI and MPCA 2023) for a brief description of the HSPF model. Model documentation contains additional details about the model development and calibration. Phosphorus loading information was exported from the HSPF Scenario Application Manager (SAM) version 2.0 model of the NFCRW.

In the Grove Lake and Lake Calhoun watersheds, the lake response model suggests that TP assimilation in the watershed reduces the TP load to the lake. The TP loads simulated in HSPF were lowered to calibrate the lake models for these two lakes.

### 2.2.2 Feedlots

Livestock are potential sources of phosphorus, particularly when direct access to surface waters is not restricted and/or where feeding structures are located adjacent to riparian areas. Animal waste from feedlots can be delivered to surface waters from failure of manure containment, runoff from the feedlots itself, or runoff from nearby fields where the manure is applied. In Minnesota, feedlots under 1,000 animal units (AUs) and those that are not federally defined as concentrated animal feeding operations (CAFOs) do not operate with permits. Feedlots with greater than 50 AUs, or greater than 10 AUs in shoreland areas, are required to register with the state. Facilities with fewer AUs are not required to register with the state. More information on feedlot permitting, feedlot registration, and feedlots as a source of phosphorus to lakes can be found in the TMDL Report (HEI and MPCA 2023).

Information on the number of feedlots and registered livestock in the lake protection watersheds is derived from the MPCA's registered feedlot database. The numbers of registered livestock do not represent the actual number of livestock but rather represent the maximum amount of animals that the feedlots can have according to their registration.

### 2.2.3 Wastewater

#### 2.2.3.1 Subsurface sewage treatment systems

Subsurface sewage treatment systems (SSTSs) can contribute phosphorus to nearby waters. SSTSs can fail for a variety of reasons, including excessive water use, poor design, physical damage, and lack of maintenance. Failure potentially results in higher levels of phosphorus loading to nearby surface waters. Overall estimated percentages of SSTS in the protection lake watersheds that are failing to protect groundwater range from 11% to 28%, and systems that are categorized as an imminent threat to public health and safety (ITPHS) range from 1% to 13%. More information on SSTS as a source of phosphorus to lakes can be found in the TMDL Report (HEI and MPCA 2023).

It was assumed that SSTSs from shoreline properties contribute phosphorus to the protection lakes. The number of shoreline properties was estimated from aerial photography, and compliance status was estimated from county records (Table 6). A conforming shoreline system is estimated to contribute on average 20% of the phosphorus that is found in the system, and nonconforming systems (both failing and ITPHS) along the shoreline contribute 43% of the phosphorus (assumptions from Barr Engineering 2004). Phosphorus loads were estimated with a spreadsheet approach using the MPCA's Detailed Assessment of Phosphorus Sources to Minnesota Watersheds (Barr Engineering 2004). Total loading is based on the number of conforming and failing SSTSs, an average of 2.3 people per household (Barr Engineering 2004), an average value for phosphorus production per person per year (MPCA 2014), and the assumption that approximately 30% of the residences are seasonally occupied.

**Table 6. Septic system inventory.**

| Lake | Estimated number of conforming SSTS | Estimated number of nonconforming SSTS |
| --- | --- | --- |
| Grove | 80 | 18 |
| Koronis | 632 | 95 |
| Calhoun | 44 | 19 |
| Minnie-Belle | 222 | 125 |
| Washington | 252 | 141 |

#### 2.2.3.2 Small community wastewater treatment areas of concern

Other sources of wastewater may include straight pipe discharges, earthen pit outhouses, and land application of septage. Straight pipe systems are unpermitted and illegal sewage disposal systems that transport raw or partially treated sewage directly to a lake, stream, drainage system, or the ground surface. Straight pipe systems are required to be addressed 10 months after discovery (Minn. Stat. § 15.55, subd. 11). Outhouses, or privies, are legal disposal systems and are regulated under Minn. R. 7080.2150, subp. 2F and Minn. R. 7080.2280.

To ensure that effective sewage treatment occurs across the state, the MPCA regularly conducts surveys of local governmental units to identify areas in the state that may be areas of concern; these areas are defined as five or more homes within a half mile of each other that have inadequate sewage treatment. These areas are generally unincorporated communities, may not have an organized structure, may consist of families with limited financial resources, and many times do not qualify for the same financial assistance as large incorporated communities. As of 2019, there were five communities in the protection lake watersheds identified as areas of concern with respect to wastewater treatment. The communities may have been listed because they were known to be noncompliant (i.e., ITPHS that backs up into the house or surface discharges inadequately treated wastewater, or a treatment system that is failing to protect groundwater and has a leaky tank or not enough soil separation under the SSTS before reaching saturated soil conditions) or due to an unknown status of SSTS compliance and were listed because of poor soils in the area, small lot size, or are older systems that may be out of compliance.

#### 2.2.3.3 Permitted municipal wastewater

The only permitted municipal wastewater discharges in the protection lake watersheds are Brooten Wastewater Treatment Plant (WWTP) (MNG585271) in the Lake Koronis Watershed and Darwin WWTP (MNG585150) in the Lake Washington Watershed.

### 2.2.4 Internal loading

Internal phosphorus loading from lake bottom sediments can be a component of the phosphorus budget in lakes. The sediment phosphorus originates as an external phosphorus load that settles out of the water column to the lake bottom. There are multiple mechanisms by which phosphorus can be released back into the water column as internal loading—low oxygen concentrations in the water overlying the sediment, wind energy in shallow depths, and physical disturbance of the bottom sediments (e.g., from bottom-feeding fish or motorized boating in shallow areas). More information on these mechanisms of internal loading can be found in the TMDL Report (HEI and MPCA 2023).

Internal loading was not quantified for most of the protection lakes because the lake response model inherently includes an internal load that is typical of lakes in the model development data set. Although internal loading was not found to be excessive, it is still a source of phosphorus and can influence water quality conditions.

In Lake Washington, an additional load was needed to calibrate the lake model. This load was attributed to internal loading and/or other sources (such as additional watershed loads, feedlots, or septic system loads) that were not quantified with the available data.

### 2.2.5 Atmospheric deposition

Phosphorus is bound to atmospheric particles that settle out of the atmosphere and are deposited directly onto surface water. Wind that blows over exposed bare soils can transport sediment and add to the phosphorus that is deposited on the surface areas of lakes. Phosphorus loading from atmospheric deposition to the surface area of the protection lakes was estimated using the average for the Upper Mississippi River Basin (0.24 pounds [lb] per acre per year, Barr Engineering 2007).

## 2.3 Water quality goals, loading targets, and implementation recommendations

The ultimate goal is to maintain or improve water quality in the protection lakes. To achieve this, individual water quality goals for each lake are presented. The water quality goal for each lake except for Lake Koronis is a 5% reduction in phosphorus concentration in the lake. The MPCA and local partner staff selected these modest phosphorus reduction goals to help protect the lakes from degradation. The Lake Koronis goal is a 9% reduction in phosphorus concentration (see Section 3.2.4). The watershed phosphorus load reductions needed to meet the lake phosphorus concentration targets and the expected corresponding lake chl-*a* concentrations and Secchi depth transparencies were estimated with a lake model and are summarized in Table 1. Phosphorus and chl-*a* concentrations were rounded to whole numbers and Secchi depths were rounded to one decimal place. Because the goals represent relatively small changes in water quality, the rounded values in some cases are the same as the existing conditions (e.g., Lake Minnie-Belle chl-*a* and Secchi goals, see Table 1). Even if the phosphorus load reductions recommended in this report do not lead to measurable improvements in chl-*a* or Secchi, the load reductions will help buffer the lake from future stressors such as changes in loading, temperature, or ecological shifts.

A spreadsheet version of the lake model BATHTUB (Walker 1987) was used to model lake water quality (i.e., phosphorus concentration, chl-*a* concentration, and Secchi transparency) in each protection lake. See the TMDL Report (HEI and MPCA 2023) for more information about the BATHTUB model. Each lake model was calibrated to the average lake phosphorus concentration, consisting of all data from 2010 through 2019. The calibrated models were used to estimate the phosphorus load reduction needed to achieve the lake phosphorus goal (i.e., 5% reduction in phosphorus concentration). *Appendix A: Lake modeling documentation* contains model inputs and outputs.

An implementation scenario was developed to illustrate an example combination of BMPs that collectively could achieve the phosphorus load reduction targets. For each protection lake, local partner staff provided a set of BMPs that are most applicable to the lake watershed, and the implementation scenario included these BMPs. Phosphorus reduction efficiencies for the BMPs were derived from the defaults in HSPF–SAM (version 2.0). In addition to reductions from the BMPs, load reductions expected if all SSTS were brought into compliance are included in the implementation scenarios. No changes to loading from atmospheric precipitation are assumed. Additionally, because of the lack of information about loading from communities with wastewater treatment areas of concern, load reductions from this source are not assumed. These example implementation scenarios should be adapted based on factors such as local knowledge about sources, interested landowners, available funding, new monitoring data, etc.

The example implementation scenarios include costs to incentivize BMP implementation, per impacted acre per year, as described in the draft SAM BMP database documentation (RESPEC 2017). The costs used in this report are from the SAM software; some of the costs were updated from the costs in the BMP database documentation (RESPEC 2017) and differ slightly. The costs in SAM are based on the 2016 Natural Resources Conservation Service (NRCS) Environmental Quality Incentives Program (EQIP) cost-share docket for Minnesota, in addition to best professional judgment. These costs do not represent the entire cost to implement the practice but rather are an **annual estimate of cost-share dollars needed to incentivize adoption of the practice**. The costs do not take into account design and construction oversight or operation and maintenance costs.

Costs to upgrade SSTSs are not included in the cost estimates. Upgrades are typically paid for by the SSTS owner and cost approximately $15,000 (ranging from approximately $10,000 to $20,000). Although SSTS upgrades are not eligible for some state-issued grants such as the federal Clean Water Act Section 319 grants, low interest loans are available to landowners and local government units (LGUs) through the Agricultural Best Management Practices (AgBMP) Loan Program, and zero interest loans are available to LGUs through the MPCA's Clean Water Partnership loan program. This cost to SSTS owners can be used by local partners as funding match for state and federal implementation grants. For example, if 10 SSTSs around a lake's shoreline were upgraded at an average cost of $15,000 per system, the local soil and water conservation district (SWCD) can use the $150,000 spent by the SSTS owners or LGUs as a match for a state grant to implement BMPs on agricultural lands. The SSTS owners' commitment to reducing phosphorus loading from their SSTSs can cover a substantial part of the grant's match to pay for the agricultural BMPs in the lake watershed.

The implementation scenario illustrates the approximate level of effort needed to achieve the phosphorus reduction targets, but other combinations of BMPs may achieve the same goals. The following additional information is provided for each protection lake for local partner staff to develop alternative implementation scenarios:

- Cropland area and simulated TP loading rate in cropland runoff that reaches the lake. Simulated TP loading rates differ among the lake watersheds due to watershed characteristics, assimilation rates in the Grove Lake and Lake Calhoun watersheds (see Section 2.2.1), and HSPF calibration zone.
- For select BMPs: TP load reduction (lb/ac), TP percent reduction, and cost. The TP load reductions (lb/ac) are unique to each lake–BMP combination because the reductions are calculated from the simulated existing cropland loading rates (which differ among lakes; see prior bullet) multiplied by the BMP's TP reduction efficiency.

An alternative implementation scenario can be calculated with the following steps:

1. Identify the TP load reduction target for the protection lake.
2. Select a BMP from the list provided for the protection lake and determine the treated area of the BMP.
3. Multiply the area by the TP load reduction (lb/ac) for the BMP to estimate the load reduction for that BMP.
4. Repeat Step 3 and sum the results to achieve the P loading target.

As BMP implementation progresses and new implementation options arise, alternative implementation scenarios will allow local partner staff to evaluate progress made towards achieving the load reduction goals.

**Table 7. BMP cost and reduction efficiencies (HSPF–SAM v. 2.0).**

| BMP | NRCS EQIP practice | Applicable land cover | TP reduction efficiency (%) [a] | Cost to incentivize ($/impacted acre/year) | Cost assumptions |
|---|---|---|---|---|---|
| Alternative tile intakes | Subsurface drain (606) | Cropland drained | 55 | 2.33 | $350 each; each intake treats 15 ac cropland at 2% slope; intakes last at least 10 yrs (SAM cost is annualized over 10 yrs) |
| Wetland restoration ("Restore tiled wetlands" in SAM | Wetland restoration (657) | Cropland drained | 42 | 30.71 | Each restored wetland acre treats 10.6 ac cropland + buffer required on 7.2% of treated crop area; payment made once every 15 yrs based on NRCS practice life |
| Conservation cover perennials | Conservation cover (327) | Cropland corn/soy | 71 | 99.23 | $496.16 per ac, payment made once every 5 years (SAM cost is annualized over 5 yrs) |
| Corn and soybeans with cover crop | Cover crop (327, 340) | Cropland corn/soy | 24 | 37.98 | Payment made annually |
| WASCOB | Water and soil control basin (638) | Cropland high slope | 73 | 49.33 | $4,933 each; average drainage area = 10 ac; payment made once every 10 yrs (SAM cost is annualized over 10 yrs) |

a. Overall efficiency takes into account surface drainage and tile drainage.

# 3. Lake evaluations

## 3.1 Grove Lake (61-0023-00)

### 3.1.1 Watershed characterization

The Grove Lake Watershed is relatively small (14.5 square miles), with a watershed to lake ratio of 26:1. Except for a small sliver in the northeast part of the watershed, the entire watershed is in Grove Lake Township, Pope County. There are no cities in the Grove Lake Watershed, and development is heaviest along the lake's shoreline. Land cover is approximately 50% cropland, with substantial areas of grassland, pasture, wetlands, and open water (Table 8, Figure 2). Many of the watercourses along the primary flow paths are altered (Figure 2). There are three registered feedlots in the Grove Lake Watershed, one of which is a CAFO with an NPDES permit. The primary livestock type in the non-CAFO feedlots is cattle, and the primary livestock type in the CAFO is swine (Table 9).

