Watershed

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Blue Earth River Watershed Lake Water Quality Improvement Study

Identifying water quality targets and phosphorus reduction goals for seven high priority lakes

MINNESOTA POLLUTION CONTROL AGENCY

CLEAN WATER LAND & LEGACY AMENDMENT

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Abbreviations

1W1P	One Watershed, One Plan
ACPF	Agricultural Conservation Planning Framework
AU	animal unit
BMP	best management practice
CAFO	concentrated animal feeding operation
CDL	Cropland Data Layer
CDOM	colored dissolved organic matter
Chl-*a*	chlorophyll-*a*
DAP	diammonium phosphate
DMR	discharge monitoring report
DNR	Minnesota Department of Natural Resources
DO	dissolved oxygen
E. coli	Escherichia coli
EDA	Environmental Data Access
EPA	United States Environmental Protection Agency
EQuIS	Environmental Quality Information System
FIBI	fish-based lake index of biological integrity
FOC	frequency of occurrence
ft	feet
GIS	geographic information system
HAB	harmful algae bloom
HSPF	Hydrologic Simulation Program–Fortran
HUC	hydrologic unit code
ITPHS	imminent threat to public health and safety
lb	pounds
LiDAR	light detection and ranging
m	meters
MAP	monoammonium phosphate
MCL	maximum containment level
MDH	Minnesota Department of Health
mg/L	milligrams per liter
MOS	margin of safety
MPCA	Minnesota Pollution Control Agency
MS4	municipal separate storm sewer system
NASS	National Agricultural Statistics Service
NKE	319 Small Watershed Nine Key Element Plan
NLCD	National Land Cover Database
NPDES	National Pollutant Discharge Elimination System

P	phosphorus
SAM	Scenario Application Manager
SDS	state disposal system
SE	Simple Estimator Model
SID	stressor identification
SSTS	subsurface sewage treatment system
SWCD	soil and water conservation district
SWAT	Soil and Water Assessment Tool
TKN	total Kjeldahl nitrogen
TMDL	total maximum daily load
TN	total nitrogen
TP	total phosphorus
TSI	trophic state index
TSS	total suspended solids
USDA	United States Department of Agriculture
WCBP	Western Corn Belt Plains
WRAPS	Watershed Restoration and Protection Strategy
WTP	water treatment plant
yr	year
µg/L	micrograms per liter

Executive summary

The Blue Earth River Watershed (hydrologic unit code [HUC]-8 0702011) is located in south central Minnesota and north central Iowa. This report addresses seven high priority lakes located in Martin County (Minnesota) and the Blue Earth River Watershed. Five of the priority lakes (Amber, Hall, Budd, Sisseton, and George Lakes) are located within the city of Fairmont (population of ~10,000) and are part of the Fairmont Chain of Lakes which flows from south to north via an Unnamed Creek to Center Creek. The other priority lakes, Fox and Big Twin Lakes, are shallow systems located west and northwest of the city of Fairmont. These seven lakes were identified as high priority by local stakeholders due to water quality conditions that are close to and/or barely exceeding Minnesota State water quality standards. Additionally, all seven lakes experience high recreational use by local residents including fishing, boating, and swimming. Finally, Budd Lake, which is located downstream of Hall and Amber Lakes, is the primary drinking water source for the city of Fairmont.

The primary goal of this report is to set nutrient (phosphorus) targets and load reduction goals for each priority lake to improve and protect water quality conditions so that they are able to meet, or continue meeting, state standards. This report is intended to accompany the Blue Earth River Watershed Restoration and Protection Strategies (WRAPS) Report (MPCA 2023) and the Blue Earth River Watershed Total Maximum Daily Load (TMDL) Report (MPCA 2023).

This report includes the following components:

- Description of each lake's physical characteristics (Section 2.2) and their drainage areas (Section 2.3)
- An assessment of recent and historic water quality data (Sections 2.4 and 2.5)
- A description and assessment of other lake features including fisheries (Section 2.6), vegetation (Section 2.7), and shoreline conditions (Section 2.8)
- A description of the primary sources of phosphorus to the lakes and the methods (i.e., data and models) used to estimate each source (Section 3)
- The process used to identify phosphorus concentration and loading targets for each priority lake (Section 4)
- A final summary of current phosphorus loading (by source) to each lake and load reductions needed to meet target conditions (Section 5)
- A brief discussion of potential watershed and in-lake phosphorus reduction strategies and future monitoring activities (Section 6)

Table 1 presents the phosphorus concentration targets identified in this report to improve and protect water quality conditions in the seven priority lakes. Table 2 provides a summary of the existing phosphorus load to each lake, the load required for each lake to meet the concentration target in Table 1, and the load reduction needed to achieve the target load. The primary phosphorus sources to the lakes covered in this study are watershed runoff (agriculture and urban lands) and internal phosphorus recycling. Finally, this report identifies various strategies and best management practices (BMPs) to achieve load reduction targets/goals and improve water quality. Some of the identified strategies include, but are not limited to offline treatment wetlands, soil health practices, livestock management, nutrient management, conservation cover, structural BMPs in critical agricultural areas, urban stormwater runoff controls, and managing internal phosphorus recycling.

Table 1. Current (observed) TP concentrations for each priority lake and target concentrations to improve water quality conditions.

Lake Name	Lake ID	TP (µg/L)	
		Observed	Target
Amber	46-0034-00	107	90
Hall	46-0031-00	79	65
Budd	46-0030-00	75	65
Sisseton	46-0025-00	85	75
George	46-0024-00	145	90
Fox	46-0109-00	78	65
Big Twin	46-0133-00	54	45

Table 2. Summary of existing P loads, target P loads, and P load reduction goals.

Lake	Existing P load (lb/yr)	Target P load (lb/yr)	P load reduction goal to meet target (lb/yr)	P load reduction goal to meet target (%)
Amber	4,958	3,848	1,110	22%
Hall	9,939	7,663	2,276	23%
Budd	4,553	3,708	845	19%
Sisseton	5,045	4,286	759	15%
George	8,509	5,271	3,238	38%
Fox	1,949	1,418	531	27%
Big Twin	489	358	132	27%

1. Overview

The Blue Earth River Watershed (HUC-8 07010204) in southern Minnesota contains numerous impaired water bodies, including 13 lakes that are impaired for aquatic recreation. This report addresses seven high priority shallow lakes in the Blue Earth River Watershed: Amber, Hall, Budd, Sisseton, George, Fox, and Big Twin Lakes. Recent in-lake monitoring data (2017 through 2021) for Amber and George suggest these lakes are currently not meeting eutrophication standards established by the State of Minnesota for shallow lakes in the Western Corn Belt Plains (WCBP) ecoregion. For these lakes, neither total phosphorus (TP) nor the response variables (i.e., chlorophyll-*a* [chl-*a*] and Secchi depth) met the WCBP shallow lake standards from 2017 through 2021. For Hall, Budd, Sisseton, and Fox, TP and Secchi depth met the WCBP standards from 2017 through 2021, however mean chl-*a* concentrations did not meet standards and algae blooms are a concern. Big Twin Lake currently meets all three water quality criteria, however chl-*a* concentrations are close to exceeding the WCBP shallow lake standard. All seven lakes are heavily used by local and regional residents for fishing, boating, swimming, and other recreational activities. Additionally, Budd Lake is the primary drinking water source for the city of Fairmont (approximately 10,000 people). Toxins from harmful algal blooms (HABs) have been identified as contaminants of concern in the source water assessment for the city of Fairmont (MDH 2019). HABs are produced by cyanobacteria, a type of photosynthetic bacteria that occur naturally in water but can become a nuisance with excess levels of phosphorus and other nutrients. Cyanobacteria blooms can contain the bacteria that create HAB toxins, which can cause illness in people and pets. For these reasons, local partners in the Blue Earth River Watershed have identified these lakes as high priority for water quality improvement (Table 3 and Figure 1).

Table 3. List of high priority lakes in Blue Earth River Watershed for water quality improvement.

Lake name	Lake ID	County	Designated use class	Reason for high priority for water quality improvement
Amber	46-0034-00	Martin	2B	high recreational use, upstream of Budd Lake (drinking water source), does not meet shallow lake water quality standards, Fish assemblage impairment [b]
Hall	46-0031-00	Martin	2B	high recreational use, contributes to Budd Lake (drinking water source), high chl-*a*, nitrate levels occasionally high (Dutch Creek) [a], Fish assemblage impairment [b]
Budd [c]	46-0030-00	Martin	2B	high recreational use, drinking water source for city of Fairmont, high chl-*a*, HAB concerns, Fish assemblage impairment [b]
Sisseton	46-0025-00	Martin	2B	high recreational use, high chl-*a*, Fish assemblage impairment [b]
George	46-0024-00	Martin	2B	high recreational use, does not meet shallow lake water quality standards
Fox	46-0109-00	Martin	2B	high recreational use, does not meet shallow lake water quality standards,

Lake name	Lake ID	County	Designated use class	Reason for high priority for water quality improvement
				development pressures, active lake association, habitat improvement projects underway
Big Twin	46-0133-00	Martin	2B	high recreational use, development pressure, does not meet shallow lake water quality standards

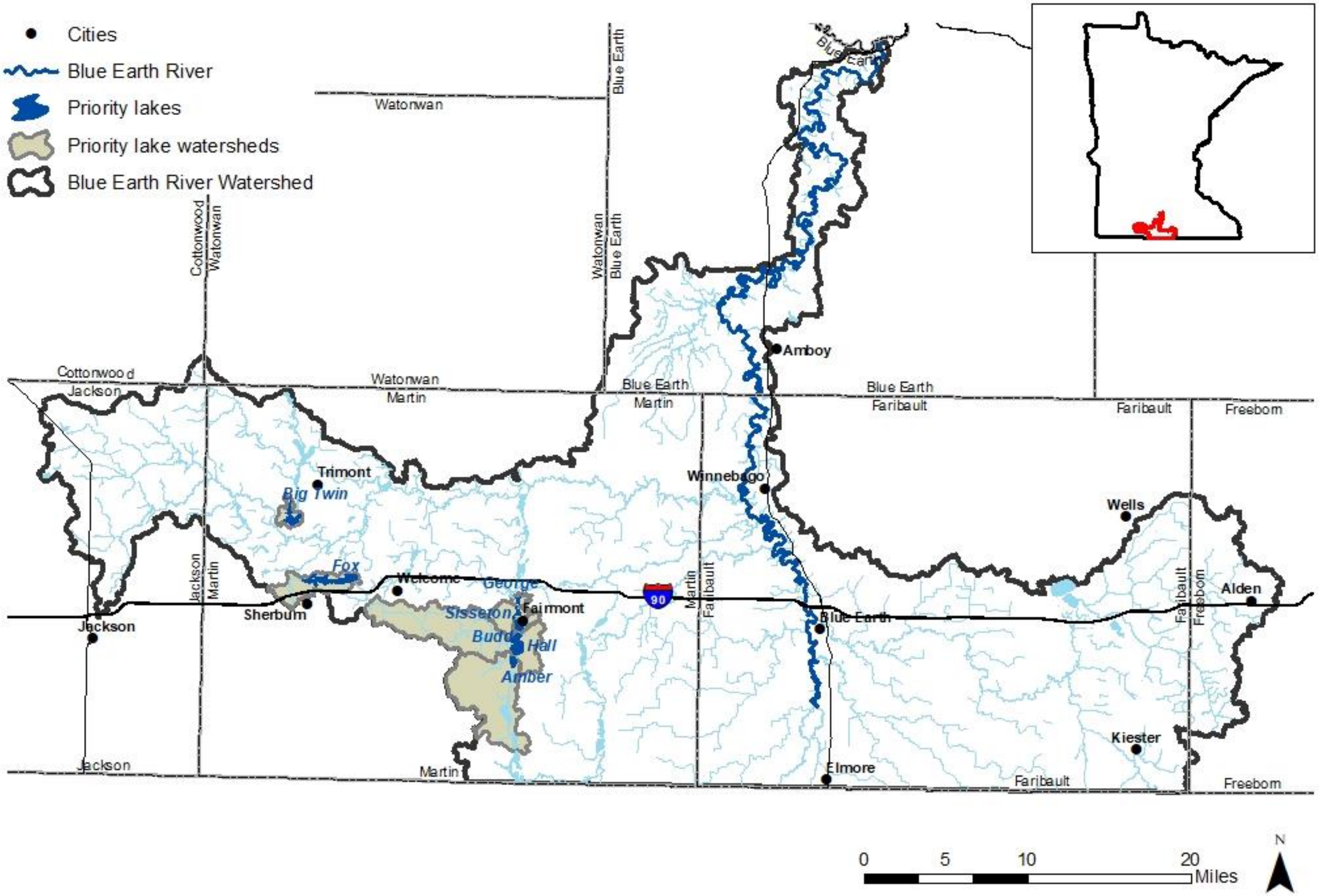
a. References: Dutch Creek and Fairmont Chain of Lakes Section 319 Small Watershed Focus Program NKE (MPCA 2020a)

b. Fish impairment covered in greater detail in the Blue Earth River Watershed Lake Stressor Identification Report (DNR 2022)

c. Budd Lake was listed as impaired by PCBs in fish tissue in 1998

This study is intended to accompany and complement the *Blue Earth River WRAPS Report* (MPCA 2023b) and the *Blue Earth River Watershed TMDL Report* (MPCA 2023a; referred to as the "TMDL Report" herein). For each of the seven lakes, this report provides a summary of the lake and watershed conditions, a phosphorus source assessment, lake water quality targets, and phosphorus loading goals. This report also presents water quality data and analyses (where available) for North Silver Lake (46-0016-00), Willmert Lake (46-0014-01), and Mud Lake (46-0023-00) which are relatively small, shallow basins located upstream of the city of Fairmont Chain of Lakes. These lakes do not have enough water quality data to be assessed for impairment, but they flow to the downstream Fairmont Chain of Lakes priority lakes included in this study. Finally, it should be pointed out that TMDLs for the Fairmont Chain of Lakes are included in the watershed-wide TMDL Report (MPCA 2023a), however all of the modeling and data analyses that were used to develop those TMDLs are presented in this report.

Figure 1. Location of priority lakes in the Blue Earth River Watershed.



2. Lake characterization and data assessment

2.1 Data sources and previous studies

Below is a summary of the data, studies, and models that were compiled and reviewed for this study. All items listed below are available online or were supplied by the Minnesota Pollution Control Agency (MPCA), Minnesota Department of Natural Resources (DNR), Minnesota Department of Health (MDH), Martin Soil and Water Conservation District (SWCD), and the City of Fairmont. These studies and data sources are referred to throughout different sections of this report.

- Phosphorus Recycling in Five Shallow Lakes (Stefan and Hanson 1981)
- Side Effects of 58 Years of Copper Sulfate Treatment of the Fairmont Lakes, Minnesota (Hanson and Stefan 1984)
- Fairmont Chain of Lakes Monitoring Report 2002 (Martin County Environmental Services and MPCA 2003)
- Blue Earth River HSPF-SAM Model (RESPEC 2014, Tetra Tech 2015, Tetra Tech 2016, and updated by MPCA in 2022 [3/31/2022 model version])
- City of Fairmont Simple Estimator Model (provided by City of Fairmont staff)
- Dutch Creek and Hall Lake SWAT Modeling Report (Tetra Tech 2018)
- 2019 Source Water Assessment – City of Fairmont Public Water System (MDH 2019)
- City of Fairmont 2040 Comprehensive Plan (City of Fairmont 2020)
- Minnesota River and Greater Blue Earth River Basin Total Suspended Solids TMDL Report (MPCA 2020a)
- Dutch Creek and Fairmont Chain of Lakes Section 319 Small Watershed Focus Program NKE (MPCA 2020)
- 2022 Surface Water Intake Protection Plan – City of Fairmont Public Water System (MDH 2022)
- The United States Department of Agriculture's (USDA) 2019 Cropland Data Layer (CDL)
- MPCA feedlot data
- DNR lake basin bathymetry and morphology spatial datasets (downloaded from Minnesota Geospatial Commons)
- Lake and stream water quality data (data accessed via MPCA's Surface Water Data Web App and University of Minnesota's LakeBrowser)
- Stream flow data for Dutch Creek (data available on DNR/MPCA Cooperative Stream Gaging website)
- DNR fisheries survey reports (data and narratives accessed via DNR LakeFinder website)
- *Blue Earth River Watershed Stressor Identification Report – Lakes* (DNR 2022)

2.2 Lake descriptions and physical characteristics

Below is a general description of the five priority lakes in the Fairmont Chain of Lakes, Fox Lake, and Big Twin Lake.

2.2.1 Fairmont Chain of Lakes

The Fairmont Chain of Lakes is comprised of eight lake basins that formed by the melting of ice blocks in the post-glacial period and have now been filled with as much as 36 ft to 45 ft of lake-derived (organic) materials (Stefan and Hanson 1981). All eight lakes are in-line with the mainstem Unnamed Creek that flows from south to north to Center Creek (Figure 2 and Figure 3). Stage within the Fairmont Chain of Lakes is controlled by a dam at the outlet of George Lake that flows to Center Creek. North Silver Lake, which is located approximately four miles south of the city of Fairmont and two miles north of the Iowa-Minnesota border, represents the headwaters of the Fairmont Chain of Lakes. North Silver Lake outlets to the northwest to an unnamed creek which flows a short distance to the next lake in the chain, Willmert Lake. From there, the unnamed creek flows approximately three miles north to Mud Lake which is located just upstream of Amber Lake—the first priority lake within the city of Fairmont's municipal boundary.

2.2.1.1 Amber Lake

Amber Lake is the southern-most priority lake within the Fairmont Chain of Lakes. Despite a maximum depth of only 16.5 feet, Amber Lake has a greater mean depth (~12 feet) and a relatively small percent littoral area (i.e., portion of the lake less than 15 feet deep) compared to many lakes in this part of the state. Although Amber Lake is located completely within the city of Fairmont, most of its drainage area (~94%) is located outside city limits. The largest tributary inputs to Amber Lake include County Ditch 28 which drains approximately 3,900 acres of land west of the lake and outflow from Mud Lake via Unnamed Creek (~7,500 acres). Similar to the other priority lakes in the Fairmont Chain of Lakes, Amber Lake has a short mean hydraulic residence time (~53 days). Lakes with short residence times tend to reflect the water quality of their drainage area and upstream lake(s) due to frequent flushing and therefore tend to be more sensitive to changes to these inputs.