**Table 8. Grove Lake Watershed land cover summary (National Land Cover Database [NLCD] 2016).**

| Land Cover | Area (acres) | Percent area (%) |
|---|---|---|
| Cropland and feedlot | 4,438 | 48 |
| Grassland and pasture | 1,906 | 20 |
| Developed [a] | 308 | 3 |
| Forest and shrub | 625 | 7 |
| Wetland and open water [b] | 2,057 | 22 |

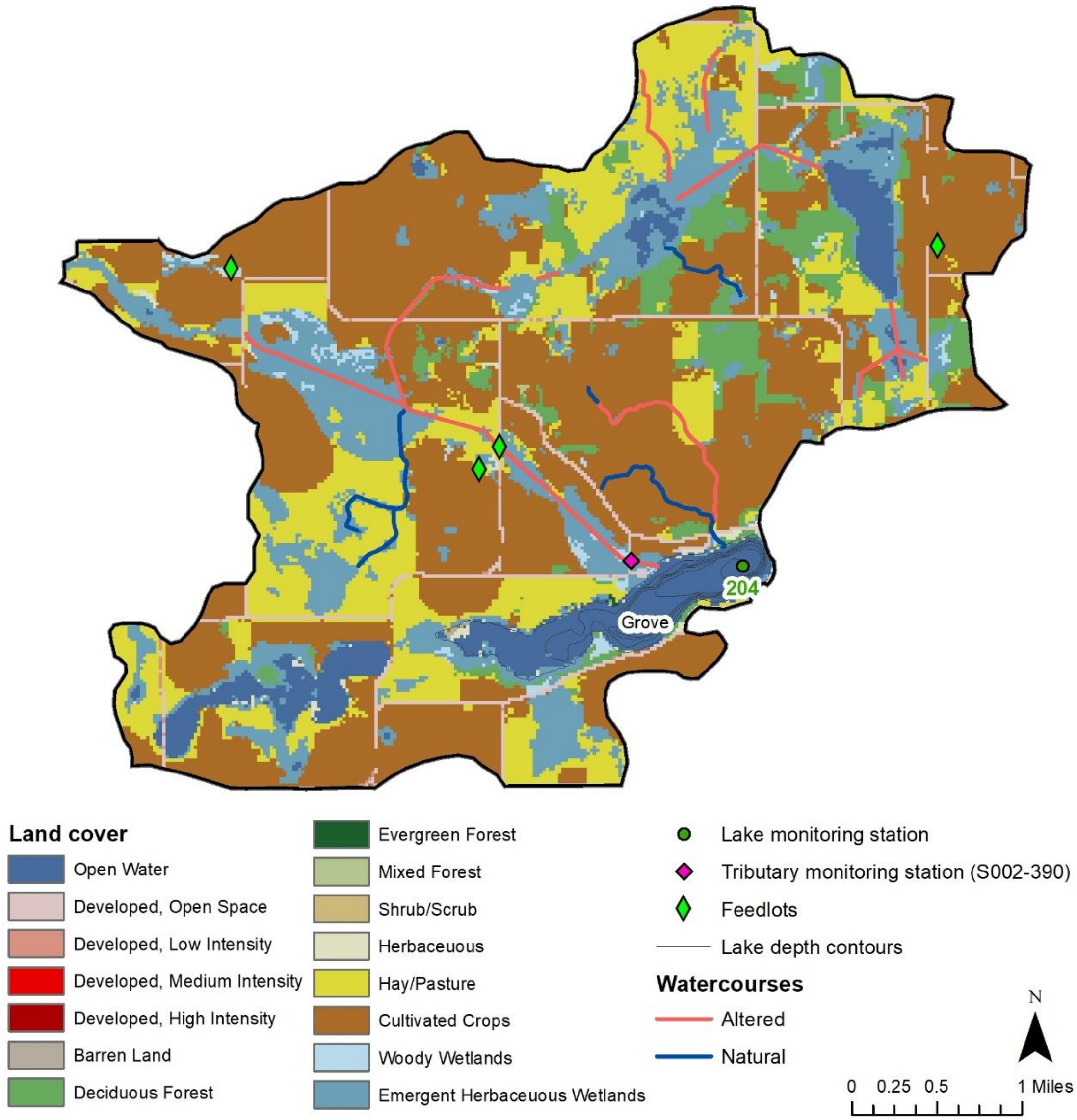
a. Shoreline development is not reflected in the "developed" land cover classes in NLCD due to scale, and the developed area is likely underestimated in this summary.

b. Wetland and open water does not include the surface area (354 ac) of Grove Lake.

**Table 9. Numbers of livestock in feedlots in the Grove Lake Watershed.**

| Feedlot type | Number of cattle | Number of swine |
|---|---|---|
| Registered, non CAFO | 162 | 2 |
| CAFO | 0 | 3,268 |

**Figure 2. Grove Lake Watershed land cover (NLCD 2016), feedlots, and monitoring sites.**




## 3.1.2 Lake conditions

Grove Lake is the headwaters of the North Fork of the Crow River, with a surface area of 354 acres and mean depth of 11 feet (Table 10). Approximately 69% of the lake is less than 15 feet deep. The western half of the lake is shallow and often has nuisance aquatic vegetation, which can compromise summer fishing and recreational boating. The eastern half of the lake is deeper and has greater water clarity. The fishery includes walleye (which have been stocked in odd years since 2011), largemouth bass, and northern pike, with limited panfishing opportunities.

**Table 10. Grove Lake morphometry and watershed size.**

| Surface area (ac) | Maximum depth (ft) | Mean depth (ft) | Watershed area (sq. mi.) | Percent littoral area |
|---|---|---|---|---|
| 354 | 31 | 10.6 | 14.5 | 69 |

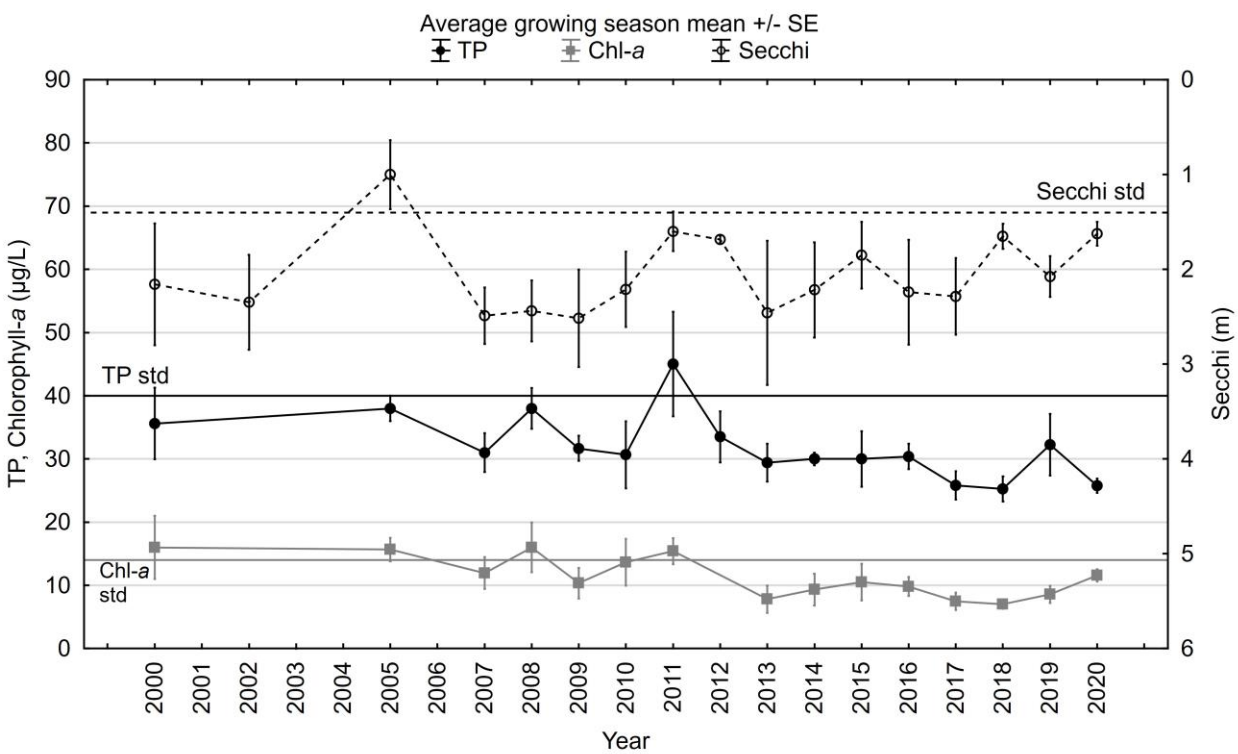
The average phosphorus concentration in Grove Lake is 31 µg/L, which is well below the standard of 40 µg/L. Similarly, the chl-*a* concentration and Secchi depth both are better than the respective standards (Table 11).

**Table 11. Grove Lake water quality summary (site 61-0023-00-204) and phosphorus targets.**

| Parameter | Observed (2010–2019) | Water quality standard for NCHF lakes | Target—5% reduction in TP and predicted chl-*a* and Secchi |
|---|---|---|---|
| TP (µg/L) | 31.2 | 40 | 30 |
| Chl-*a* (µg/L) | 10.0 | 14 | 9 |
| Secchi (m) | 2.03 | 1.4 | 2.1 |

The North Fork Crow River Watershed Water Assessment and Trends Update (MPCA 2020) summarizes data from Grove Lake. Improvements in the fish index of biological integrity (IBI) scores were observed from 2012 through 2017, and a trend line of phosphorus concentrations suggests a decrease over the last 20 years. The variability in phosphorus and chlorophyll concentrations decreased beginning in 2013 (Figure 3). Water quality standards were met in most, but not all, years when water quality data were collected; the chl-*a* standard was violated more frequently than the phosphorus and Secchi standards (Figure 3). The water column of Grove Lake thermally stratifies, which can lead to low dissolved oxygen (DO) in bottom waters. Whereas this stratification likely leads to release of phosphorus from the lake sediments, internal load does not appear to be greater than what would be expected from Grove Lake given its size and depth.

**Figure 3. Grove Lake (61-0023-00-204) growing season means of TP, chl-*a*, and Secchi.**



### 3.1.3 Phosphorus source summary

The majority of the phosphorus loading to Grove Lake is from cropland runoff. Other sources of phosphorus include runoff from grassland and pasture, runoff from developed areas, SSTS, and atmospheric deposition (Table 12).

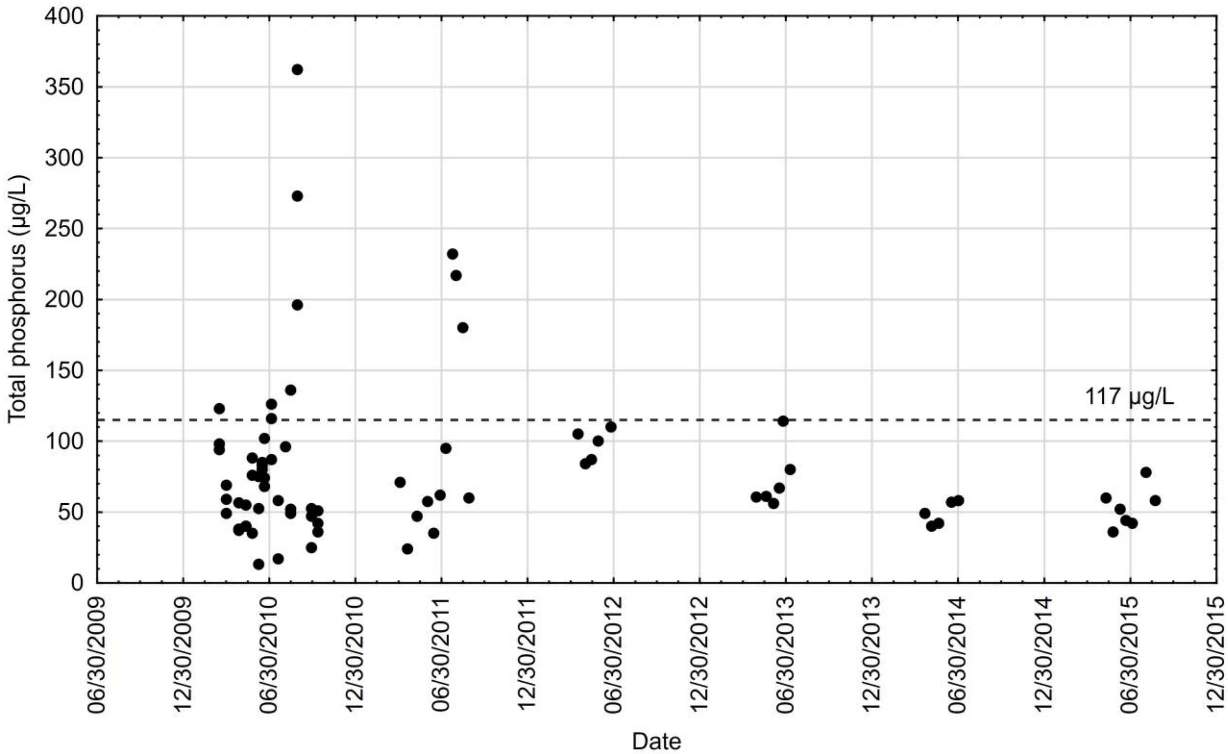
**Table 12. Phosphorus source summary for Grove Lake.**

| Source | | TP Load (lb/yr) | % Load |
|---|---|---|---|
| Watershed runoff | Cropland and feedlot | 867 | 69 |
| | Grassland and pasture | 114 | 9 |
| | Developed [a] | 64 | 5 |
| | Forest and shrub | 8 | < 1 |
| | Wetland and open water | 10 | < 1 |
| SSTS | | 101 | 8 |
| Atmospheric deposition | | 84 | 7 |
| *Total:* | | *1,248* | *100* |

a. Loading from shoreline development may be underestimated in HSPF because shoreline development often is classified as a natural land cover in a land cover dataset such as NLCD 2016.

The watershed loads presented in Table 12 (1,248 lb/yr) are lower than the watershed loads predicted in HSPF (1,923 lb/yr). Given the observed lake TP concentrations, the lake response model suggests that TP assimilation in the watershed reduces the TP load to the lake. To calibrate the model, the watershed loads were reduced by 45% for a total watershed load of 1,063 lb/yr (equivalent to a TP concentration in the tributary of 117 µg/L). This adjustment is reasonable given the observed TP concentrations in the main tributary inlet to Grove Lake (JD1 at 208th St, monitoring station S002-390) (Figure 4).

**Figure 4. Phosphorus concentrations in Grove Lake inlet (S002-390, JD1 at 208th St), 2010–2015.**




117 µg/L TP is the modeled average phosphorus concentration in watershed runoff that reaches Grove Lake.

## 3.1.4 Water quality goals, loading targets, and implementation recommendations

The Grove Lake water quality goal is 30 µg/L TP (based on a 5% decrease in the average lake TP concentration). The BATHTUB model predicts that this TP concentration corresponds to 9 µg/L chl-*a* and 2.1 m Secchi depth (Table 11). To reach the lake TP goal of 30 µg/L, a TP load reduction of 112 lb/yr is needed, which represents an overall 9% reduction in the phosphorus load to the lake.

Approximately 69% of the phosphorus load to Grove Lake is from cropland runoff (Table 12), and the primary focus of the BMP implementation scenario is to reduce this cropland runoff load. The BMPs of primary interest in the Grove Lake Watershed are alternative tile intakes and wetland restoration; cover crops and shoreline restoration are also applicable. In addition to practices that reduce phosphorus loading from cropland, all SSTS around the shoreline of Grove Lake should be brought into compliance.

A variety of implementation scenarios could achieve the 112 lb/yr TP reduction needed to meet the Grove Lake protection goals. Table 13 can be used to develop alternative scenarios by multiplying the TP reductions (lb/ac) by treated areas to estimate the load reduction for each BMP (see Section 2.3 for more detailed guidance). In addition to the BMP options in Table 13, shoreline restoration should also be considered.

**Table 13. Options for Grove Lake implementation scenario.**

| BMP name | BMP applicable land cover | TP percent reduction (%) | TP reduction (lb/ac) | Cost to incentivize ($/ac/yr) |
|---|---|---|---|---|
| Alternative tile intakes | Drained cropland | 55 | 0.14 | 2.33 |
| Restore tiled wetlands (cropland) | Drained cropland | 42 | 0.11 | 30.71 |
| Conservation cover perennials | Corn and soy | 71 | 0.18 | 99.23 |
| Corn and soybeans with cover crop | Corn and soy | 24 | 0.06 | 37.98 |

Alternative BMP scenarios can be developed for Grove Lake to achieve a reduction of 94 lb/yr over the 4,438 acres of cropland. The simulated existing TP loading from cropland in the Grove Lake Watershed is on average 0.26 lb/ac-yr.

One implementation option is provided in Table 14. In addition to SSTS compliance (18 lb/yr), the implementation scenario incorporates a mix of alternative tile intakes and wetland restoration to achieve the 94 lb/yr reduction needed from cropland, which amounts to an 11% decrease in TP loads from cropland (Table 15).