2.2.1.2 Hall Lake

With a surface area of approximately 548 acres and maximum depth of 27 feet, Hall Lake is the largest and deepest lake in the Fairmont Chain of Lakes. Hall Lake's deep area is relatively small and therefore its mean depth (~8 feet) and littoral area (91%) are more indicative of a shallow lake. The largest watershed inputs to Hall Lake are Amber Lake (~12,000 acres) and Dutch Creek, which drains approximately 11,000 acres west of the lake. Approximately 11% (~2,700 acres) of Hall Lake's drainage area is located within the city of Fairmont's municipal boundary and flows to the lake or Dutch Creek via direct overland flow, stormsewer connections, pond outflows, and small drainage ditches/channels. Hall Lake has a similar mean hydraulic residence time (~47 days) to Amber Lake despite a slightly smaller watershed to lake area ratio (47:1 compared to 66:1).

2.2.1.3 Budd Lake

Budd Lake is located immediately north of Hall Lake and the two lakes are connected via a 600-foot channel that runs beneath West Lair Road. Budd Lake is about half the size of Hall Lake (228 acres);

however, it has a greater mean depth (~13 feet) and a smaller littoral area (49%). Budd Lake's drainage area includes outflow from Hall Lake (25,787 acres) and its direct watershed (751 acres), which is entirely developed and within the city of Fairmont municipal boundary. Since Budd Lake's direct watershed only accounts for 3% of its drainage area, inputs to Budd Lake are dominated by Hall Lake and its contributing areas. Budd Lake's watershed to lake area ratio (~116:1) is significantly larger than Hall Lake and its mean hydraulic residence time is less (~31 days). The city of Fairmont obtains nearly all of its public water supply from Budd Lake. The water plant intakes on Budd Lake are located at 4 to 6 feet and 18 to 20 feet (MDH 2019). The City's average daily water supply production is approximately 1.26 million gallons (~1,700 acre-ft) which is about 6% of Budd Lake's annual water budget.

2.2.1.4 Sisseton Lake

Sisseton Lake is located directly downstream (i.e., north) of Budd Lake and is the second smallest of the priority lakes in terms of both surface area and total volume. Sisseton Lake's maximum depth is approximately 19 feet, but its littoral area is 79% which is more characteristic of a shallow lake. Sisseton Lake's drainage area is 28,510 acres and is dominated by Budd Lake (93%). Direct drainage to the lake includes developed areas immediately around the lake and an unnamed ditch that enters the lake on the southwest corner. Approximately 82% (1,615 acres) of Sisseton's direct drainage area is within the city of Fairmont's municipal boundary, of which about one-third is developed.

2.2.1.5 George Lake

George Lake is by far the smallest (83 acres) and shallowest (max depth 10 feet; mean depth 5.6 feet) priority lake in the Fairmont Chain of Lakes. George Lake also has the largest watershed area, which is dominated by outflow from Sisseton Lake (98% of total drainage area). As a result, George Lake has the largest watershed to lake area ratio (349:1) and shortest mean residence time (5 days) of the priority lakes in the Fairmont Chain of Lakes. Direct drainage to George Lake includes 428 acres of mostly developed area within the city of Fairmont municipal boundary. George Lake outlets to Center Creek where it flows approximately 30 miles to its confluence with the Blue Earth River. Water levels and outflow from George Lake are controlled by the George Lake Dam.

2.2.2 Fox Lake

Fox Lake is the largest lake in this study (~949 acres) and has a maximum depth of 20 feet and a mean depth of approximately 10 feet. The Fox Lake Watershed is relatively small (approximately 4,000 acres), with a watershed to lake ratio of 4:1. The entire watershed is in Martin County. A portion of the city of Sherburn is in the watershed, and the unincorporated community of Fox Lake is located on the eastern shore of the lake (Figure 4). Fox Lake was originally assessed as impaired in 2010 based on the lake eutrophication standards (as opposed to the shallow lake standards; see Section 2.5.1). The lake was later assessed in 2019 as a shallow lake due to the lake's weak stratification potential, maximum depth of 20 feet, and 75% littoral area. The 2019 assessment concluded that the lake nutrient impairment should remain.

2.2.3 Big Twin Lake

Big Twin Lake is a 461-acre shallow lake with a maximum depth of 19 feet and a mean depth of 7 feet. Big Twin Lake has a relatively small drainage area (1,143 acres) and it has the lowest watershed to lake area ratio and longest residence time of all the lakes included in this study. The lake and its drainage are completely within Martin County, and there are no cities in its watershed (Figure 5).

Table 4. Physical characteristics for the priority lakes included in this study.

Characteristic	Amber	Hall	Budd	Sisseton	George	Fox	Big Twin
Surface area (acres)	182	548	228	138	83	949	461
Max depth (ft)	16.5	27.0	23.0	18.5	10.0	20	19
Mean depth (ft)	12.1	7.8	12.8	9.5	5.6	10.2	7.0
Littoral area (%)	64%	91%	49%	79%	100%	75%	100%
Volume (acre-ft)	2,199	4,294	2,910	1,318	463	9,652	3,176
Total drainage area[a] (acres)	11,926	25,787	26,538	28,510	28,938	4,022	1,143
Watershed:lake Area Ratio	65.5	47.1	116	207	349	4.24	2.48
Direct drainage area[b] (acres)	8,323	13,861	751	1,972	428	2,306	1,143
Drainage area within Fairmont municipal boundary (acres)[c]	743	2,738	751	1,615	428	–	–
Mean hydraulic residence time (days)[d]	53 [d]	47 [d]	31 [d]	13 [d]	5 [d]	1,596 [e]	2,547 [e]

[a] includes all lake and open water surface areas and upstream lake drainage area(s)

[b] does not include drainage area of upstream lake(s)

[c] delineated based on city of Fairmont municipal boundary, stormsewer files, and drainage information supplied by the City. Areas for each lake do not include upstream lake direct drainage areas

[d] averaging period used for this calculation is 2017 through 2021

[e] averaging period used for this calculation is 2007 through 2018

Figure 2. Fairmont Chain of Lakes Watershed overview.

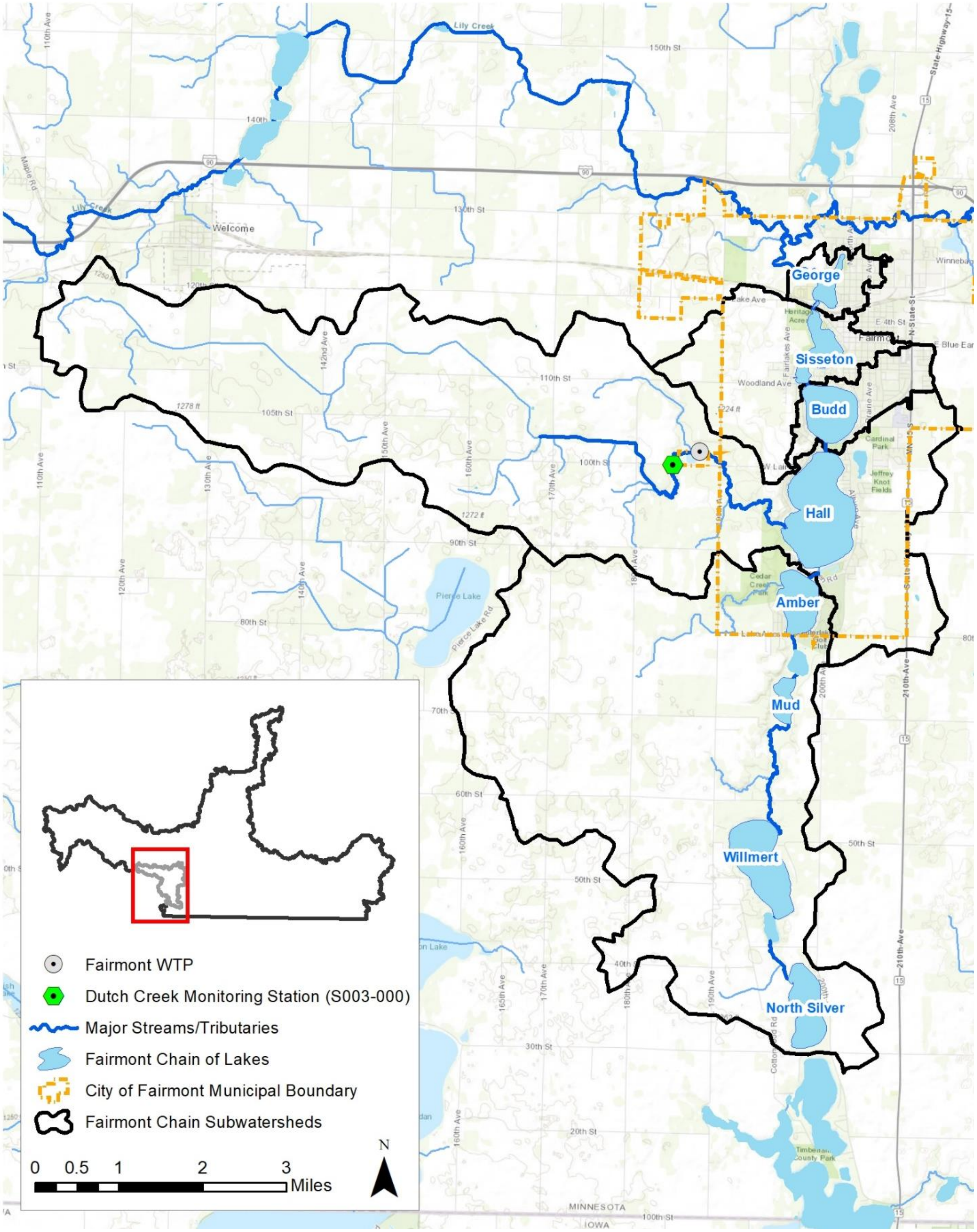
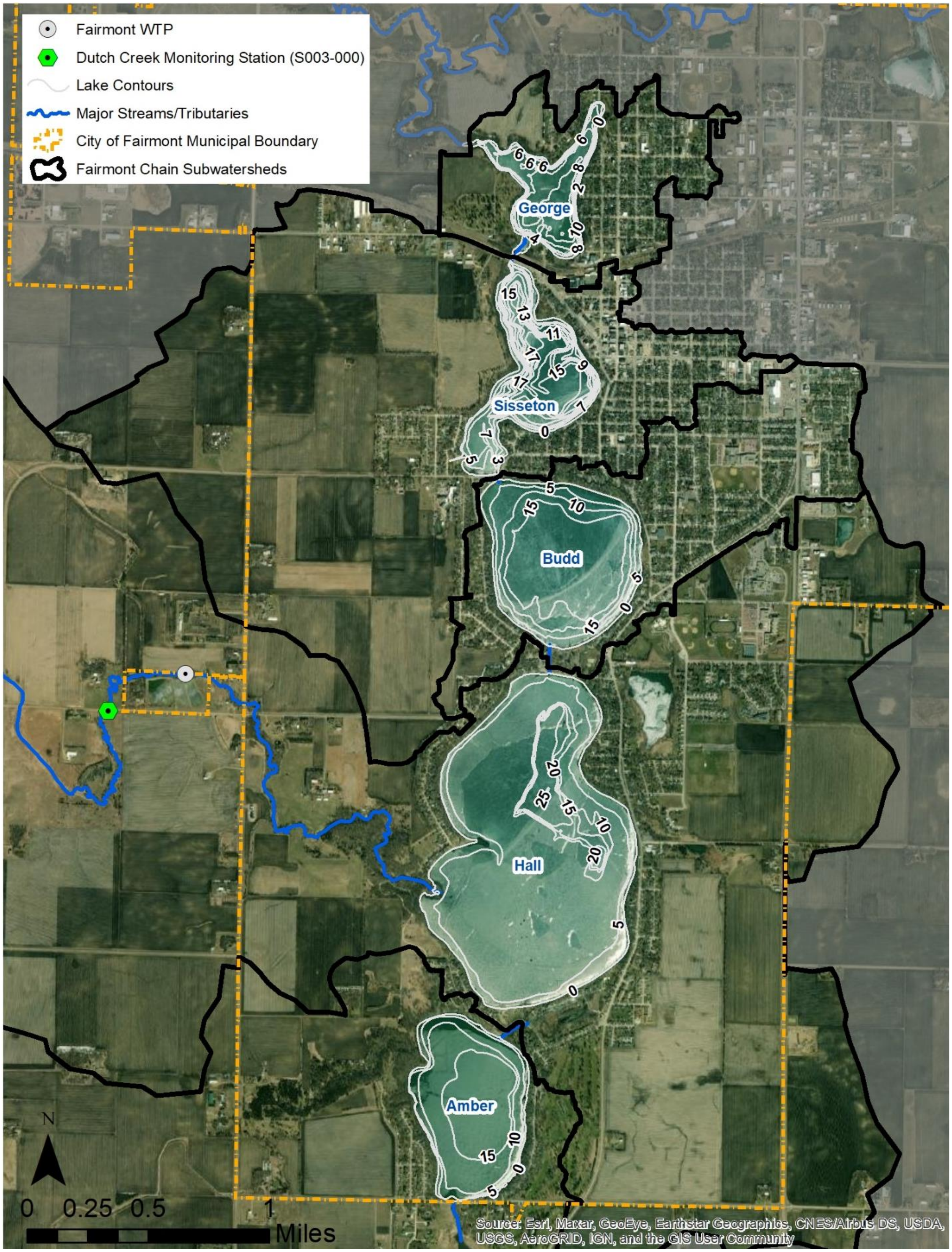