**Table 14. Implementation scenario for Grove Lake.**

In addition to the BMPs presented here, the implementation scenario assumes that all SSTS are conforming, which is predicted to achieve a reduction of 18 lb/yr.

| BMP | TP load reduction (%) | Cost to incentivize ($/ac/yr) | Cropland area treated by BMP (ac) | TP load reduction (lb/yr) | Cost to incentivize ($/yr) |
|---|---|---|---|---|---|
| Alternative tile intakes | 55 | 2.33 | 537 | 75 | 1,252 |
| Restore tiled wetlands | 42 | 30.71 | 171 | 19 | 5,249 |
| *Total* | | | *708* [a] | *94* | *6,501* |

a. 708 acres represents 16% of the cropland area in the Grove Lake Watershed

**Table 15. Grove Lake phosphorus loading targets.**

| P source | | Existing P load (lb/yr) | Target P load (lb/yr) | Target P load reduction (lb/yr) | Target P load reduction (%) |
|---|---|---|---|---|---|
| Watershed runoff | Cropland and feedlot | 867 | 773 | 94 | 11 |
| | Grassland and pasture | 114 | 114 | 0 | 0 |
| | Developed | 64 | 64 | 0 | 0 |
| | Forest and shrub | 8 | 8 | 0 | 0 |
| | Wetland and open water | 10 | 10 | 0 | 0 |
| SSTS [a] | | 101 | 83 | 18 | 18 |
| Atmospheric deposition | | 84 | 84 | 0 | 0 |
| *Total* | | *1,248* | *1,136* | *112* | *9* |

a. Approximately 18 SSTS around the lake shoreline are nonconforming (Table 6). SSTS loading goal assumes that all SSTS are conforming.

## 3.2 Lake Koronis (73-0200-02)

### 3.2.1 Watershed characterization

Lake Koronis is along the flow path of the North Fork Crow River, which enters the lake along the east shore, downstream of Rice Lake, and outlets near the southeast part of the lake (Figure 5). The watershed is relatively large (297 square miles) compared to the lake surface area, with a watershed to lake ratio of approximately 66:1.

Rice Lake's (lake ID 73-0196-00) aquatic recreation use is impaired due to high phosphorus, and a completed TMDL report (Wenck 2012a) indicates that a phosphorus load reduction of 53% is needed for Rice Lake to meet its lake water quality standard of 40 µg/L. The Rice Lake outlet is treated as a boundary condition in the Lake Koronis evaluation presented here, and the Lake Koronis Watershed "focus area" in this report is the portion of the watershed that is downstream of the Rice Lake outlet (Figure 5 inset). The lake is in Stearns and Meeker counties, with parts of the watershed also in Pope and Kandiyohi Counties (Figure 1). The cities of Paynesville, Regal, Elrosa, and Brooten are located in the watershed.

Land cover is approximately 65% cropland, with substantial areas of grassland, pasture, wetlands, and open water (Table 16, Figure 5). A majority of the lake shoreline is developed. Many of the streams in the watershed have been hydrologically altered.

There are 23 registered feedlots in the focus area, one of which is a CAFO with an NPDES permit. The primary livestock type in the non-CAFO feedlots is cattle, and the primary livestock type in the CAFO is turkey (Table 17). The full Lake Koronis Watershed has over 250 registered feedlots, consisting of cattle, swine, poultry, and other livestock types (Table 18).

**Table 16. Lake Koronis Watershed land cover summary (NLCD 2016).**

| Land Cover | Area (acres) | Percent area (%) |
|---|---|---|
| Cropland and feedlot | 124,644 | 65 |
| Grassland and pasture | 24,704 | 13 |
| Developed [a] | 8,632 | 4 |
| Forest and shrub | 8,068 | 4 |
| Wetland and open water [b] | 27,169 | 14 |

a. Shoreline development is not reflected in the "developed" land cover classes in NLCD due to scale, and the developed area is likely underestimated in this summary.

b. Wetland and open water does not include the surface area of Lake Koronis.

**Figure 5. Lake Koronis Watershed land cover (NLCD 2016), feedlots, wastewater, and monitoring sites.**

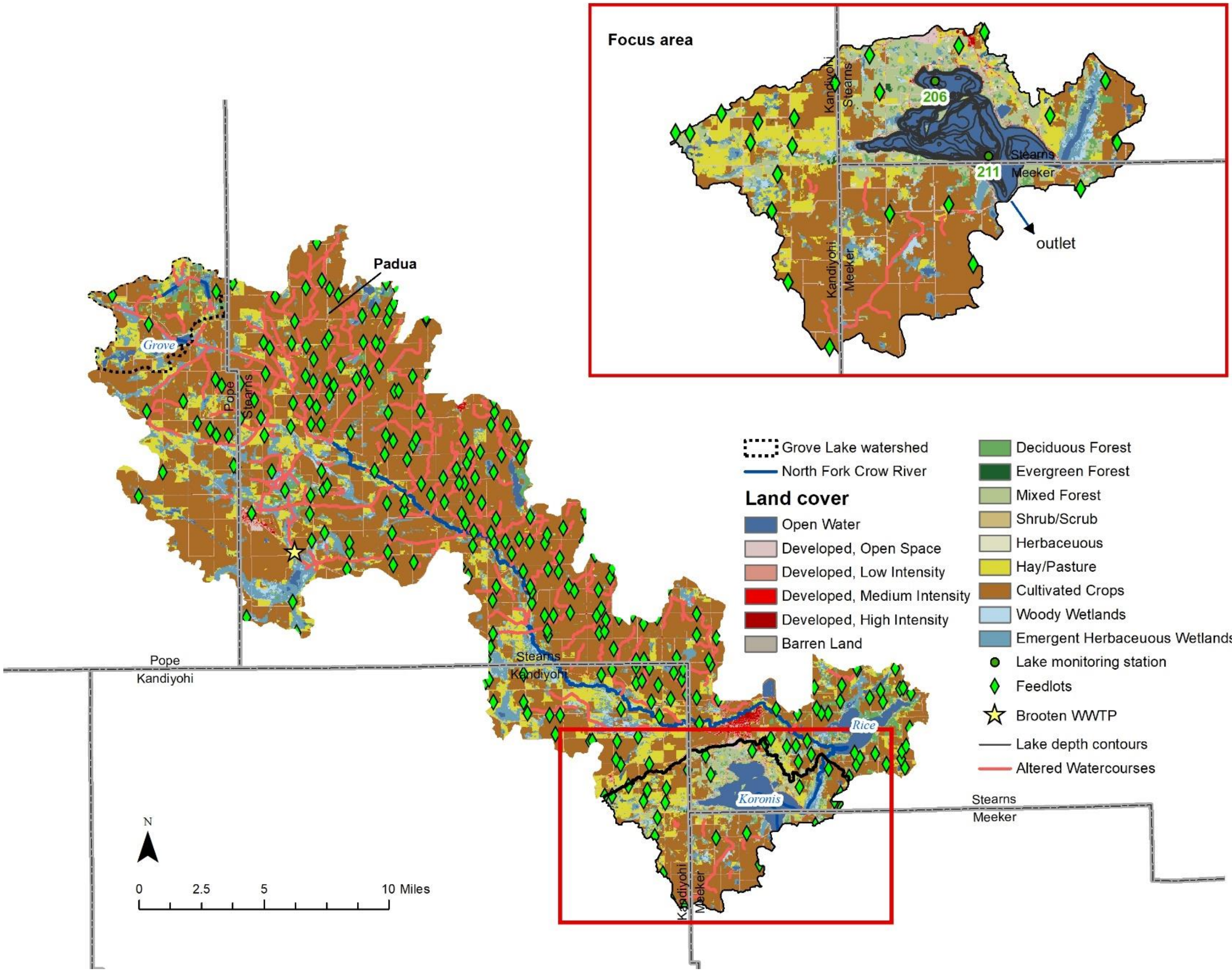


**Table 17. Animal unit summary in feedlots in the Lake Koronis focus area.**

| | Registered, Non CAFO | | CAFO | |
|---|---|---|---|---|
| Livestock type | AU | % AU | AU | % AU |
| Cattle | 1,357 | 69 | 0 | 0 |
| Poultry (turkey) | 551 | 28 | 1,591 | 100 |
| Other (swine and horse) | 63 | 3 | 0 | 0 |

**Table 18. Animal unit summary in feedlots in the full Lake Koronis Watershed.**

| Livestock type | AU | % AU |
|---|---|---|
| Cattle | 32,623 | 57 |
| Swine | 8,353 | 15 |
| Poultry | 15,612 | 27 |
| Other | 557 | 1 |

## 3.2.2 Lake conditions

Lake Koronis has a surface area of 2,942 acres and a mean depth of 29 feet (Table 19).

**Table 19. Lake Koronis morphometry and watershed size.**

| Surface area (ac) | Maximum depth (ft) | Mean depth (ft) | Watershed area (sq. mi.) | Percent littoral area |
|---|---|---|---|---|
| 2,942 | 132 | 29 | 297 | 40 |

Water quality data were evaluated separately for site 206, which is in the northwest basin, and site 211, which is in the main basin of Lake Koronis (Figure 5 inset). Since 2010, the phosphorus and Secchi standards were not met during one year each, and the chlorophyll standard was not met during five years (Figure 6). On average, phosphorus concentrations were lower in the NW basin (site 206) than in the main basin (site 211) (Table 20), but chl-*a* concentrations and Secchi depths at the two sites did not differ consistently (Figure 6).

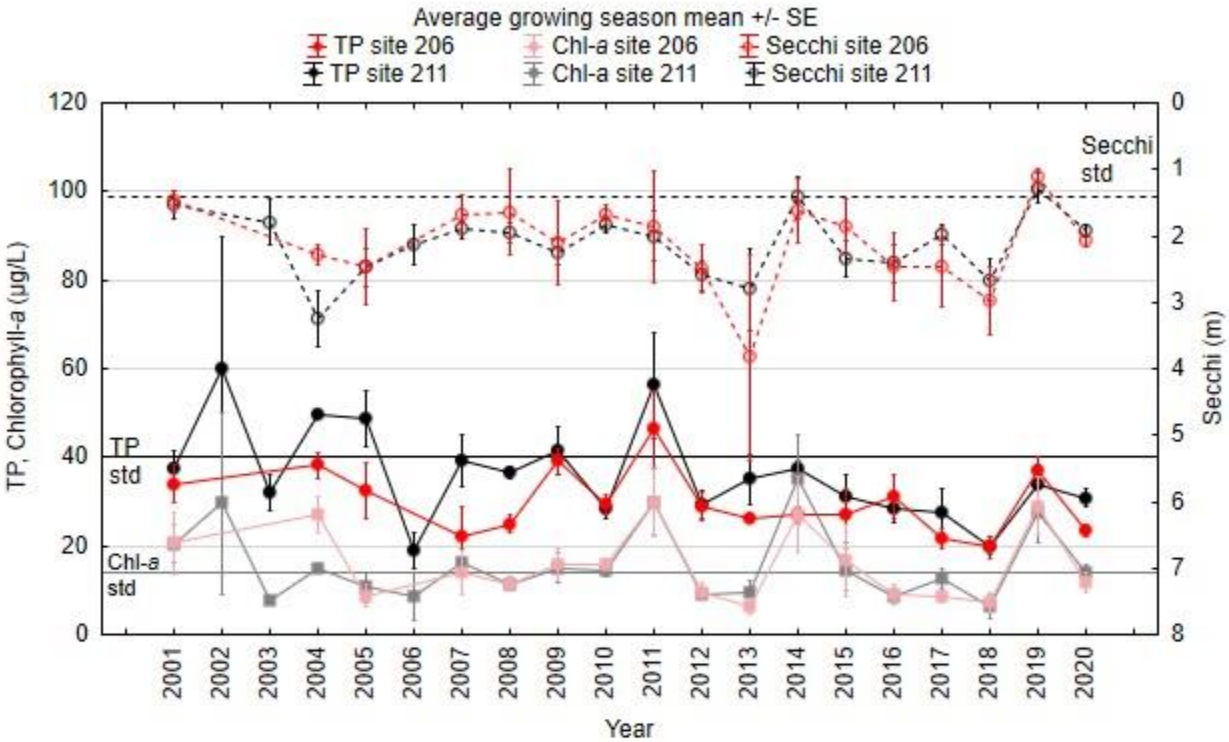
The water column of Lake Koronis thermally stratifies, which can lead to low DO in bottom waters. Whereas this stratification likely leads to release of phosphorus from the lake sediments, internal load does not appear to be greater than what would be expected from Lake Koronis given its size and depth.

**Table 20. Lake Koronis water quality summary (sites 73-0200-02-206 and 211) and phosphorus targets.**

| Bay | Parameter | Observed (2010–2019) | Water quality standard for NCHF lakes | Target—Rice Lake at 40 µg/L TP, 5% reduction in watershed loading |
|---|---|---|---|---|
| NW basin (site 206) | TP (µg/L) | 29.4 | 40 | NA [a] |
| | Chl-*a* (µg/L) | 15.9 | 14 | |
| | Secchi (m) | 2.24 | 1.4 | |
| Main basin (site 211) | TP (µg/L) | 33 | 40 | 30 |
| | Chl-*a* (µg/L) | 17 | 14 | 16 |
| | Secchi (m) | 2.1 | 1.4 | 2.2 |

a. Water quality goals were set for the main basin only (Section 3.2.4).

**Figure 6. Lake Koronis (73-0200-02-206 and 211) growing season means of TP, chl-*a*, and Secchi.**




The following is a summary from Aquatic Vegetation of Lake Koronis (Simon et al. 2020), which describes historical and recent vegetation surveys in Lake Koronis. Submerged aquatic vegetation is common in the lake, and recent (2015 through 2020) surveys show a moderately diverse submerged plant community. Emergent and floating-leaved plants, which are important for fish and wildlife habitat and erosion protection, are lacking in the nearshore zone. Starry stonewort (*Nitellopsis obtusa*), a nonnative submerged plant, was first found in the lake in 2015, and its occurrence increased from 17% to 44% of survey sites within the shore to the 20-foot depth zone from 2015 through 2018. Starry stonewort can create dense mats at the water surface, can outcompete native aquatic plants, and does not provide suitable habitat or food for native animals. Attempts to control starry stonewort with herbicide and mechanical treatments occurred annually from 2015 through 2020. Because these approaches are not selective, native plant species can also be harmed.

Walleye fry were stocked annually in the lake since 2011, and northern pike fingerlings were also stocked in 2011. The fish assemblage was assessed as not meeting aquatic life standards in a 2016–2017 survey. Although intolerant species such as cisco, rock bass, and smallmouth bass were present, there were also a high number of intolerant species (i.e., black bullhead, bigmouth buffalo, common carp, and green sunfish). It was observed that cisco habitat (i.e., oxygenated, cold water) was reduced. The cause of the fish impairment is being investigated—potential stressors to the biota include physical habitat alteration, elevated nutrients, and pesticides. If a pollutant stressor (e.g., nutrients or pesticides) is confirmed, then a TMDL can be developed for the pollutant(s). Nonpollutant stressors such as habitat alteration will be addressed through other mechanisms (e.g., WRAPS, One Watershed, One Plan [1W1P]). Planning efforts to improve the fish community should take into account the protection goals and phosphorus loading targets presented in this report, in addition to fisheries management goals.

### 3.2.3 Phosphorus source summary

The Rice Lake Watershed represents a majority of the Lake Koronis Watershed (90% by area), and the majority of the phosphorus loading to Lake Koronis is from the Rice Lake outlet (Table 21). In the Lake Koronis focus area, the majority of the phosphorus loading is from cropland runoff. Other sources of phosphorus include SSTS and atmospheric deposition.

**Table 21. Phosphorus source summary for Lake Koronis.**

| Source | | TP Load (lb/yr) | % Load |
|---|---|---|---|
| Rice Lake outlet boundary condition [a,b] | | 10,471 | 62 |
| Watershed runoff from focus area | Cropland and feedlot | 4,361 | 26 |
| | Grassland and pasture | 265 | 2 |
| | Developed [c] | 200 | 1 |
| | Forest and shrub | 56 | < 1 |
| | Wetland and open water | 70 | < 1 |
| SSTS | | 708 | 4 |
| Atmospheric deposition | | 703 | 4 |
| *Total:* | | *16,834* | *100* |

a. Assumes 48 µg/L TP in Rice Lake (site 209; 2010–2019 growing season mean).

b. Less than 1% of the watershed load to Rice Lake is from WWTP effluent. Paynesville WWTP (formerly MN0020168) and Brooten WWTP (formerly MN0025909) are represented in the HSPF model. The Paynesville WWTP was reissued an SDS only permit in 2019 and it does not currently discharge phosphorus to surface waters. The Brooten WWTP current permit is MNG585271, with a phosphorus limit of 184 kg/yr (406 lb/yr) and a 1.0 mg/L calendar monthly average limit; the amount of load that reaches Rice Lake is lower due to assimilation in the watershed. The Brooten WWTP discharges into the Skunk River and is located over 25 miles upstream of Rice Lake.

c. Loading from shoreline development may be underestimated in HSPF because shoreline development often is classified as a natural land cover in a land cover dataset such as NLCD 2016.

### 3.2.4 Water quality goals, loading targets, and implementation recommendations

The goals are based on water quality in the lake's main basin (site 211). If Rice Lake were meeting the water quality standard of 40 µg/L and there were no load reductions in the Lake Koronis focus area, the phosphorus concentration in Lake Koronis is expected to be 30 µg/L. This is lower than 31 µg/L, which represents a 5% improvement in lake phosphorus concentration. To improve water quality in Rice Lake, the primary implementation strategies outlined in the *Rice Lake TMDL Implementation Plan* (Wenck 2012b) are improving manure and feedlot management, developing rules to minimize the impacts of development, evaluating and prioritizing wetlands for protection and restoration, continuing efforts to identify and update nonconforming septic systems, and reducing internal load.

In order to further protect Lake Koronis, a 5% reduction in watershed runoff loading from the Lake Koronis focus area is proposed, which translates to a reduction of 248 lb/yr, in addition to bringing all SSTS around the Lake Koronis shoreline into compliance (reduction of 92 lb/yr). Under these conditions (i.e., Rice Lake at 40 µg/L and a 5% reduction in watershed loading), the BATHTUB model predicts 30 µg/L TP (which is a 9% reduction in lake phosphorus concentration), 16 µg/L chl-*a*, and 2.2 m Secchi. These values serve as the Lake Koronis targets (Table 20). To reach the lake TP goal of 30 µg/L, a TP load reduction of 2,085 lb/yr is needed, which represents an overall 12% reduction in the phosphorus load to the lake.

Of the load that originates in the Lake Koronis focus area, approximately 69% is from cropland runoff, and the primary focus of the BMP implementation scenario is to reduce this cropland runoff load. The BMPs of primary interest in the Lake Koronis focus area are alternative tile intakes, wetland restoration, and water and sediment control basins (WASCOBs).

A variety of implementation scenarios could achieve the 248 lb/yr TP reduction needed to meet the Lake Koronis protection goals in the focus area. Table 22 can be used to develop alternative scenarios by multiplying the TP reductions (lb/ac) by treated areas to estimate the load reduction for each BMP (see Section 2.3 for more detailed guidance).

**Table 22. Options for Lake Koronis implementation scenario.**

| BMP name | BMP applicable land cover | TP percent reduction | TP reduction (lb/ac) | Cost to incentivize ($/ac/yr) |
|---|---|---|---|---|
| Alternative tile intakes | Drained cropland | 55 | 0.30 | 2.33 |
| Restore tiled wetlands (cropland) | Drained cropland | 42 | 0.23 | 30.71 |
| WASCOBs | High slope cropland | 73 | 0.40 | 49.33 |

Alternative BMP scenarios can be developed for Lake Koronis to achieve a reduction of 248 lb/yr over the 10,034 acres of cropland in the focus area. The simulated existing TP loading from cropland in the Lake Koronis focus area is on average 0.55 lb/ac-yr.

One implementation option is provided in Table 23. In addition to SSTS compliance (92 lb/yr), the implementation scenario incorporates a mix of alternative tile intakes, wetland restoration, and WASCOBs to achieve the 248 lb/yr reduction needed from cropland, which amounts to a 6% decrease in TP loads from cropland in the focus area (Table 24).

**Table 23. Implementation scenario for Lake Koronis focus area.**

In addition to the BMPs presented here, the implementation scenario assumes that all SSTS are conforming, which is predicted to achieve a reduction of 92 lb/yr.

| BMP | TP load reduction (%) | Cost to incentivize ($/ac/yr) | Cropland area treated by BMP (ac) | TP load reduction (lb/yr) | Cost to incentivize ($/yr) |
|---|---|---|---|---|---|
| Alternative tile intakes | 55 | 2.33 | 661 | 198 | 1,541 |
| Restore tiled wetlands | 42 | 30.71 | 108 | 25 | 3,311 |
| WASCOBs | 73 | 49.33 | 62 | 25 | 3,058 |
| *Total* | | | *831* [a] | *248* | *7,910* |

a. 831 acres represents 8% of the cropland area in the Lake Koronis focus area

**Table 24. Lake Koronis phosphorus loading targets.**

| P source | | Existing P load (lb/yr) | Target P load (lb/yr) | Target P load reduction (lb/yr) | Target P load reduction (%) |
|---|---|---|---|---|---|
| Rice Lake outlet [a] | | 10,471 | 8,726 | 1,745 | 17 |
| Watershed runoff | Cropland and feedlot | 4,361 | 4,113 | 248 | 6 |
| | Grassland and pasture | 265 | 265 | 0 | 0 |
| | Developed | 200 | 200 | 0 | 0 |
| | Forest and shrub | 56 | 56 | 0 | 0 |
| | Wetland and open water | 70 | 70 | 0 | 0 |
| SSTS [b] | | 708 | 616 | 92 | 13 |
| Atmospheric deposition | | 703 | 703 | 0 | 0 |
| *Total* | | *16,834* | *14,749* | *2,085* | *12* |

a. Existing load based on Rice Lake average concentration of 48 µg/L; target load based on 40 µg/L

b. Approximately 95 SSTS around the lake shoreline are nonconforming (Table 6). SSTS loading goal assumes that all SSTS are conforming.

# 3.3 Lake Calhoun (34-0062-00)

## 3.3.1 Watershed characterization

The Lake Calhoun Watershed is located in the central-northwest part of the NFCRW. The lake outlets into the Middle Fork Crow River from the southern part of the lake. Upstream of the outlet, along the southwest part of the lake, is a bypass channel from the Middle Fork Crow River to Lake Calhoun (Figure 7). This channel can serve as an inlet from the river to Lake Calhoun. However, flow from the Middle Fork Crow River typically does not enter Lake Calhoun but rather continues along the path of the Middle Fork Crow River. The flow direction is influenced by relative water levels in the area. For the analyses in this report, it was assumed that the Middle Fork Crow River does not enter Lake Calhoun through the bypass channel.


**Figure 7. Hydrologic connections between Lake Calhoun and Middle Fork Crow River inlet.**

The watershed is relatively small (11 square miles), with a watershed to lake ratio of approximately 11:1. The entire watershed is in Irving Township, Kandiyohi County. There are no cities in the Lake Calhoun Watershed, and development is heaviest along the lake's north and east shoreline. Land cover is approximately 50% cropland, with substantial areas of grassland, pasture, and forest (Table 8, Figure 8).

Many of the watercourses in the watershed have been hydrologically altered (Figure 8). There are eight registered feedlots in the Lake Calhoun Watershed; none of these feedlots are CAFOs. The primary livestock type in the registered feedlots is cattle (approximately 460 registered cattle), with small numbers of horses (45) and chickens (10).

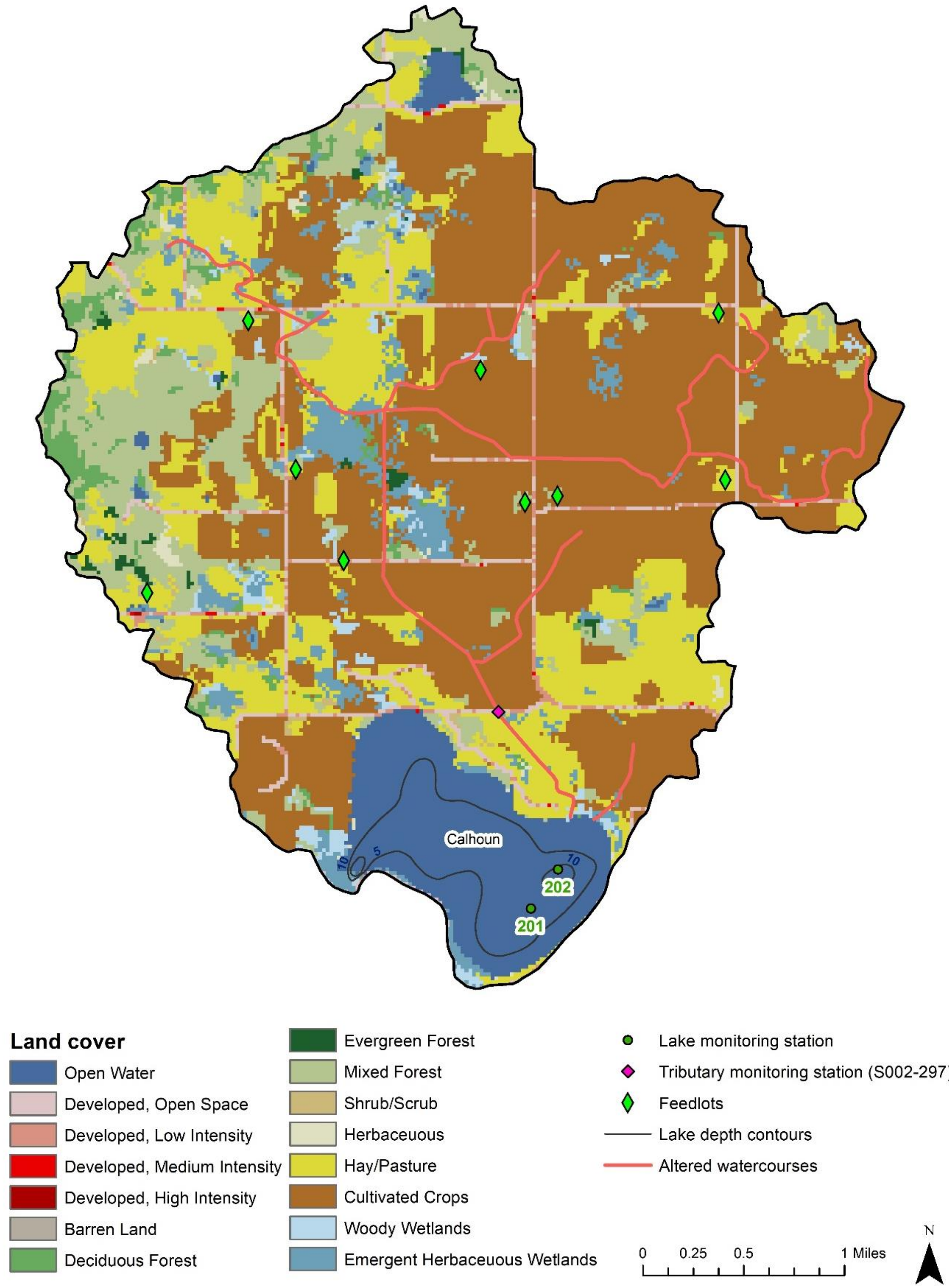
**Table 25. Lake Calhoun Watershed land cover summary (NLCD 2016).**

| Land Cover | Area (acres) | Percent area (%) |
|---|---|---|
| Cropland and feedlot | 3,534 | 50 |
| Grassland and pasture | 1,510 | 22 |
| Developed [a] | 284 | 4 |
| Forest and shrub | 1,084 | 16 |
| Wetland and open water [b] | 543 | 8 |

a. Shoreline development is not reflected in the “developed” land cover classes in NLCD due to scale, and the developed area is likely underestimated in this summary.

b. Wetland and open water does not include the surface area of Lake Calhoun.

**Figure 8. Lake Calhoun Watershed land cover (NLCD 2016), feedlots, and monitoring sites.**



### 3.3.2 Lake conditions

Lake Calhoun has a surface area of 619 acres and a mean depth of 5 feet (Table 26). Emergent vegetation (i.e., bulrush and cattails) is present along the western and southern portions of the lake. Submergent vegetation such as northern milfoil, muskgrass, filamentous algae, water moss, and various pondweed species can be dense. The invasive species Eurasian watermilfoil was first found in Lake Calhoun in 2010, mostly near the Middle Fork Crow River inlet. Zebra mussels, another invasive species, are also present in the lake. Lake Calhoun is a popular bluegill and northern pike fishery. Walleye were stocked in the lake in 2012, 2014, 2017, and 2019.

**Table 26. Lake Calhoun morphometry and watershed size.**

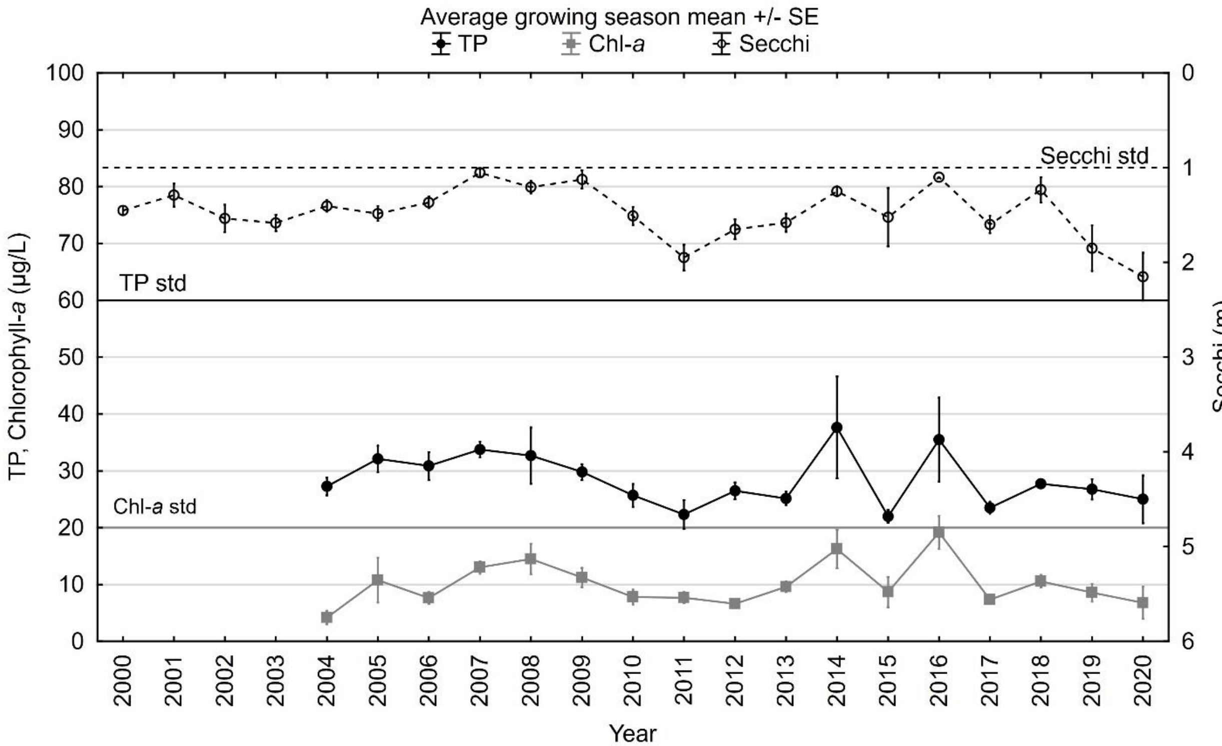
| Surface area (ac) | Maximum depth (ft) | Mean depth (ft) | Watershed area (sq. mi.) | Percent littoral area |
|---|---|---|---|---|
| 619 | 13 | 5 | 10.8 | 100 |

The average phosphorus concentration in Lake Calhoun is 27 µg/L, which is well below the standard of 60 µg/L. Similarly, the chl-*a* concentration and Secchi depth both are better than the respective standards (Table 27). Water quality standards were met in all years during which water quality data were collected (Figure 9).