Figure 3. Lake bathymetry for the Fairmont Chain of Lakes priority lakes.



Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 4. Fox Lake Watershed overview.

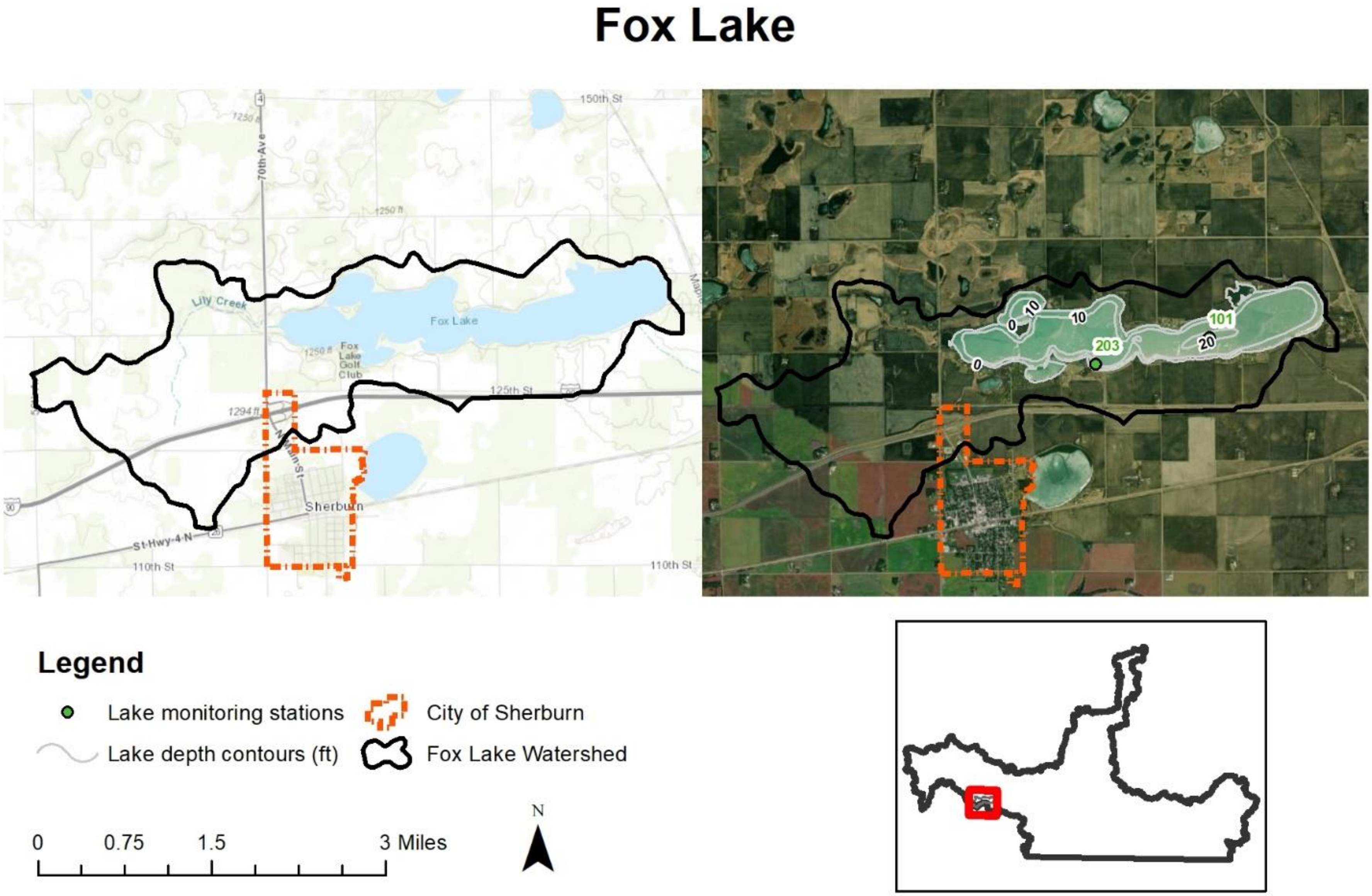
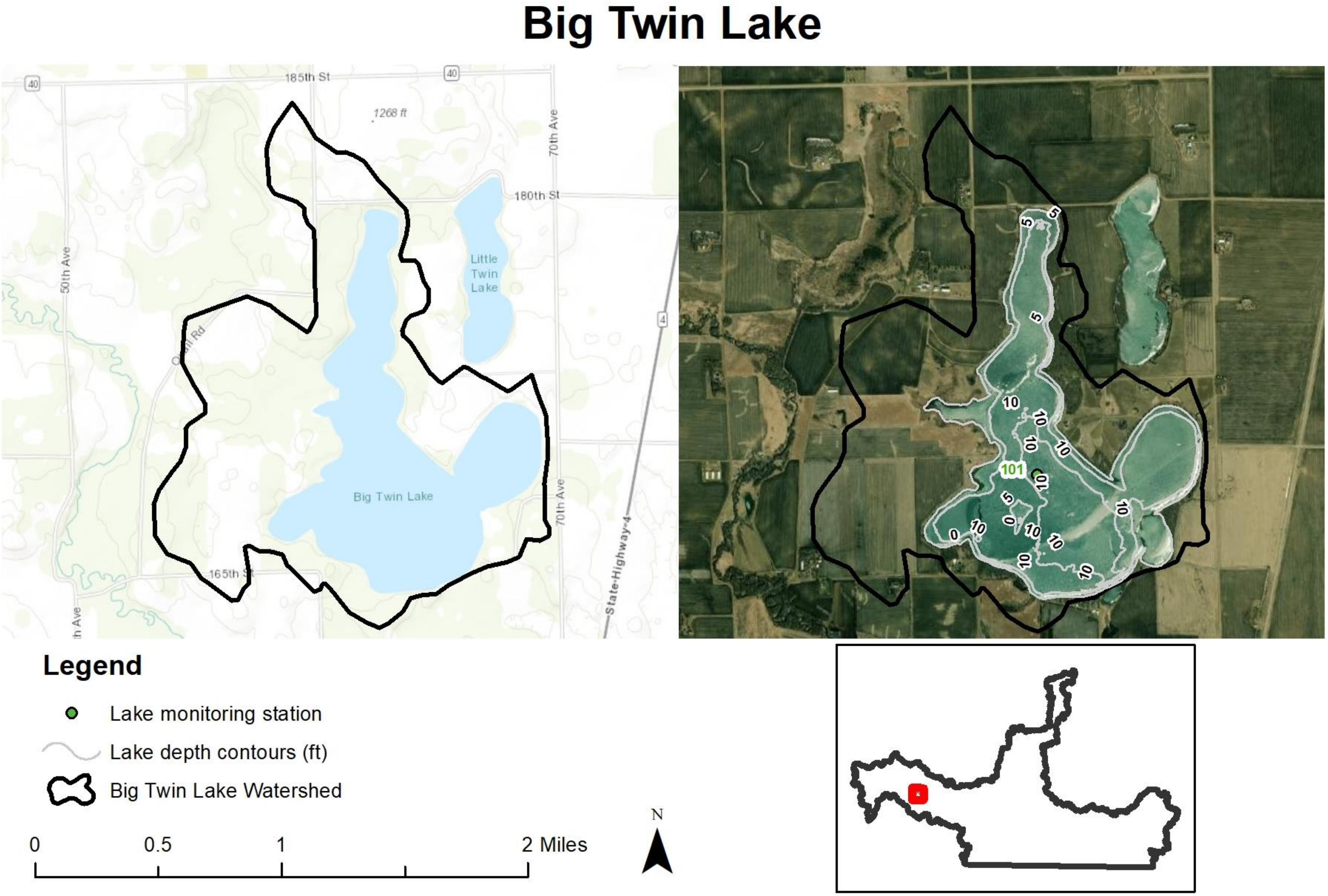