**Table 27. Lake Calhoun water quality summary (sites 34-00062-00-201 and 202) and phosphorus targets.**

| Parameter | Observed (2010–2019) | Water quality standard for NCHF shallow lakes | Target—5% reduction in TP and predicted chl-*a* and Secchi |
|---|---|---|---|
| TP (µg/L) | 27 | 60 | 26 |
| Chl-*a* (µg/L) | 10 | 20 | 9 |
| Secchi (m) | 1.5 | 1.0 | 1.5 |

**Figure 9. Lake Calhoun (34-0062-00-201 and -202) growing season means of TP, chl-*a*, and Secchi.**




## 3.3.3 Phosphorus source summary

The majority of the phosphorus loading to Lake Calhoun is from cropland runoff. Other sources of phosphorus include SSTS, runoff from grassland and pasture, runoff from developed areas, and atmospheric deposition (Table 28).

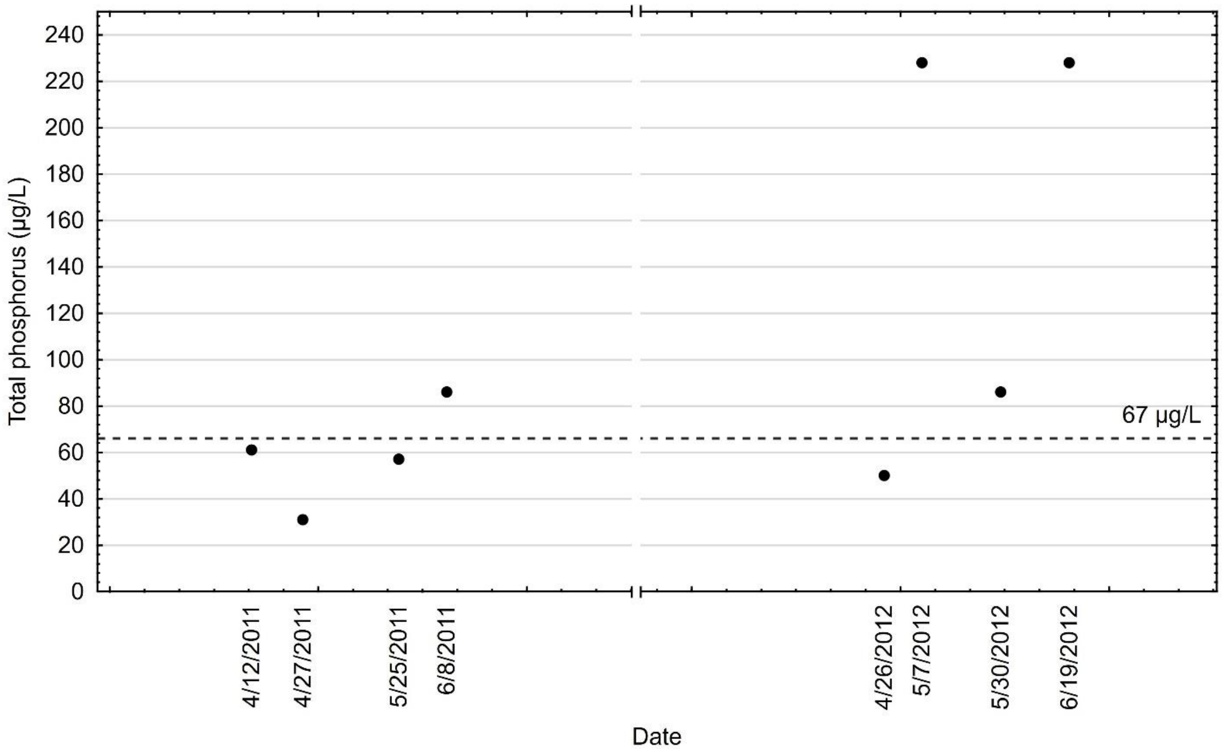
**Table 28. Phosphorus source summary for Lake Calhoun.**

| Source | | TP Load (lb/yr) | % Load |
|---|---|---|---|
| Watershed runoff | Cropland and feedlot | 405 | 60 |
| | Grassland and pasture | 21 | 3 |
| | Developed [a] | 15 | 2 |
| | Forest and shrub | 10 | 1 |
| | Wetland and open water | 7 | 1 |
| SSTS | | 72 | 11 |
| Atmospheric deposition | | 148 | 22 |
| *Total:* | | *678* | *100* |

a. Loading from shoreline development may be underestimated in HSPF because shoreline development often is classified as a natural land cover in a land cover dataset such as NLCD 2016.

The watershed loads presented in Table 28 (458 lb/yr) are lower than the watershed loads predicted in HSPF (1,702 lb/yr). Given the observed lake TP concentrations, the lake response model suggests that TP assimilation in the watershed reduces the TP load to the lake. The watershed loads were reduced by 73% for a total watershed load of 448 lb/yr (equivalent to a TP concentration in the tributary of 67 µg/L). TP monitoring data in the main tributary inlet to Lake Calhoun (County Ditch 26, monitoring station S002-297) are limited in the last 10 years (Figure 10). The average of the four samples collected in 2011 is 59 µg/L, and the average of the four samples from 2012 is 148 µg/L. Because of the limitations of the recent monitoring data (i.e., the few samples that were collected are from April through June, with no data from later in the season), the average TP concentration in the tributary is not known. However, because an average concentration of 67 µg/L is possible given the observed 2011 data and the generally high water quality of Lake Calhoun itself, the load adjustment is considered reasonable. If the load from SSTS to Lake Calhoun is overestimated, then the estimated watershed load would be higher. Additional monitoring of phosphorus loads in the primary tributary would support revisions to this loading analysis.

**Figure 10. Phosphorus concentrations in Lake Calhoun inlet (S002-297, CD 26 above Lk Calhoun), 2011–2012.**




67 µg/L TP is the modeled average phosphorus concentration in watershed runoff that reaches Lake Calhoun.

### 3.3.4 Water quality goals, loading targets, and implementation recommendations

The Lake Calhoun water quality goal is 26 µg/L TP (based on a 5% decrease in the average TP concentration). The BATHTUB model predicts that this TP concentration corresponds to 9 µg/L chl-*a* and 1.5 m Secchi depth (Table 27). To reach the lake TP goal of 26 µg/L, a TP load reduction of 59 lb/yr is needed, which represents an overall 9% reduction in the phosphorus load to the lake.

Approximately 60% of the phosphorus load to Lake Calhoun is from cropland runoff (Table 28), and the primary focus of the BMP implementation scenario is to reduce this cropland runoff load. The BMPs of primary interest in the Lake Calhoun Watershed are alternative tile intakes, wetland restoration, and WASCOBs. In addition to practices that reduce phosphorus loading from cropland, all SSTS around the shoreline of Lake Calhoun should be brought into compliance.

A variety of implementation scenarios could achieve the 59 lb/yr TP reduction needed to meet the Lake Calhoun protection goals. Table 29 can be used to develop alternative scenarios by multiplying the TP reductions (lb/ac) by treated areas to estimate the load reduction for each BMP (see Section 2.3 for more detailed guidance).

**Table 29. Options for Lake Calhoun implementation scenario.**

| BMP name | BMP applicable land cover | TP percent reduction | TP reduction (lb/ac) | Cost to incentivize ($/ac/yr) |
|---|---|---|---|---|
| Alternative tile intakes | Drained cropland | 55 | 0.09 | 2.33 |
| Restore tiled wetlands (cropland) | Drained cropland | 42 | 0.07 | 30.71 |
| WASCOBs | High slope cropland | 73 | 0.11 | 49.33 |

Alternative BMP scenarios can be developed for Lake Calhoun to achieve a reduction of 40 lb/yr over the 3,534 acres of cropland. The simulated existing TP loading from cropland in the Lake Calhoun Watershed is on average 0.16 lb/ac-yr.

One implementation option is provided in Table 30. In addition to SSTS compliance (19 lb/yr), the implementation scenario incorporates a mix of alternative tile intakes, wetland restoration, and WASCOBs to achieve the 40 lb/yr reduction needed from cropland. This amounts to a 10% decrease in TP loads from cropland (Table 31).

**Table 30. Implementation scenario for Lake Calhoun.**
In addition to the BMPs presented here, the implementation scenario assumes that all SSTS are conforming, which is predicted to achieve a reduction of 19 lb/yr.

| BMP | TP load reduction (%) | Cost to incentivize ($/ac/yr) | Cropland area treated by BMP (ac) | TP load reduction (lb/yr) | Cost to incentivize ($/yr) |
|---|---|---|---|---|---|
| Alternative tile intakes | 55 | 2.33 | 356 | 32 | 828 |
| Restore tiled wetlands | 42 | 30.71 | 57 | 4 | 1,755 |
| WASCOBs | 73 | 49.33 | 33 | 4 | 1,644 |
| *Total* | | | *446* [a] | *40* | *4,227* |

a. 446 acres represents 13% of the cropland area in the Lake Calhoun Watershed

**Table 31. Lake Calhoun phosphorus loading targets.**

| P source | | Existing P load (lb/yr) | Target P load (lb/yr) | Target P load reduction (lb/yr) | Target P load reduction (%) |
|---|---|---|---|---|---|
| Watershed runoff | Cropland and feedlot | 405 | 365 | 40 | 10 |
| | Grassland and pasture | 21 | 21 | 0 | 0 |
| | Developed | 15 | 15 | 0 | 0 |
| | Forest and shrub | 10 | 10 | 0 | 0 |
| | Wetland and open water | 7 | 7 | 0 | 0 |
| SSTS [a] | | 72 | 53 | 19 | 26 |
| Atmospheric deposition | | 148 | 148 | 0 | 0 |
| *Total* | | *678* | *619* | *59* | *9* |

a. Approximately 19 SSTS around the lake shoreline are nonconforming (Table 6). SSTS loading goal assumes that all SSTS are conforming.

# 3.4 Lake Minnie-Belle (47-0119-00)

## 3.4.1 Watershed characterization

Lake Minnie-Belle is located the south-central portion of the NFCRW. The lake and most of its watershed are in the WCP ecoregion, and part of the watershed is in the NCHF ecoregion (Figure 11). The lake outlets to Sucker Creek, which flows through a series of water bodies before reaching Lake Washington, another protection lake. The watershed is relatively small (2.1 square miles), with a watershed to lake ratio of 2.3:1. The lake and its watershed are located in Meeker County. There are no cities in the Lake Minnie-Belle Watershed, and development is heaviest along the lake's shoreline. Land cover is approximately 58% cropland, with substantial areas of grassland, pasture, developed areas, and forest and shrub (Table 32, Figure 11). Many of the watercourses along the primary flow paths are altered (Figure 11). There are no registered feedlots in the Lake Minnie-Belle Watershed.

The Minnie-Belle Lake Aquatic Management Area (AMA) is a 16-acre area managed by the Minnesota Department of Natural Resources (DNR) on the north side of the lake. The AMA is designated for general use, which includes angling, nonmotorized travel, wildlife observation, and hunting and trapping.

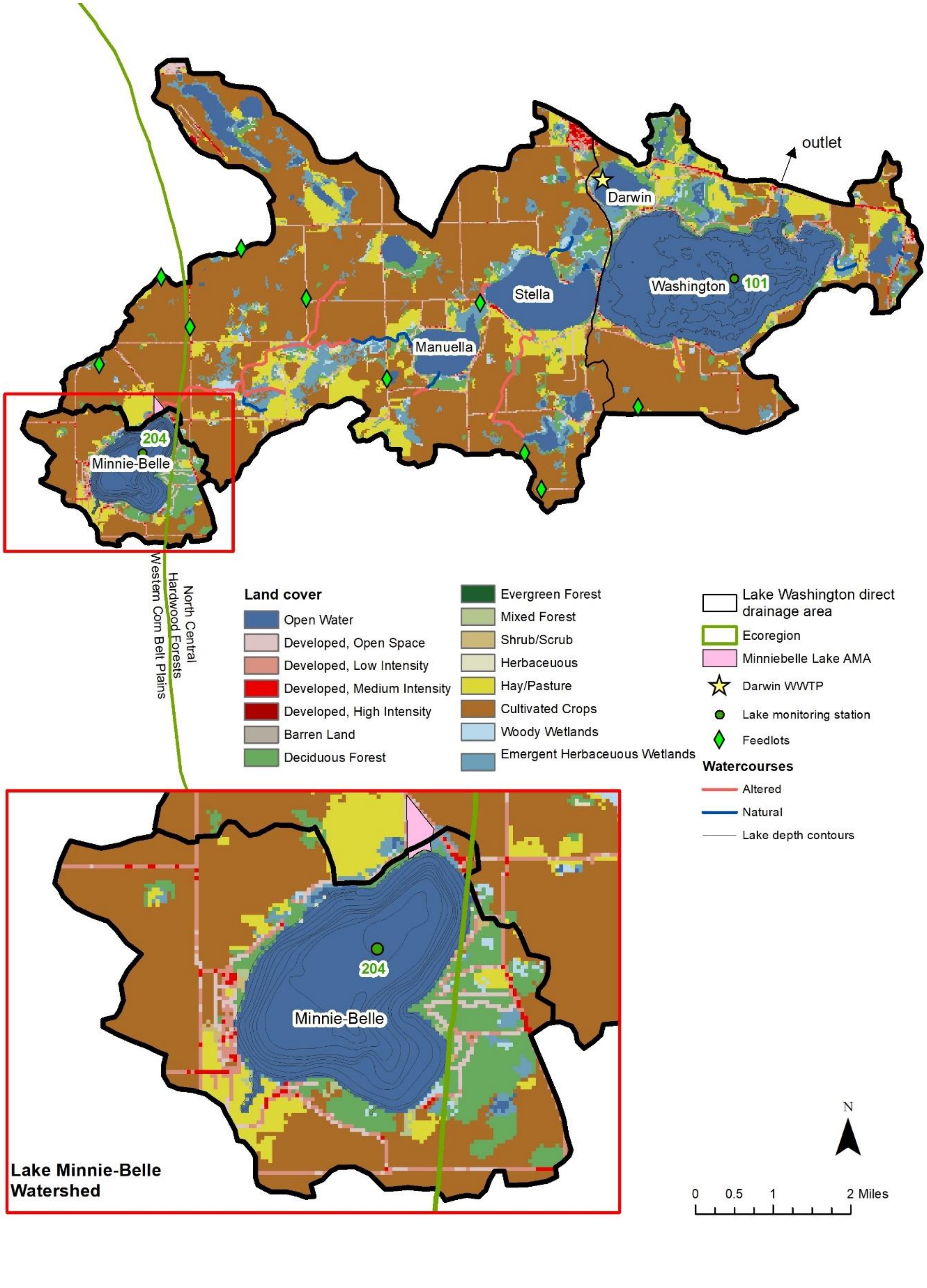
**Table 32. Lake Minnie-Belle Watershed land cover summary (NLCD 2016).**

| Land Cover | Area (acres) | Percent area (%) |
|---|---|---|
| Cropland and feedlot | 772 | 58 |
| Grassland and pasture | 99 | 7 |
| Developed [a] | 162 | 12 |
| Forest and shrub | 255 | 19 |
| Wetland and open water [b] | 57 | 4 |

a. Shoreline development is not reflected in the "developed" land cover classes in NLCD due to scale, and the developed area is likely underestimated in this summary.

b. Wetland and open water does not include the surface area of Lake Minnie-Belle.

**Figure 11. Lake Minnie-Belle and Washington Lake Watershed land cover (NLCD 2016), feedlots, and monitoring sites.**



### 3.4.2 Lake conditions

Lake Minnie-Belle has the highest water quality of the five protection lakes addressed in this report. The lake has a surface area of 591 acres and mean depth of 32 feet (Table 33). Approximately 31% of the lake is less than 15 feet deep. The fishery includes northern pike, bluegill, and largemouth bass, which are listed as primary management species in the 2011 lake management plan, in addition to walleye, which are a secondary management species and have been stocked in even years since 2012. A 2004 aquatic vegetation survey (Perleberg and Brown 2006) found 17 native aquatic plant species in the lake, which is a high number relative to other lakes in the region. Plants were found to a maximum depth of approximately 20 feet. Although the invasive species curly-leaf pondweed was found in the lake, it did not form single-species beds. A 2007 plant species survey (DNR 2007) also found curly-leaf pondweed in addition to 18 other submergent, emergent, and shoreline species.

**Table 33. Lake Minnie-Belle morphometry and watershed size.**

| Surface area (ac) | Maximum depth (ft) | Mean depth (ft) | Watershed area (sq. mi.) | Percent littoral area |
|---|---|---|---|---|
| 591 | 49 | 32 | 2.1 | 31 |

The average phosphorus concentration in Lake Minnie-Belle is 17 µg/L, which is well below the standard of 65 µg/L. Similarly, the chl-*a* concentration and Secchi depth both are better than the respective standards (Table 34). Water quality standards were met in all years during which water quality data were collected, and there are no apparent long-term trends in water quality (Figure 12). At times, the deep hole in the lake thermally stratifies in the summer, with low DO concentrations developing in bottom waters. These low DO conditions can lead to phosphorus release from the sediments and high phosphorus concentrations in the bottom waters (Figure 13). When the water column mixes in late summer/early fall, this phosphorus can be released to surface waters.

**Table 34. Lake Minnie-Belle water quality summary (site (47-0119-00-204) and phosphorus targets.**

| Parameter | Observed (2014–2019) | Water quality standard for WCBP lakes | Target—5% reduction in TP and predicted chl-*a* and Secchi |
|---|---|---|---|
| TP (µg/L) | 17 | 65 | 16 |
| Chl-*a* (µg/L) | 4 | 22 | 4 |
| Secchi (m) | 4.5 | 0.9 | 4.5 |

**Figure 12. Lake Minnie-Belle (47-0119-00-204) growing season means of TP, chl-*a*, and Secchi.**

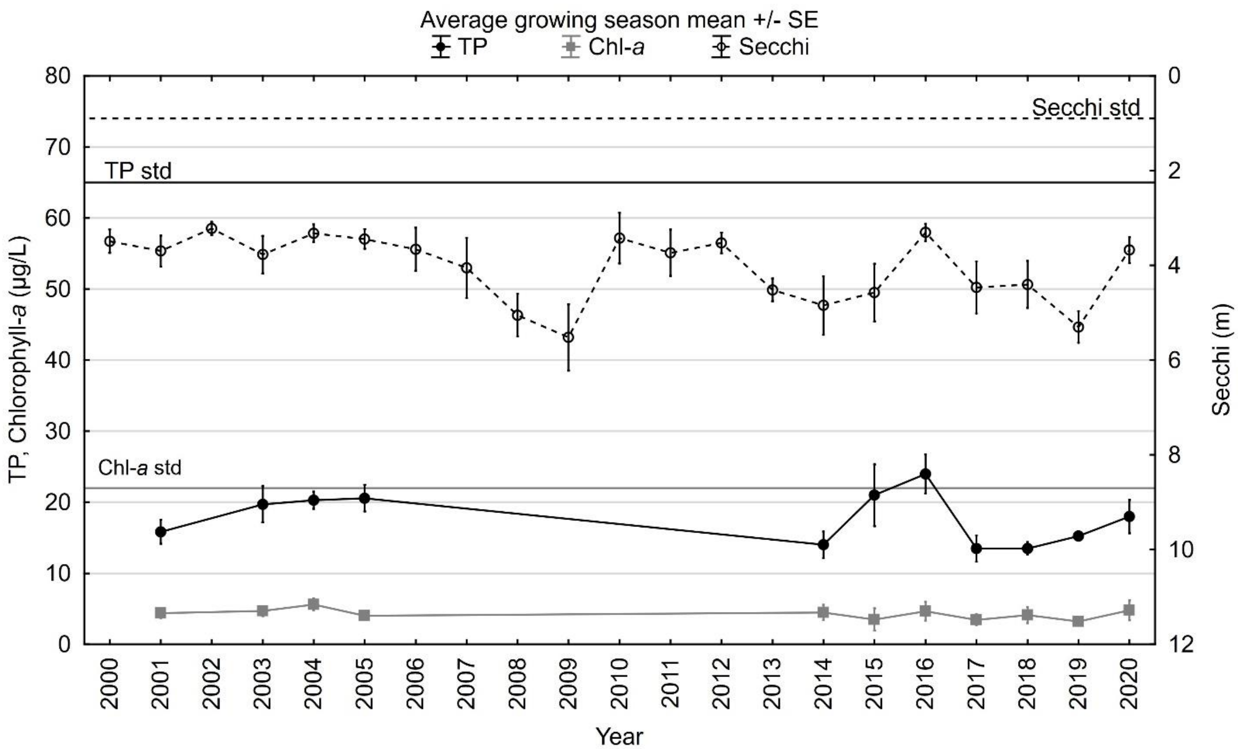
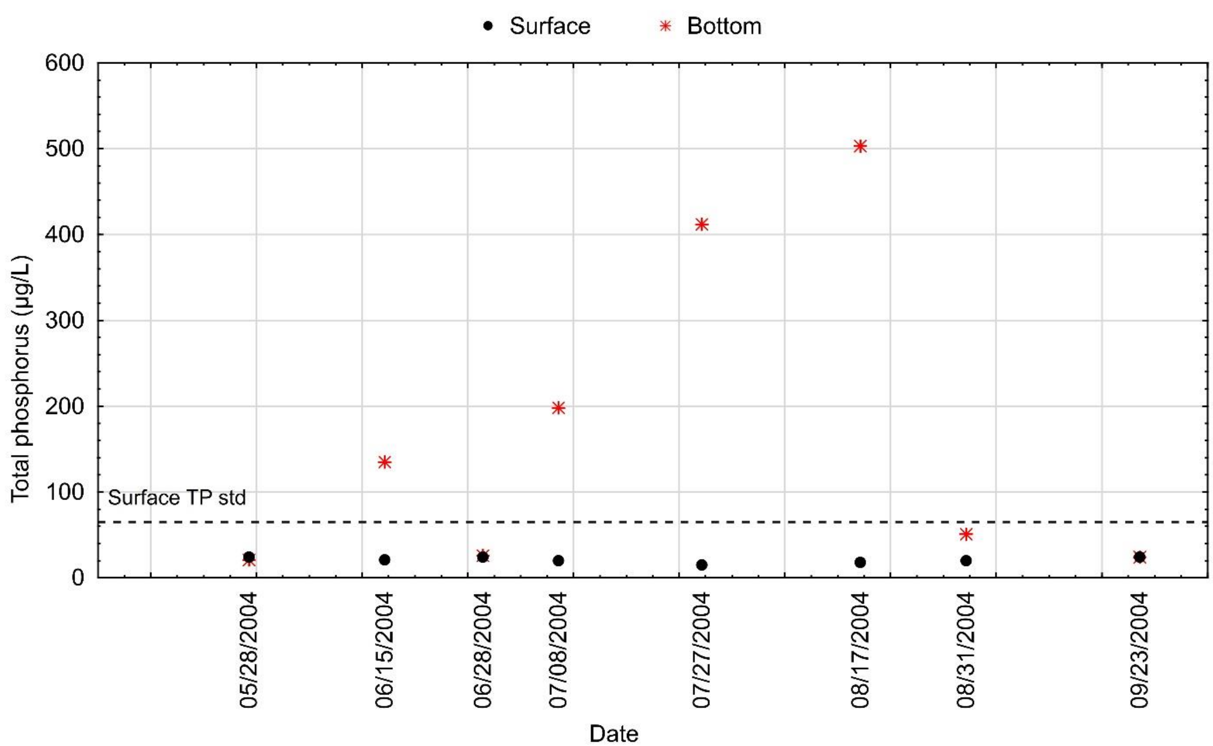



**Figure 13. Lake Minnie-Belle surface and bottom total phosphorus concentrations, 2004.**



### 3.4.3 Phosphorus source summary

The majority of the phosphorus loading to Lake Minnie-Belle is from cropland runoff. Other sources of phosphorus include SSTS and atmospheric deposition (Table 35).

**Table 35. Phosphorus source summary for Lake Minnie-Belle.**

| **Source** | | **TP Load (lbs/yr)** | **% Load** |
|---|---|---|---|
| Watershed runoff | Cropland and feedlot | 864 | 57 |
| | Grassland and pasture | 21 | 1 |
| | Developed [a] | 49 | 3 |
| | Forest and shrub | 24 | 2 |
| | Wetland and open water | 5 | < 1 |
| SSTS | | 416 | 27 |
| Atmospheric deposition | | 141 | 9 |
| *Total:* | | *1,520* | *100* |

a. Loading from shoreline development may be underestimated in HSPF because shoreline development often is classified as a natural land cover in a land cover dataset such as NLCD 2016.

### 3.4.4 Water quality goals, loading targets, and implementation recommendations

The Lake Minnie-Belle water quality goal is 16 µg/L TP (based on a 5% decrease in the average lake TP concentration). The Bathtub model predicts that this TP concentration corresponds to 4 µg/L chl-*a* and 4.5 m Secchi depth (Table 34). To reach the lake TP goal of 16 µg/L, a TP load reduction of 140 lb/yr is needed, which represents an overall 9% reduction in the phosphorus load to the lake.

Approximately 57% of the phosphorus load to Lake Minnie-Belle is from cropland runoff (Table 35), and the primary focus of the watershed BMP implementation scenario is to reduce this cropland runoff load. The BMPs of primary interest in the Lake Minnie-Belle Watershed are cover crops, perennial conservation cover (through the Conservation Reserve Program [CRP]), and wetland restoration. In addition to practices that reduce phosphorus loading from cropland, all SSTS around the shoreline of Lake Minnie-Belle should be brought into compliance.

A variety of implementation scenarios could achieve the 140 lb/yr TP reduction needed to meet the Lake Minnie-Belle protection goals. Table 36 can be used to develop alternative scenarios by multiplying the TP reductions (lb/ac) by treated areas to estimate the load reduction for each BMP (see Section 2.3 for more detailed guidance).

**Table 36. Options for Lake Minnie-Belle implementation scenario.**

| BMP name | BMP applicable land cover | TP percent reduction | TP reduction (lb/ac) | Cost to incentivize ($/ac/yr) |
|---|---|---|---|---|
| Restore tiled wetlands (cropland) | Drained cropland | 42 | 0.65 | 30.71 |
| Corn and soybeans with cover crop | Corn and soy | 24 | 0.37 | 37.98 |
| Conservation cover perennials | Corn and soy | 71 | 1.09 | 99.23 |
| Land conversion from cropland to grassland | Cropland | 91 | 1.41 | – [a] |

Alternative BMP scenarios can be developed for Lake Minnie-Belle to achieve a reduction of 70 lb/yr over the 772 acres of cropland. The simulated existing TP loading from cropland in the Lake Minnie-Belle Watershed is on average 1.54 lb/ac-yr.

a. Costs for land conversion are not included in SAM.

One implementation option is provided in Table 37 and Table 38. This scenario assumes that 85% of SSTS are conforming and 15% are failing to protect groundwater. This differs from the implementation scenarios for the other protection lakes, which assume 100% conforming SSTS. If all SSTS around Lake Minnie-Belle were conforming, the watershed load reduction goal would be 18 lb/yr, or a 2% reduction. A more balanced scenario is presented in Table 37 and Table 38 that splits the load reductions between cropland (70 lb/yr) and SSTS (70 lb/yr). The implementation scenario incorporates a mix of wetland restoration, corn and soybeans with cover crop, and conservation cover perennials to achieve the 70 lb/yr reduction needed from cropland, which amounts to an 8% decrease in TP loads from cropland (Table 38).

**Table 37. Implementation scenario for Lake Minnie-Belle.**

In addition to the BMPs presented here, the implementation scenario assumes that 85% of SSTS are conforming, which is predicted to achieve a reduction of 70 lb/yr.

| BMP | TP load reduction (%) | Cost to incentivize ($/ac/yr) | Cropland area treated by BMP (ac) | TP load reduction (lb/yr) | Cost to incentivize ($/yr) |
|---|---|---|---|---|---|
| Restore tiled wetlands | 42 | 30.71 | 22 | 14 | 661 |
| Corn and soybeans with cover crop | 24 | 37.98 | 114 | 42 | 4,311 |
| Conservation cover perennials | 71 | 99.23 | 13 | 14 | 1,275 |
| *Total* | | | *148* [a] | *70* | *6,247* |

a. 148 acres represents 19% of the cropland area in the Lake Minnie-Belle Watershed

**Table 38. Lake Minnie-Belle phosphorus loading targets.**

| P source | | Existing P load (lb/yr) | Target P load (lb/yr) | Target P load reduction (lb/yr) | Target P load reduction (%) |
|---|---|---|---|---|---|
| Watershed runoff | Cropland and feedlot | 864 | 794 | 70 | 8 |
| | Grassland and pasture | 21 | 21 | 0 | 0 |
| | Developed | 49 | 49 | 0 | 0 |
| | Forest and shrub | 24 | 24 | 0 | 0 |
| | Wetland and open water | 5 | 5 | 0 | 0 |
| SSTS [a] | | 416 | 346 | 70 | 17 |
| Atmospheric deposition | | 141 | 141 | 0 | 0 |
| *Total* | | *1,520* | *1,380* | *140* | *9* |

a. Approximately 125 SSTS around the lake shoreline are nonconforming (Table 6). The SSTS loading goal assumes 85% of SSTS are conforming and 15% are failing to protect groundwater. If all SSTS were conforming, the SSTS loading goal would be 294 lb/yr (122 lb/yr reduction).