Figure 5. Big Twin Lake Watershed overview.



2.3 Watershed characteristics

2.3.1 Fairmont Chain of Lakes

The drainage area boundaries for the priority lakes (Figure 2 and Figure 3) were developed using multiple data sources. For areas outside the city of Fairmont municipal boundary, the DNR Level 8 and Level 9 watershed boundaries were used to define lake drainage area boundaries. Within the city of Fairmont municipal boundary, the City's subcatchment geographic information system (GIS) layer was used to define the areas draining to each priority lake. The City's subcatchment layer was developed by City staff using their most recent light detection and ranging (LiDAR) and stormsewer information. See discussion in Section 3.1 for more details about this layer and how it was used in the modeling for this study.

The USDA's 2019 CDL was used to evaluate land cover for all areas outside the city of Fairmont boundary. The City's 2021 zoning district GIS layer was used to define land cover for areas within their municipal boundary (see Section 3.1). Land cover throughout the watershed is primarily agricultural, with corn and soybeans the dominant crops (Table 5 and Figure 6). Other crops are present, such as alfalfa and other hay crops, but generally represent less than 3% of each lake's direct drainage area. There is little variation in elevation across the Fairmont Chain of Lakes Watershed. Agricultural lands are flat (slope less than 3%) and are typically tile-drained, which impacts watershed hydrologic pathways (MPCA 2020a). All five lakes are situated within the city of Fairmont and therefore developed land (e.g., residential, commercial/industrial, park land) represents a substantial portion of the priority lakes' direct drainage areas (Table 5). Overall, developed land represents approximately 12% of the Fairmont Chain of Lakes' total drainage area.

There are 24 registered feedlots within the Fairmont Chain of Lakes drainage area, four of which are concentrated animal feeding operations (CAFOs) with an NPDES permit. All of the feedlots are located in the Amber and Hall Lake drainage areas (Table 6). Pigs account for nearly all (94%) of the registered livestock in the watershed, followed by cattle (6%).

Table 5. Land cover summary for the Fairmont Chain of Lakes (Data sources: USDA 2019 CDL and 2021 City of Fairmont zoning layer).

Land Cover [a]	Amber [b]		Hall [c]		Budd [c]		Sisseton [c]		George [c]	
	Area (acres)	Percent (%)	Area (acres)	Percent (%)	Area (acres)	Percent (%)	Area (acres)	Percent (%)	Area (acres)	Percent (%)
Cropland & feedlot	9,160	77%	11,119	80%	25	3%	1,262	64%	60	14%
Grassland & pasture	317	3%	250	2%	0	0%	19	1%	0	0%
Developed	700	6%	1,352	10%	498	67%	532	27%	283	66%
Forest & shrub	169	1%	135	1%	0	0%	9	<1%	0	0%
Wetland & open water	1,580	13%	1,005	7%	228	30%	150	8%	85	20%

a. The 2016 NLCD GIS layer was used to define land cover for areas outside the city of Fairmont jurisdictional boundary. A modified version of the city of Fairmont zoning district was used to define land cover within the city of Fairmont.

b. Land cover values for Amber Lake include its direct drainage area as well as all upstream lake drainage areas (i.e., North Silver and Willmert Lakes)

c. Land cover values for Hall, Budd, Sisseton, and George Lakes include only direct drainage areas (i.e., does not include upstream lake drainage areas)

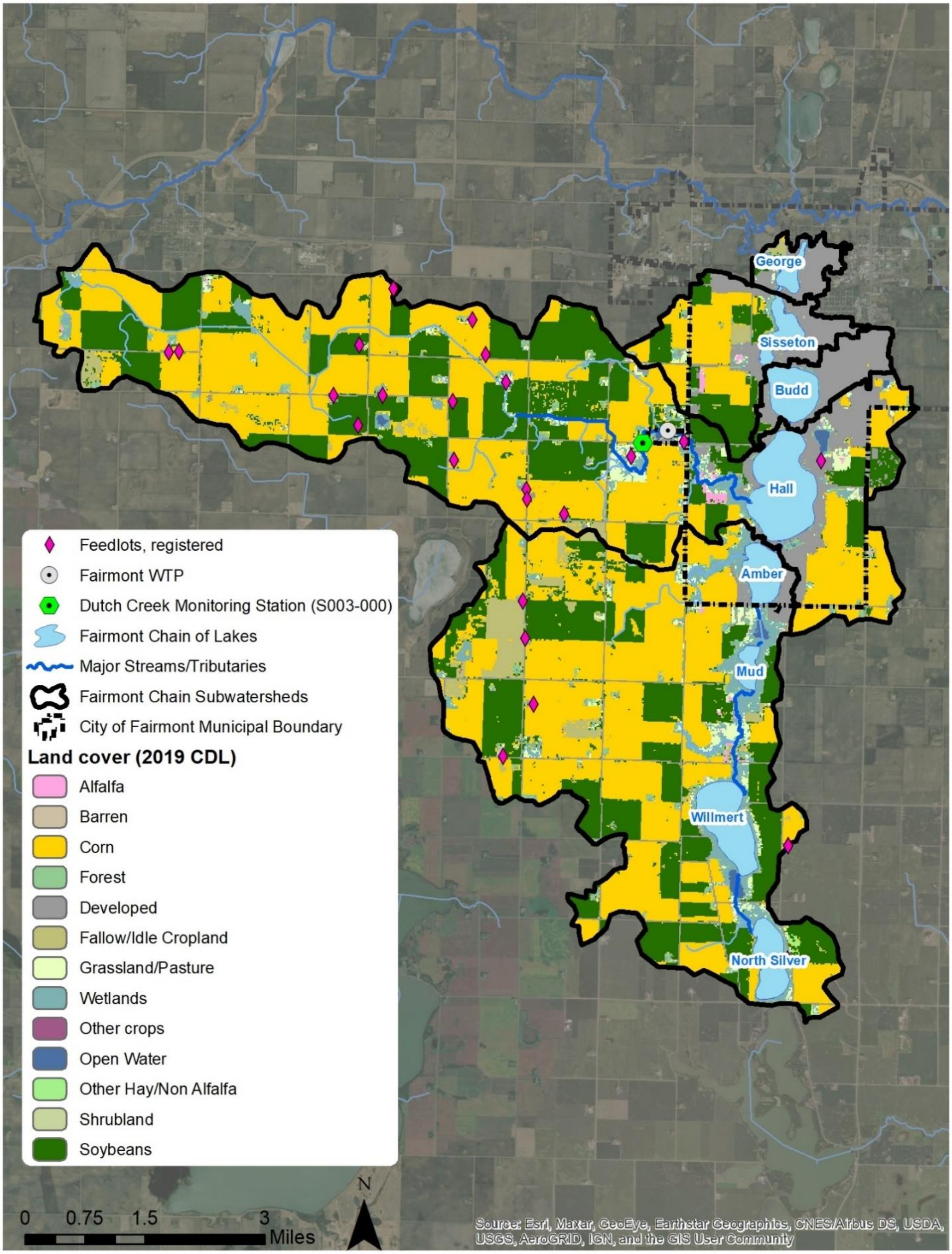
Table 6. Animal unit summary for feedlots in the Fairmont Chain of Lakes priority lake drainage areas.