# 3.5 Lake Washington (47-0046-00)

## 3.5.1 Watershed characterization

Lake Washington is located the south-central portion of the NFCRW approximately seven miles downstream of Lake Minnie-Belle. Sucker Creek, the outlet of Lake Minnie-Belle, flows through Manuella Lake and Lake Stella before entering Lake Washington (Figure 11). The most upstream portion (approximately four square miles) of the watershed is in the WCBP ecoregion, and the remaining area is in the NCHF ecoregion. The watershed is approximately 29 square miles, with a watershed to lake ratio of 7.7:1. The lake and its watershed are located in Meeker County. Portions of the cities of Darwin and Dassel are in the watershed (Figure 1), with additional development along the lake's shoreline. Land cover is approximately 57% cropland, with substantial areas of grassland, pasture, and wetlands and open water (Table 39, Figure 11). Most of the altered watercourses in the Lake Washington Watershed are located upstream of Lake Stella (Figure 11). There are 10 registered feedlots in the Lake Washington Watershed; none of these feedlots are CAFOs. The primary livestock type in the feedlots is cattle (approximately 1,205 registered cattle) and swine (110), with smaller numbers of horses (7) and chickens (25).

**Table 39. Lake Washington Watershed land cover summary (NLCD 2016).**

| Land Cover | Area (acres) | Percent area (%) |
|---|---|---|
| Cropland and feedlot | 11,417 | 57 |
| Grassland and pasture | 2,250 | 11 |
| Developed [a] | 1,219 | 6 |
| Forest and shrub | 1,310 | 6 |
| Wetland and open water [b] | 3,962 | 20 |

a. Shoreline development is not reflected in the "developed" land cover classes in NLCD due to scale, and the developed area is likely underestimated in this summary.

b. Wetland and open water does not include the surface area of Lake Washington.

### 3.5.2 Lake conditions

Lake Washington has a surface area of 2,420 acres and a mean depth of 8 feet (Table 40). Over 90% of the lake is less than 15 feet deep. The invasive species Eurasian watermilfoil was first documented in Lake Washington in 1999, and zebra mussels, another invasive species, were documented in 2015. The DNR's 2017 lake management plan for the lake lists walleye as primary management species. Walleye fry were stocked in the lake in even years from 2011 through 2019.

**Table 40. Lake Washington morphometry and watershed size.**

| Surface area (ac) | Maximum depth (ft) | Mean depth (ft) | Watershed area (sq. mi.) | Percent littoral area |
|---|---|---|---|---|
| 2,420 | 17 | 8 | 29 | 93 |

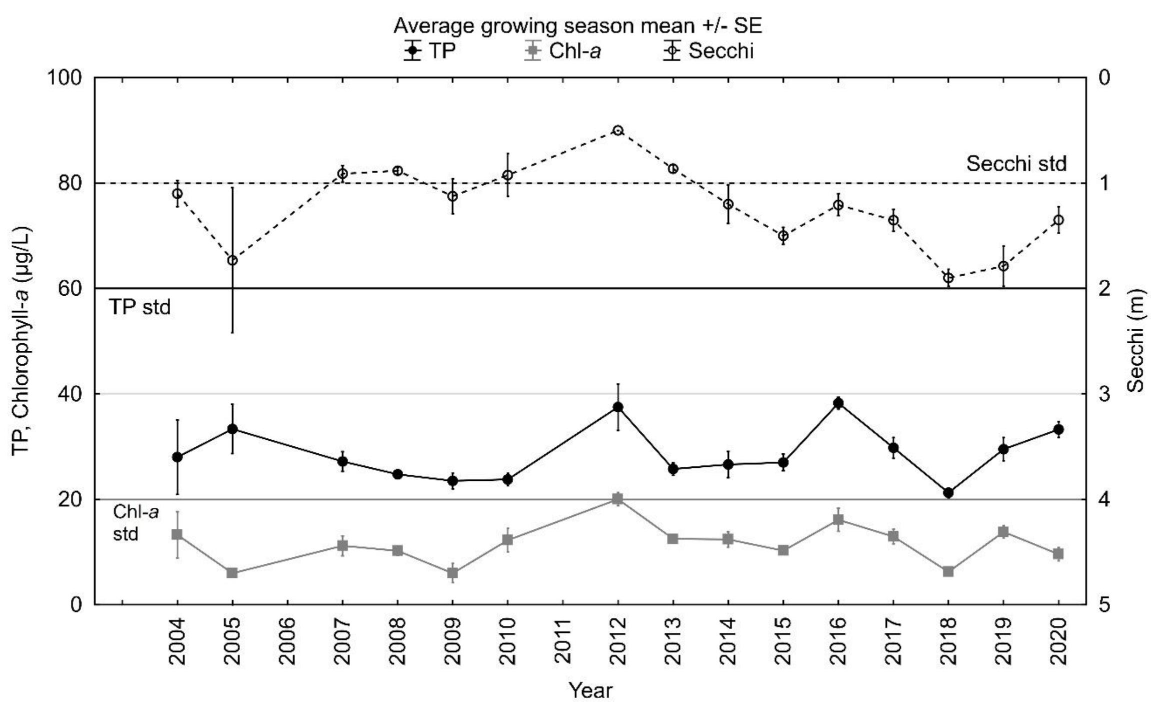
The average phosphorus concentration in Lake Washington is 29 µg/L, which is well below the standard of 60 µg/L. Similarly, the chl-*a* concentration and Secchi depth both are better than the respective standards (Table 41). The TP and chl-*a* water quality standards were met in all years during which water quality data were collected (Figure 14). The Secchi standard was not met in five of the 15 years.

**Table 41. Lake Washington water quality summary (sites 47-00046-00-101) and phosphorus targets.**

| Parameter | Observed (2010–2019) [a] | Water quality standard for NCHF shallow lakes | Target—5% reduction in TP and predicted chl-*a* and Secchi |
|---|---|---|---|
| TP (µg/L) | 29 | 60 | 27 |
| Chl-*a* (µg/L) | 13 | 20 | 12 |
| Secchi (m) | 1.2 | 1.0 | 1.3 |

a. Data from 2011 not included because sample size < 3

**Figure 14. Lake Washington (47-00046-00-101) growing season means of TP, chl-*a*, and Secchi.**



### 3.5.3 Phosphorus source summary

The majority of the phosphorus loading to Lake Washington is from cropland runoff and internal load. Other primary sources are from the Lake Stella outlet, SSTS, and atmospheric deposition (Table 42).

**Table 42. Phosphorus source summary for Lake Washington.**

| Source | | TP Load (lb/yr) | % Load |
|---|---|---|---|
| Lake Stella outlet [a] | | 450 | 9 |
| Watershed runoff (direct drainage) | Cropland and feedlot | 1,516 | 30 |
| | Grassland and pasture | 60 | 1 |
| | Developed [b] | 87 | 2 |
| | Forest and shrub | 33 | < 1 |
| | Wetland and open water | 34 | < 1 |
| SSTS | | 471 | 9 |
| Darwin WWTP [c] | | 24 | < 1 |
| Atmospheric deposition | | 578 | 11 |
| Internal and unidentified [d] | | 1,882 | 37 |
| *Total:* | | *5,135* | *100* |

a. Assumes 19 µg/L TP in Lake Stella (site 202; 2017 surface water growing season mean).

b. Loading from shoreline development may be underestimated in HSPF because shoreline development often is classified as a natural land cover in a land cover dataset such as NLCD 2016.

c. The Darwin WWTP (MNG585150, formerly MNG580150) discharges into Lake Darwin. The existing load is based on 2006–2015 (the same years that were simulated in the HSPF watershed runoff model). The TP permit limit is 69 kg/yr (152 lb/yr), 1.0 mg/L calendar monthly average limit.

d. This load is attributed to internal loading and/or other sources (such as additional watershed loads, feedlots, or septic system loads) that were not quantified with the available data.

### 3.5.4 Water quality goals, loading targets, and implementation recommendations

The Lake Washington water quality goal is 27 µg/L TP (based on a 5% decrease in the average lake TP concentration). The Bathtub model predicts that this TP concentration corresponds to 12 µg/L chl-*a* and 1.3 m Secchi depth (Table 41). To reach the lake TP goal of 27 µg/L, a TP load reduction of 436 lb/yr is needed, which represents an overall 8% reduction in the phosphorus load to the lake. When the permitted load from Darwin WWTP is taken into account, a TP load reduction of 564 lb/yr is needed (see below).

Aside from reductions in SSTS loads, load reduction goals were split evenly between watershed runoff and internal load. The individual load reduction goals take into account the permitted load from Darwin WWTP, which discharges to Lake Darwin in the Lake Washington Watershed (Figure 11). The existing load from the WWTP (24 lb/yr) represents less than 1% of the TP load to Lake Washington (Table 42). The Lake Washington implementation scenario includes the permitted load from the Darwin WWTP (69 kg/yr, or 152 lb/yr). Because phosphorus assimilation of the WWTP load in Lake Darwin was not modeled, the load from the WWTP that reaches Lake Washington is likely lower. The load reduction goals for watershed runoff and internal load, which compensate for the permitted WWTP load (which is higher than the estimated existing WWTP load), are therefore conservative estimates.

Lake Stella, which is directly upstream of Lake Washington, meets water quality standards; therefore, load reductions should be targeted to the portion of the Lake Washington Watershed that is downstream of Lake Stella, referred to as the direct drainage area (Figure 11).

Approximately 30% of the phosphorus load to Lake Washington is from cropland runoff in the direct drainage area (Table 42), and the primary focus of the watershed BMP implementation scenario is to reduce this cropland runoff load. The BMPs of primary interest in the Lake Washington Watershed are WASCOBs, alternative drain tile inlets, and wetland restoration. In addition to practices that reduce phosphorus loading from cropland, all SSTS around the shoreline of Lake Washington should be brought into compliance.

A variety of implementation scenarios could achieve the 213 lb/yr TP reduction in watershed loading needed to meet the Lake Washington protection goals. Table 43 can be used to develop alternative scenarios by multiplying the TP reductions (lb/ac) by treated areas to estimate the load reduction for each BMP (see Section 2.3 for more detailed guidance). In addition to the BMP options in Table 43, shoreline restoration should also be considered. Management practices to reduce internal loading may also be considered; however, internal loading may be reduced on its own in response to reductions in external phosphorus loading. Therefore, reductions from the watershed and from SSTS should be a priority. For information on methods to reduce internal phosphorus loads, see *Minnesota State and Regional Government Review of Internal Phosphorus Load Control* (MPCA et al. 2020).

**Table 43. Options for Lake Washington implementation scenario.**

| BMP name | BMP applicable land cover | TP percent reduction | TP reduction (lb/ac) | Cost to incentivize ($/ac/yr) |
|---|---|---|---|---|
| Alternative tile intakes | Drained cropland | 55 | 0.09 | 2.33 |
| Restore tiled wetlands (cropland) | Drained cropland | 42 | 0.11 | 30.71 |
| WASCOBs | High slope cropland | 73 | 0.11 | 49.33 |

Alternative BMP scenarios can be developed for Lake Washington to achieve a reduction of 213 lb/yr over the 11,417 acres of cropland. The simulated existing TP loading from cropland in the Lake Washington direct drainage area is on average 1.19 lb/ac-yr.

One implementation option is provided in Table 44. In addition to SSTS compliance (138 lb/yr), the implementation scenario incorporates a mix of WASCOBs, alternative tile intakes, and wetland restoration to achieve the 213 lb/yr reduction needed from cropland, which amounts to a 14% decrease in TP loads from cropland (Table 45).

**Table 44. Implementation scenario for Lake Washington.**

In addition to the BMPs presented here, the implementation scenario assumes that all SSTS are conforming, which is predicted to achieve a reduction of 138 lb/yr.

| BMP | TP load reduction (%) | Cost to incentivize ($/ac/yr) | Cropland area treated by BMP (ac) | TP load reduction (lb/yr) | Cost to incentivize ($/yr) |
|---|---|---|---|---|---|
| Alternative tile intakes | 55 | 2.33 | 262 | 171 | 611 |
| Restore tiled wetlands | 42 | 30.71 | 43 | 21 | 1,308 |
| WASCOBs | 73 | 49.33 | 24 | 21 | 1,208 |
| *Total* | | | *329* [a] | *213* | *3,127* |

a. 329 acres represents 18% of the cropland area (1,879 ac) in the Lake Washington direct drainage area.

**Table 45. Lake Washington phosphorus loading targets.**

| P source | | Existing P load (lb/yr) | Target P load (lb/yr) | Target P load reduction (lb/yr) | Target P load reduction (%) |
|---|---|---|---|---|---|
| Lake Stella outlet | | 450 | 450 | 0 | 0 |
| Watershed runoff (direct drainage area) | Cropland and feedlot | 1,516 | 1,303 | 213 | 14 |
| | Grassland and pasture | 60 | 60 | 0 | 0 |
| | Developed | 87 | 87 | 0 | 0 |
| | Forest and shrub | 33 | 33 | 0 | 0 |
| | Wetland and open water | 34 | 34 | 0 | 0 |
| SSTS [a] | | 471 | 333 | 138 | 29 |
| Darwin WWTP | | 24 | 152 | (-128) [b] | NA |
| Atmospheric deposition | | 578 | 578 | 0 | 0 |
| Internal and unidentified [c] | | 1,882 | 1,669 | 213 | 11 |
| *Total* | | *5,135* | *4,699* | *436* [d] | *8* |

a. Approximately 141 SSTS around the lake shoreline are nonconforming (Table 6). SSTS loading goal assumes that all SSTS are conforming.

b. Because the Darwin WWTP permitted load (152 lb/yr) is higher than the estimated existing load (24 lb/yr), a 128 lb/yr increase in loading from the WWTP is taken into account in the loading targets; reductions in loads from cropland and internal loading accommodate for the potential increase in loading from the WWTP.

c. This load is attributed to internal loading and/or other sources (such as additional watershed loads, feedlots, or septic system loads) that were not quantified with the available data.

d. Overall, a 436 lb/yr reduction is needed to meet the Lake Washington protection goals. Taking into account the potential increase in loading from Darwin WWTP up to its permitted load, a load reduction of 564 lb/yr (11% reduction) from other sources is needed.

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# 5. Appendix A. Lake modeling documentation

A spreadsheet version of the lake model Bathtub (Walker 1987) was used to model lake water quality (i.e., phosphorus concentration, chl-*a* concentration, and Secchi transparency) in each protection lake. See the TMDL Report (HEI and MPCA 2023) and Section 2.3 of this report for more information on the lake modeling. The tables in this appendix show model inputs and select outputs.