Feedlot Type	Livestock type	Amber [a]	Hall [b]	Budd [b]	Sisseton [b]	George [b]
Non CAFO	Number of feedlots	4	16	–	–	–
	Cattle (AU)	6	766	–	–	–
	Swine (AU)	1,548	6,523	–	–	–
	Other (AU)	–	5	–	–	–
CAFO	Number of feedlots	2	2	–	–	–
	Cattle (AU)	–	–	–	–	–
	Swine (AU)	1,728	2,424	–	–	–
	Other (horses) (AU)	–	–	–	–	–
All Types	Number of feedlots	6	18	–	–	–
	Total AU	3,282	9,718	–	–	–

a. Feedlots for Amber includes feedlots in its direct drainage area as well as all upstream lake drainage areas (i.e., North Silver and Willmert Lakes)

b. Feedlots for Hall, Budd, Sisseton, and George Lakes include only feedlots in their direct drainage areas (i.e., does not include feedlots in upstream lake drainage areas)

Figure 6. Registered feedlots and land cover in the Fairmont Chain of Lakes drainage area.



Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

2.3.2 Fox and Big Twin Lakes

Land cover in the Fox Lake drainage area is approximately 49% corn and soybean rotation, 8% developed, with the majority of the rest fallow cropland, developed, and wetland (Table 7, Figure 7). Residential development is primarily along the Fox Lake shoreline. Other development around the shoreline includes the Fox Lake Golf Club (southwest shore), a decommissioned power plant (south shore), and the Fox Lake Campground (southeast shore). A structure that was diverting water to the lake on the west side was shut down in the mid-2000s. There are two registered feedlots in the Fox Lake Watershed, with capacity for up to 1,000 swine (300 AU). Land application of manure from nearby feedlots that are located outside of the Fox Lake Watershed may also contribute nutrients to Fox Lake.

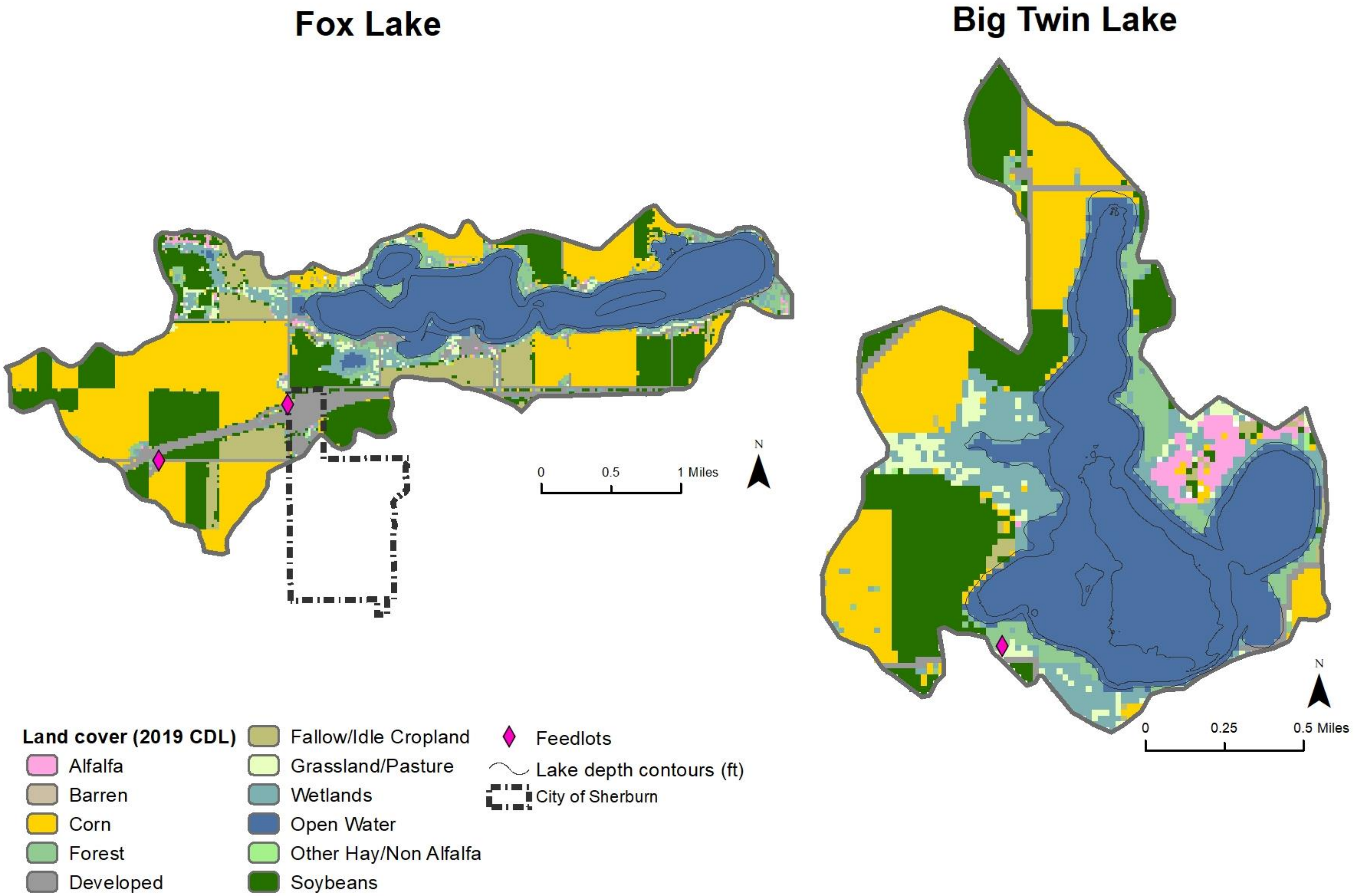
Big Twin Lake land cover is approximately 36% corn and soybean rotation, with the majority of the rest of the watershed open water and wetland (Table 7, Figure 7). There is one registered feedlot in the Big Twin Lake Watershed, with capacity for up to 100 cattle (70 AU). Land application of manure from nearby feedlots that are located outside of the Big Twin Lake Watershed may also contribute nutrients to Big Twin Lake.

Table 7. Land cover summary for Fox and Big Twin Lakes.
Percentages rounded to nearest whole number. Data source: 2019 Cropland Data Layer, USDA, National Agricultural Statistics Service (NASS)

Land cover	Fox	Big Twin
Corn	29%	18%
Soybeans	20%	18%
Other crops[a]	1%	2%
Fallow/idle cropland	7%	1%
Grassland/pasture	2%	3%
Developed	8%	3%
Forest and shrub	3%	5%
Wetland	6%	10%
Open water[b]	24%	40%

a. Other crops include sweet corn, spring wheat, oats, alfalfa, other hay, and peas
b. Open water includes the surface area of the impaired water bodies.

Figure 7. Registered feedlots and land cover in the Fox and Big Twin Lake watersheds.



2.4 Stream water quality data summary

2.4.1 Fairmont Chain of Lakes

Water quality samples have been collected at various stream and tributary stations throughout the Fairmont Chain of Lakes study area, including Unnamed Creek upstream of Amber Lake (S001-333), County Ditch 28 upstream of Amber Lake (S005-474), and Dutch Creek upstream of Hall Lake (S001-332, S003-000, S001-610, S010-498). Data from these stations were downloaded from the MPCA's Environmental Quality Information System (EQuIS) database. Based on review of the available data for these stations, only Dutch Creek station S003-000 has more than five water chemistry samples since 2020. Dutch Creek station S003-000 (Figure 2) has been sampled over 400 times in the past 20 years for various parameters including total suspended solids (TSS), TP, ortho-phosphate, nitrate, total nitrogen (TN), fecal coliform, and Escherichia coli (*E. coli*). Additionally, the Minnesota Department of Agriculture (MDA) has maintained continuous flow monitoring equipment at this site since 2016 as part of the Minnesota Department of Natural Resources (DNR)/MPCA Cooperative Stream Gaging Program. The water quality and continuous flow data for Dutch Creek Station S003-000 (Surface Water Data Access) were used by MDA and MPCA to calculate flow volumes and pollutant loads. Details of MPCA's pollutant load calculations are available upon request. The Dutch Creek flow and load calculations were integral to this study as they were used to calibrate and adjust the Fairmont Chain of Lakes Watershed loading model (see Section 3.1), which served as the primary tool in quantifying and assessing external phosphorus inputs to the priority lakes.

The Dutch Creek water quality and flow data were processed and analyzed for this study using various statistical methods and data visualization techniques to identify potential long-term and seasonal trends. Analyses are presented in Appendix A and primarily focus on phosphorus since it is generally believed to be the limiting nutrient to algae growth in Minnesota Lakes and is the focus of the State of Minnesota's lake water quality standards (MPCA 2005). However, TSS analyses for Dutch Creek are also included in Appendix A because there is a strong relationship between phosphorus and TSS. Dutch Creek was listed as impaired by turbidity in 2006 and a TSS TMDL was completed for the creek in 2020 as part of the *Minnesota River and Greater Blue Earth River Watershed TSS TMDL* (MPCA 2020b). While the analyses presented in Appendix A are limited to Dutch Creek, similar trends likely occur in the other streams and tributaries throughout the Fairmont Chain of Lakes study area. Below are key takeaways from our Dutch Creek TSS and phosphorus analyses:

- Although there are gaps in the 2000 through 2021 TSS monitoring record, mean annual TSS concentrations and individual exceedances of the 65 mg/L Southern River Nutrient Region TSS standard were higher during the recent four-year monitoring period (2017 through 2020) compared to the data collected from 2000 through 2008 (Figure 28 through Figure 31 and Table 32 in Appendix A).
- Over 5,000 tons of TSS (~0.58 tons/acre/year; flow-weighted mean concentration of ~113 mg/L) were delivered to Hall Lake from Dutch Creek from 2017 through 2020 (Figure 32 through Figure 37 in Appendix A).
- From 2017 through 2020, seasonal (i.e., April through October) flow-weighted mean TSS concentrations ranged from 72 to 189 mg/L and TSS loads have ranged from 430 to 2,743

tons/season. As expected TSS loads were greatest in years with the highest rainfall (Figure 32 through Figure 37 in Appendix A).