## 5.1 Grove Lake

| | | |
|---|---|---|
| **Global variables** | | |
| Averaging period (yrs) | 1 | |
| Precipitation (in/yr) | 24.8 | |
| Evaporation (in/yr) | 24.8 | |
| Atmospheric TP Load (kg/km$^2$-yr) | 26.8 | |
| **Model options** | | |
| P balance | 2nd Order, Fixed | |
| P calibration | decay rates | |
| **Model coefficients** | | |
| TP | 1 | |
| TP availability factor | 1 | |
| **Segment** | | |
| Area (ac) | 353 | |
| Mean depth (ft) | 10.3 | |
| Mean depth of mixed layer (ft) | 6.6 | |
| Observed TP (µg/L) | 31.2 | |
| Target TP (µg/L) | 29.6 | |
| Observed chl-*a* (µg/L) | 10.0 | |
| Target chl-*a* (µg/L) | 9.5 | |
| Observed Secchi (m) | 2.03 | |
| Target Secchi (m) | 2.08 | |
| TP internal load release rate (mg/m2-d) | 0.0 | 0.0 |
| TP internal load time of release (d) | 0 | 0 |
| Hydraulic residence time (yr) | 1.1 | |
| Overflow rate (m/yr) | 2.9 | |
| | | |
| **Watershed** | | |
| Watershed area (ac) | 9254.1 | |
| Watershed:lake area | 26 | |

| **Segment mass balance: Baseline** | **Flow (hm3/yr)** | **% Flow** | **TP load (lb/yr)** | **% TP load** | **TP concentration (µg/L)** |
|---|---|---|---|---|---|
| Precipitation | 0.90 | 18% | 84.49 | 7% | 43 |
| SSTS | 0.02 | 0% | 100.59 | 8% | 3016 |
| Watershed Runoff | 4.14 | 82% | 1064.26 | 85% | 117 |
| Total | 5.05 | 100% | 1249.33 | 100% | 112 |
| Evaporation | 0.90 | 18% | | | |
| Sedimentation/retention | | | 963.62 | 77% | |
| Outflow | 4.15 | 82% | 285.71 | 23% | 31 |
| | | | | | |

| Segment mass balance: Target | Flow (hm3/yr) | % Flow | TP load (lb/yr) | % TP load | TP concentration (µg/L) |
|---|---|---|---|---|---|
| Precipitation | 0.90 | 18% | 84.49 | 7% | 43 |
| SSTS | 0.02 | 0% | 83.34 | 7% | 2498 |
| Watershed Runoff | 4.14 | 82% | 970.57 | 85% | 106 |
| Total | 5.05 | 100% | 1138.39 | 100% | 102 |
| Evaporation | 0.90 | 18% | 0 | 0% | 437 |
| Sedimentation/retention | | | 867.33 | 76% | |
| Outflow | 4.15 | 82% | 271.06 | 24% | 30 |

| Load Reductions | TP load reduction (lb/yr) | % TP reduction |
|---|---|---|
| Precipitation | 0.00 | 0% |
| SSTS | 17.25 | 17% |
| Watershed Runoff | 93.69 | 9% |
| Total | 110.94 | 9% |

## 5.2 Lake Koronis

| Global variables | | |
|---|---|---|
| Averaging period (yrs) | 1 | |
| Precipitation (in/yr) | 26 | |
| Evaporation (in/yr) | 26 | |
| Atmospheric TP Load (kg/km$^2$-yr) | 26.8 | |
| **Model options** | | |
| P balance | CB-Lakes | |
| P calibration | decay rates | |
| **Model coefficients** | | |
| TP | 1.03 | |
| TP availability factor | 1 | |
| **Segment** | | |
| Area (ac) | 2941 | |
| Mean depth (ft) | 29.0 | |
| Mean depth of mixed layer (ft) | 19.7 | |
| Observed TP (µg/L) | 32.8 | |
| Target TP (µg/L) | 29.7 | |
| Observed chl-*a* (µg/L) | 16.8 | |
| Target chl-*a* (µg/L) | 15.4 | |
| Observed Secchi (m) | 2.14 | |
| Target Secchi (m) | 2.28 | |
| TP internal load release rate (mg/m2-d) | 0.0 | 0.0 |
| TP internal load time of release (d) | 0 | 0 |
| Hydraulic residence time (yr) | 1.0 | |
| Overflow rate (m/yr) | 9.1 | |
| | | |
| **Watershed** | | |
| Watershed area (ac) | 193232.3 | |
| Watershed:lake area | 66 | |

| Segment mass balance: Baseline | Flow (hm3/yr) | % Flow | TP load (lb/yr) | % TP load | TP concentration (µg/L) |
|---|---|---|---|---|---|
| Precipitation | 7.85 | 7% | 703.10 | 4% | 41 |
| SSTS | 0.11 | 0% | 708.31 | 4% | 2872 |
| Rice Lake outflow | 98.95 | 85% | 10471.19 | 62% | 48 |
| Focus area (watershed runoff) | 8.84 | 8% | 4951.78 | 29% | 254 |
| Total | 115.76 | 100% | 16834.38 | 100% | 66 |
| Evaporation | 7.85 | 7% | | | |
| Sedimentation/retention | | | 9031.81 | 54% | |
| Outflow | 107.90 | 93% | 7802.57 | 46% | 33 |
| | | | | | |
| **Segment mass balance: Target** | **Flow (hm3/yr)** | **% Flow** | **TP load (lb/yr)** | **% TP load** | **TP concentration (µg/L)** |
| Precipitation | 7.85 | 7% | 703.10 | 5% | 41 |
| SSTS | 0.11 | 0% | 616.19 | 4% | 2498 |
| Rice Lake outflow | 98.95 | 85% | 8725.99 | 59% | 40 |
| Focus area (watershed runoff) | 8.84 | 8% | 4704.20 | 32% | 241 |
| Total | 115.76 | 100% | 14749.47 | 100% | 58 |
| Evaporation | 7.85 | 7% | 0 | 0% | 444 |
| Sedimentation/retention | | | 7690.72 | 52% | |
| Outflow | 107.90 | 93% | 7058.75 | 48% | 30 |

| Load Reductions | TP load reduction (lb/yr) | % TP reduction |
|---|---|---|
| Precipitation | 0.00 | 0% |
| SSTS | 92.12 | 13% |
| Rice Lake outflow | 1745.20 | 17% |
| Focus area (watershed runoff) | 247.59 | 5% |
| Total | 2084.91 | 12% |

## 5.3 Lake Calhoun

| Global variables | |
|---|---|
| Averaging period (yrs) | 1 |
| Precipitation (in/yr) | 26.0 |
| Evaporation (in/yr) | 26.0 |
| Atmospheric TP Load (kg/km$^2$-yr) | 26.8 |
| **Model options** | |
| P balance | 2nd Order, Fixed |
| P calibration | decay rates |
| **Model coefficients** | |
| TP | 1 |
| TP availability factor | 1 |
| **Segment** | |
| Area (ac) | 620 |
| Mean depth (ft) | 4.0 |
| Mean depth of mixed layer (ft) | 4.0 |
| Observed TP (µg/L) | 27.3 |
| Target TP (µg/L) | 25.9 |
| Observed chl-*a* (µg/L) | 10.2 |

| | | |
|---|---|---|
| Target chl-*a* (µg/L) | 9.4 | |
| Observed Secchi (m) | 1.52 | |
| Target Secchi (m) | 1.54 | |
| TP internal load release rate (mg/m2-d) | 0.0 | 0.0 |
| TP internal load time of release (d) | 0 | 0 |
| Hydraulic residence time (yr) | 1.1 | |
| Overflow rate (m/yr) | 1.1 | |
| | | |
| **Watershed** | | |
| Watershed area (ac) | 6918.3 | |
| Watershed:lake area | 11 | |

| **Segment mass balance: Baseline** | **Flow (hm3/yr)** | **% Flow** | **TP load (lb/yr)** | **% TP load** | **TP concentration (µg/L)** |
|---|---|---|---|---|---|
| Precipitation | 1.66 | 37% | 148.30 | 22% | 41 |
| SSTS | 0.01 | 0% | 71.72 | 11% | 3360 |
| Watershed Runoff | 2.82 | 63% | 457.79 | 68% | 74 |
| Total | 4.49 | 100% | 677.81 | 100% | 68 |
| Evaporation | 1.66 | 37% | | | |
| Sedimentation/retention | | | 507.23 | 75% | |
| Outflow | 2.83 | 63% | 170.57 | 25% | 27 |
| | | | | | |
| **Segment mass balance: Target** | **Flow (hm3/yr)** | **% Flow** | **TP load (lb/yr)** | **% TP load** | **TP concentration (µg/L)** |
| Precipitation | 1.66 | 37% | 148.30 | 24% | 41 |
| SSTS | 0.01 | 0% | 53.32 | 9% | 2498 |
| Watershed Runoff | 2.82 | 63% | 416.77 | 67% | 67 |
| Total | 4.49 | 100% | 618.39 | 100% | 62 |
| Evaporation | 1.66 | 37% | 0 | 0% | 125 |
| Sedimentation/retention | | | 456.56 | 74% | |
| Outflow | 2.83 | 63% | 161.83 | 26% | 26 |

| **Load Reductions** | **TP load reduction (lb/yr)** | **% TP reduction** |
|---|---|---|
| Precipitation | 0.00 | 0% |
| SSTS | 18.40 | 26% |
| Watershed Runoff | 41.02 | 9% |
| Total | 59.41 | 9% |

## 5.4 Lake Minnie-Belle

| | |
|---|---|
| **Global variables** | |
| Averaging period (yrs) | 1 |
| Precipitation (in/yr) | 31.1 |
| Evaporation (in/yr) | 31.1 |
| Atmospheric TP Load ($kg/km^2$-yr) | 26.8 |
| **Model options** | |
| P balance | 2nd Order, Fixed |
| P calibration | decay rates |
| **Model coefficients** | |

| | | |
|---|---|---|
| TP | 1.02 | |
| TP availability factor | 1 | |
| **Segment** | | |
| Area (ac) | 591 | |
| Mean depth (ft) | 31.5 | |
| Mean depth of mixed layer (ft) | 26.2 | |
| Observed TP (µg/L) | 16.9 | |
| Target TP (µg/L) | 16.1 | |
| Observed chl-*a* (µg/L) | 3.9 | |
| Target chl-*a* (µg/L) | 3.7 | |
| Observed Secchi (m) | 4.48 | |
| Target Secchi (m) | 4.53 | |
| TP internal load release rate (mg/m2-d) | 0.0 | 0.0 |
| TP internal load time of release (d) | 0 | 0 |
| Hydraulic residence time (yr) | 19.0 | |
| Overflow rate (m/yr) | 0.5 | |
| | | |
| **Watershed** | | |
| Watershed area (ac) | 1343.8 | |
| Watershed:lake area | 2.3 | |

| **Segment mass balance: Baseline** | **Flow (hm3/yr)** | **% Flow** | **TP load (lb/yr)** | **% TP load** | **TP concentration (µg/L)** |
|---|---|---|---|---|---|
| Precipitation | 1.89 | 61% | 141.21 | 9% | 34 |
| SSTS | 0.05 | 2% | 415.92 | 27% | 3533 |
| Watershed Runoff | 1.16 | 37% | 963.33 | 63% | 378 |
| Total | 3.10 | 100% | 1520.46 | 100% | 223 |
| Evaporation | 1.89 | 61% | | | |
| Sedimentation/retention | | | 1475.37 | 97% | |
| Outflow | 1.21 | 39% | 45.09 | 3% | 17 |
| | | | | | |
| **Segment mass balance: Target** | **Flow (hm3/yr)** | **% Flow** | **TP load (lb/yr)** | **% TP load** | **TP concentration (µg/L)** |
| Precipitation | 1.89 | 61% | 141.21 | 10% | 34 |
| SSTS | 0.05 | 2% | 294.15 | 21% | 2498 |
| Watershed Runoff | 1.16 | 37% | 944.90 | 68% | 371 |
| Total | 3.10 | 100% | 1380.25 | 100% | 202 |
| Evaporation | 1.89 | 61% | 0 | 0% | 321 |
| Sedimentation/retention | | | 1337.32 | 97% | |
| Outflow | 1.21 | 39% | 42.93 | 3% | 16 |

| **Load Reductions** | **TP load reduction (lb/yr)** | **% TP reduction** |
|---|---|---|
| Precipitation | 0.00 | 0% |
| SSTS | 121.78 | 29% |
| Watershed Runoff | 18.43 | 2% |
| Total | 140.21 | 9% |

## 5.5 Lake Washington

| | | |
|---|---|---|
| **Global variables** | | |
| Averaging period (yrs) | 1 | |
| Precipitation (in/yr) | 28 | |
| Evaporation (in/yr) | 28 | |
| Atmospheric TP Load (kg/km$^2$-yr) | 26.8 | |
| **Model options** | | |
| P balance | 2nd Order, Fixed | |
| P calibration | decay rates | |
| **Model coefficients** | | |
| TP | 1.00 | |
| TP availability factor | 1 | |
| **Segment** | | |
| Area (ac) | 2419 | |
| Mean depth (ft) | 7.9 | |
| Mean depth of mixed layer (ft) | 7.9 | |
| Observed TP (µg/L) | 28.8 | |
| Target TP (µg/L) | 27.4 | |
| Observed chl-*a* (µg/L) | 12.9 | |
| Target chl-*a* (µg/L) | 12.0 | |
| Observed Secchi (m) | 1.25 | |
| Target Secchi (m) | 1.34 | |
| TP internal load release rate (mg/m2-d) | 0.7 | 0.6 |
| TP internal load time of release (d) | 122 | 122 |
| Hydraulic residence time (yr) | 1.8 | |
| Overflow rate (m/yr) | 1.4 | |
| | | |
| **Watershed** | | |
| Watershed area (ac) | 18659.5 | |
| Watershed:lake area | 7.7 | |

| **Segment mass balance: <u>Baseline</u>** | **Flow (hm3/yr)** | **% Flow** | **TP load (lb/yr)** | **% TP load** | **TP concentration (µg/L)** |
|---|---|---|---|---|---|
| Precipitation | 6.95 | 34% | 578.43 | 11% | 38 |
| SSTS | 0.06 | 0% | 470.85 | 9% | 3533 |
| Lake Stella outflow | 10.75 | 53% | 450.47 | 9% | 19 |
| Direct drainage (watershed runoff) | 2.40 | 12% | 1730.81 | 34% | 327 |
| Point | 0.02 | 0% | 24.32 | 0% | 525 |
| Internal (excess) or unknown | | | 1882.19 | 37% | |
| Total | 20.19 | 100% | 5137.07 | 100% | 115 |
| Evaporation | 6.95 | 34% | | | |
| Sedimentation/retention | | | 4296.46 | 84% | |
| Outflow | 13.24 | 66% | 840.61 | 16% | 29 |
| | | | | | |
| **Segment mass balance: <u>Target</u>** | **Flow (hm3/yr)** | **% Flow** | **TP load (lb/yr)** | **% TP load** | **TP concentration (µg/L)** |
| Precipitation | 6.95 | 34% | 578.43 | 12% | 38 |
| SSTS | 0.06 | 0% | 332.99 | 7% | 2498 |
| Lake Stella outflow | 10.75 | 53% | 450.47 | 10% | 19 |
| Direct drainage (watershed runoff) | 2.40 | 12% | 1517.75 | 32% | 286 |
| Point | 0.23 | 1% | 152.12 | 3% | 303 |

| | | | | | |
|---|---|---|---|---|---|
| Internal (excess) or unknown | | | 1669.18 | 36% | |
| Total | 20.40 | 100% | 4700.94 | 100% | 105 |
| Evaporation | 6.95 | 34% | 0 | 0% | 254 |
| Sedimentation/retention | | | 3888.71 | 83% | |
| Outflow | 13.45 | 66% | 812.23 | 17% | 27 |

| **<u>Load Reductions</u>** | | **TP load reduction (lb/yr)** | **% TP reduction** |
|---|---|---|---|
| Precipitation | | 0.00 | 0% |
| SSTS | | 137.86 | 29% |
| Rice Lake outflow | | 0.00 | 0% |
| Focus area (watershed runoff) | | 213.06 | 12% |
| Point | | -127.80 | -526% |
| Internal (excess) or unknown | | 213.01 | 11% |
| Total | | 436.13 | 8% |