- TSS loading during the months of May (~55%) and June (~21%) accounted for the majority of the TSS load from Dutch Creek to Hall Lake from 2017 through 2020 (Figure 36 in Appendix A).
- The Dutch Creek TSS-TP relationship (log-transformed $R^2 = 0.69$) suggests sediment-bound phosphorus is a large source of TP to Hall Lake and the Fairmont Chain of Lakes. When TSS levels were below 65 mg/L (i.e., the Southern River Nutrient Region TSS standard) the 150 µg/L river eutrophication TP standard was met 72% of the time. Alternatively, when TSS levels were above 65 mg/L the river eutrophication TP standard was exceeded 95% of the time (Figure 42 in Appendix A).
- Similar to TSS, the long-term TP record suggests mean TP concentrations and individual exceedances of the 150 µg/L river eutrophication standard have increased during the recent four-year monitoring period (Figure 38 through Figure 41 and Table 33 in Appendix A)
- Over 24,000 lbs of TP (~0.67 lbs/acre/year; flow-weighted mean concentration of ~260 µg/L) were delivered to Hall Lake from Dutch Creek from 2017 through 2020 (Figure 43 through Figure 48 in Appendix A).
- Seasonal (i.e., April through October) flow-weighted mean TP concentrations and TP loads from 2017 through 2020 ranged from 157–310 µg/L and 1,342–12,002 lbs/season, respectively. Similar to TSS, TP loads were greater in years with higher rainfall totals (Figure 43 through Figure 48 in Appendix A).
- Similar to TSS, TP loading during the months of May (~41%) and June (~26%) have accounted for the majority of the TP load from Dutch Creek to Hall Lake (Figure 47 in Appendix A).

While this study focuses mainly on phosphorus, other pollutants such as *E. coli* and nitrogen can have significant impacts on eutrophication, drinking water quality, recreation activities, and biotic communities. Dutch Creek was listed as impaired by fecal coliform in 2006 and a TMDL was completed in 2006 as part of the *Fecal Coliform TMDL Assessment for the Blue Earth River Basin* (Minnesota State University and Blue Earth River Basin Alliance 2007). This TMDL identified bacteria reductions of approximately 86% during summer months in order for Dutch Creek to meet state standards. Based on a quick review of the available data in EQuIS for Dutch Creek, bacteria sampling (i.e., *E. coli* and fecal coliform) has not been performed in Dutch Creek since 2008 so it is difficult to determine if conditions have changed since the 2007 TMDL Report.

Nitrogen loading, specifically in the form of nitrate, has been a concern for the Fairmont Chain of Lakes. Nitrate data for Dutch Creek suggest that approximately 63% of the more than 350 samples from 2000 through 2021 exceeded the 10 mg/L maximum contaminant level (MCL) for drinking water. Approximately 69% of the samples that exceeded the MCL were collected from April through June. Although there is less nitrogen monitoring data available in EQuIS for the lakes in the Fairmont Chain of Lakes, high levels of nitrate have occasionally been recorded. In May 2016, nitrate concentrations in Budd Lake exceeded the MCL, which resulted in increased public awareness on the effect of nitrate and nutrient runoff to the chain of lakes (MPCA 2020a). Nitrate concentrations in Budd Lake have not exceeded the MCL since 2016; however, concentrations are often 5 to 6 mg/L, which is a concern for the city.

2.4.2 Fox and Big Twin Lakes

There is not watershed monitoring data available at this time for Fox and Big Twin Lakes

2.5 Lake water quality data assessment and summary

Lake water quality is often evaluated using three associated parameters: TP, chl-*a*, and Secchi depth. TP is typically considered to be the limiting nutrient in Minnesota lakes, meaning that algal growth will increase with increases in phosphorus. chl-*a* is the primary pigment in aquatic algae and has been shown to have a direct correlation with algal biomass. Secchi depth is a physical measurement of water transparency. Increasing Secchi depths indicate less turbidity in the water column and increasing water quality. Conversely, rising TP and chl-*a* concentrations point to decreasing water quality and thus decreased water transparency. Measurements of these three parameters are interrelated and can be combined into an index that describes water quality.

Historic and existing water quality conditions for the lakes in this report are described using data downloaded from the MPCA's EQuIS database and the University of Minnesota's Lake Browser. EQuIS stores data collected by the MPCA, partner agencies, grantees, and volunteers. All water quality sampling data utilized for assessments, modeling, and data analysis for this report and reference reports are stored in this database and are accessible through the MPCA's Environmental Data Access (EDA) website. The University of Minnesota's Lake Browser provides satellite derived water quality data for over 10,000 Minnesota lakes. Data are created using an automated image processing system developed with resources from the University of Minnesota and the Environment and Natural Resources Trust Fund — Legislative and Citizens Commission on Minnesota Resources. The automated image processing system processes satellite data from Landsat 8 and Sentinel 2 and provides daily and monthly (May through October) lake clarity (i.e., Secchi depth), chl-*a*, and colored dissolved organic matter (CDOM) data for 2017 through 2020 (Page et al. 2019).

Below is an overview of the applicable water quality standards for the priority lakes followed by summaries of the long-term, recent, and seasonal water quality data and trends in the priority lakes. It should be noted that because this study uses a combination of different data sources (i.e., EQuIS and Minnesota's Lake Browser), the data summaries and numbers provided in the following sections may differ slightly from those provided on the MPCA's water quality dashboard and in previous studies and reports.

2.5.1 Lake water quality standards

Water quality for the priority lakes is evaluated against Minnesota's lake eutrophication standards for the WCBP ecoregion (Table 8). Minnesota State statute defines various categories of lakes for assessment purposes, including lake, reservoir, shallow lake, and wetland (Minn. R. ch. 7050.0150). The determination between the four categories requires an analysis of basin depth, littoral area, and other characteristics in Appendix D of the *Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment* (MPCA 2022). All of the priority lakes in this study were assessed as shallow lakes during the water quality assessment process. Table 8 shows the WCBP shallow lake water quality standards.

Table 8. Lake eutrophication standards.

Parameter	WCBP shallow lakes
Total phosphorus (µg/L)	≤ 90
Chlorophyll-a (µg/L)	≤ 30
Secchi transparency (m)	≥ 0.7
Applicable priority lake	Amber, Hall, Budd, Sisseton, George, Fox, Big Twin

2.5.2 Fairmont Chain of Lakes water quality

2.5.2.1 Long-term water quality data record

The earliest water chemistry samples available for the Fairmont Chain of Lakes priority lakes in MPCA's EQuIS database are from 1988. Prior to this, the only known published data for the Fairmont Chain of Lakes was a 1981 study by Stefan et al. that presents and reviews water quality measurements from 1972 through 1979 for Amber, Hall, Budd, Sisseton, and George Lakes (Figure 49 in Appendix B). The authors of this study noted that excessive growth of blue-green algae had been a problem throughout the Fairmont Chain of Lakes dating back to at least the 1920s.

Water quality data is rather limited for the priority lakes in the Fairmont Chain of Lakes throughout the 1980s and 1990s. When data was collected during this period, it was often inconsistent in terms of sampling frequency and the number of samples collected in a given year. In 2003, Martin County Environmental Services partnered with the MPCA on a water quality study of the priority lakes in the Fairmont Chain of Lakes. For this study, Martin County staff monitored the priority lakes in 2001 and 2002 and worked with the MPCA to produce a final monitoring report that presented the data. The report also contains a brief summary of historic lake water quality data for the Fairmont Chain of Lakes that includes unpublished data from 1992–1995 that is not available in EQuIS (Table 34 in Appendix B).

Limited water quality data were collected in the Fairmont Chain of Lakes between 2003 and 2016. Monitoring in the Fairmont Chain of Lakes intensified in 2017 when Martin SWCD began collecting monthly water quality samples in the five priority lakes during the summer growing season. The University of Minnesota's Lake Browser website also went online in 2017 which provides remote sensing-derived water quality measurements for each priority lake in the chain, as well as North Silver, Willmert, and Mud Lakes. The Lake Browser has provided over 50 additional chl-*a* and Secchi depth measurements for each priority lake from 2017 through 2020 (~12–15 measurements per year).

Although gaps in the data record and a general lack of older data (i.e., pre-2017) prohibit us from assessing long-term statistical trends, some general observations can be made regarding the history of water quality in the Fairmont Chain of Lakes:

- Maximum summer TP concentrations for the priority lakes prior to 2000 were significantly higher (range = 500–900 µg/L) than the maximum TP concentrations recorded after 2000 (range = 150–300 µg/L) (Figure 49 through Figure 60 and Table 34 in Appendix B).

- Maximum summer chl-*a* concentrations for the five priority lakes from 1970 through 1999 (range = 170 to 570 µg/L) do not appear to be significantly different from the maximum chl-*a* concentrations from 2000 through 2021 (range = 140 to 460 µg/L) (Figure 49 through Figure 61 and Table 34 in Appendix B). There is insufficient data to evaluate whether the frequency of nuisance algae blooms (i.e., chl-*a* levels exceeding 30 µg/L) has changed over time in the Fairmont Chain of Lakes priority lakes.
- Similar to chl-*a*, summer minimum Secchi depth measurements in the priority lakes do not appear to have changed much from 1970–1999 (range = 0.3–0.5 m) to 2000 through 2021 (range = 0.2-0.3 m) (Figure 49 through Figure 62 and Table 34 in Appendix B).
- It is not clear what the main drivers are for the lower maximum TP concentrations observed since 2000. Several management activities occurred in the Fairmont Chain of Lakes between 1970 and 2000, including but not limited to adoption of urban and rural watershed BMPs, sediment dredging in three of the four priority lakes, termination of the Fairmont Lakes Copper Sulfate Treatment Program, fisheries stocking and management by the DNR, and installation of an aeration system in Budd Lake. These activities are discussed in more detail in Section 2.9.

2.5.2.2 Recent Lake Water Quality Data

Water quality samples were collected by Martin SWCD staff on each of the Fairmont Chain of Lakes priority lakes in 2017, 2018, 2020, and 2021. For each lake, surface samples were collected approximately one time per month from May through September for the three main water quality parameters described above: TP, chl-*a*, and Secchi depth. University of Minnesota Lake Browser chl-*a* and Secchi depth data are available for each priority lake from 2017 through 2021 and were combined with the field samples collected by Martin SWCD for the analyses presented in this report. No field samples were collected by Martin SWCD in 2019, so surface TP was estimated by applying chl-*a*/TP regression relationships that were developed using paired chl-*a* and TP field measurements from 2017, 2018, 2020, and 2021 (Appendix B). These chl-*a* /TP regressions were also used to predict TP concentrations for all days in which University of Minnesota Lake Browser chl-*a* measurements are available, but TP was not sampled in the field. In addition to the priority lakes, North Silver Lake, Willmert Lake, and Mud Lake have chl-*a* and Secchi depth measurements available through University of Minnesota Lake Browser, and Willmert Lake was sampled by Martin SWCD approximately one time per month from June through September in 2017 and 2018. Results of the 2017 through 2021 water quality data for the priority lakes are summarized in Table 9 and Figure 8. Table 9 also presents trophic state indices for each lake using Carlson's Trophic State Index (TSI) (Carlson 1977). This index was developed from the interrelationships of summer Secchi depth and surface chl-*a* and TP concentrations. TSI values generally range from 0 to 100 with increasing values indicating more eutrophic conditions. Appendix B contains additional figures and analyses (e.g., box plots) presenting the 2017 through 2021 water quality data for all lakes in the Fairmont Chain of Lakes.

TP data for the priority lakes indicate mean summer growing season concentrations for Hall, Budd, and Sisseton Lakes, when averaged over the recent five-year monitoring period (2017 through 2021), were below the 90 µg/L WCBP shallow lake standard. Amber and George lakes are the only priority lakes that exceeded the shallow lake TP standard. Although TP was monitored for only two summers in Willmert Lake, mean concentrations (93 µg/L) also exceeded the shallow lake standard (Table 35 in Appendix B).

Figure 8 shows mean summer TP concentrations fluctuate from year to year in each lake depending on various environmental factors such as temperature, rainfall, timing of storm events and drought conditions, antecedent water quality conditions (i.e., previous fall or summer), and water quality conditions in upstream lakes.

The 2017 through 2021 data show that none of the priority lakes in the Fairmont Chain of Lakes met the 30 µg/L WCBP shallow lake chl-*a* standard. Mean summer chl-*a* concentrations ranged from 44 µg/L in Hall Lake to 81 µg/L in George Lake. The chl-*a* standard was exceeded over 65% of the summer growing season in all the priority lakes indicating nuisance algae blooms are common throughout the Fairmont Chain of Lakes. Mean summer chl-*a* in North Silver Lake (87 µg/L), Willmert Lake (70 µg/L), and Mud Lake (62 µg/L) were also well above the shallow lake standard (Figure 61 and Table 35 in Appendix B). In general, algae growth per unit of phosphorus is higher in the Fairmont Chain of Lakes than in the 90 reference lakes from throughout the state that were used in Minnesota's nutrient criteria development (MPCA 2005). See Figure 65 and Figure 66 in Appendix B for the chl-*a* –TP regression relationships for the Fairmont Chain of Lakes.

Despite high chl-*a* levels, mean summer Secchi depths for all five priority lakes met the 0.7-meter shallow lake standard from 2017 through 2021, while North Silver, Willmert, and Mud Lakes failed to meet the Secchi standard (Table 9; Figure 62 and Table 35 in Appendix B). Water clarity in the priority lakes generally followed a pattern of clear conditions early in the season (i.e., May, June, and early July) followed by sharp declines in clarity in late summer when chl-*a* levels increased.

For a lake to be considered impaired, Minnesota assessment guidance requires monitoring data be collected over a minimum of two years with at least eight total sample points, and the data must be collected from June to September (MPCA 2022). Once these requirements are met, a lake is considered impaired if TP and at least one of the response variables (chl-*a* or Secchi depth) exceed State water quality standards. The WCBP shallow lake TP and Secchi depth standards are currently (2017 through 2021) being met in Hall, Budd, and Sisseton Lakes. However, these lakes remain on the State's impaired waters list based on the 2019 impaired waters assessment. Amber and George Lakes failed to meet the TP and chl-*a* standards based on the data collected between 2017 and 2021 and are also considered impaired. The 2017 through 2021 chl-*a* and Secchi depth measurements available through the University of Minnesota Lake Browser for North Silver, Willmert, and Mud Lakes suggest these are highly eutrophic lakes and therefore likely affect water quality conditions in the downstream priority lakes. It is possible that North Silver, Willmert, and Mud Lakes could be considered impaired if/when more water quality field samples are collected in these lakes.

Table 9. Summary of 2017–2021 summer growing season water quality for the Fairmont Chain of Lakes priority lakes.

Parameter		Amber	Hall	Budd	Sisseton	George
TP	TP TSI (value)	72	67	66	68	76
	TP TSI (description)	hypereutrophic	eutrophic	eutrophic	eutrophic	hypereutrophic
	Mean Summer TP (µg/L)	107 (n=54)	79 (n=56)	75 (n=52)	85 (n=51)	145 (n=39)

Parameter		Amber	Hall	Budd	Sisseton	George
	TP Standard (µg/L)	90				
Chl-*a*	Chl-*a* TSI (value)	71	68	71	73	74
	Chl-*a* TSI (description)	hypereutrophic	eutrophic	hypereutrophic	hypereutrophic	hypereutrophic
	Mean Summer Chl-*a* (µg/L)	63 (n=67)	44 (n=67)	64 (n=61)	73 (n=60)	81 (n=58)
	Chl-*a* Standard (µg/L)	30				
Secchi	Secchi TSI (value)	62	58	56	57	60
	Secchi TSI (description)	eutrophic	eutrophic	eutrophic	eutrophic	eutrophic
	Mean Summer Secchi (m)	1.0 (n=97)	1.1 (n=68)	1.3 (n=78)	1.2 (n=85)	1.0 (n=70)
	Secchi Standard (m)	0.7				

Figure 8. Fairmont Chain of Lakes priority lake summer growing season mean TP concentrations (solid bars) and annual precipitation (2017–2021). Error bars represent maximum and minimum summer growing season TP concentrations.

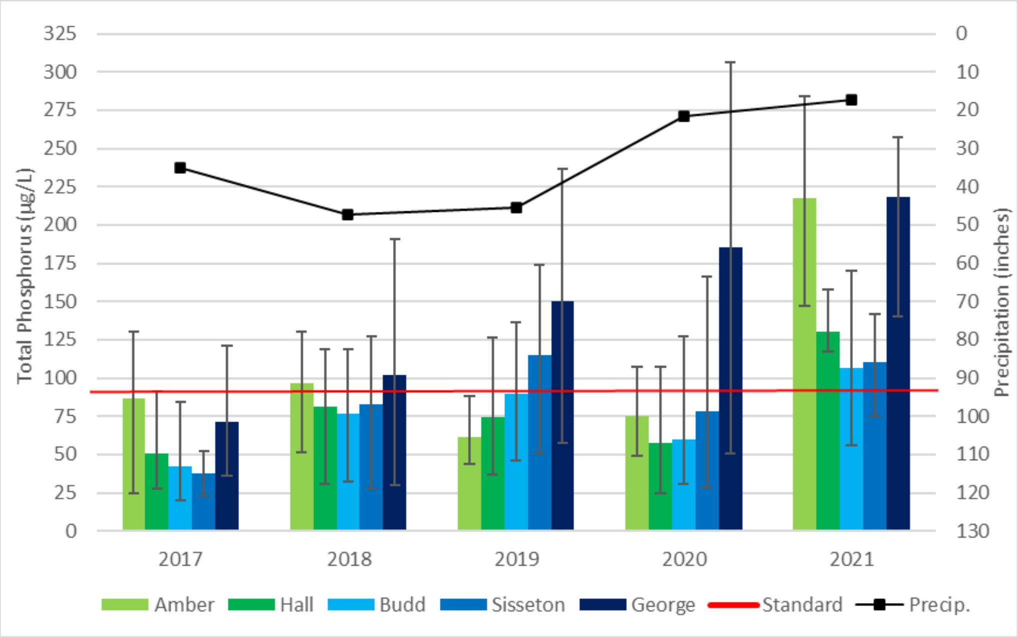


Figure 9. Fairmont Chain of Lakes priority lake summer growing season mean chl-*a* concentrations and annual precipitation (2017–2021). Error bars represent maximum and minimum summer growing season chl-*a* concentrations.

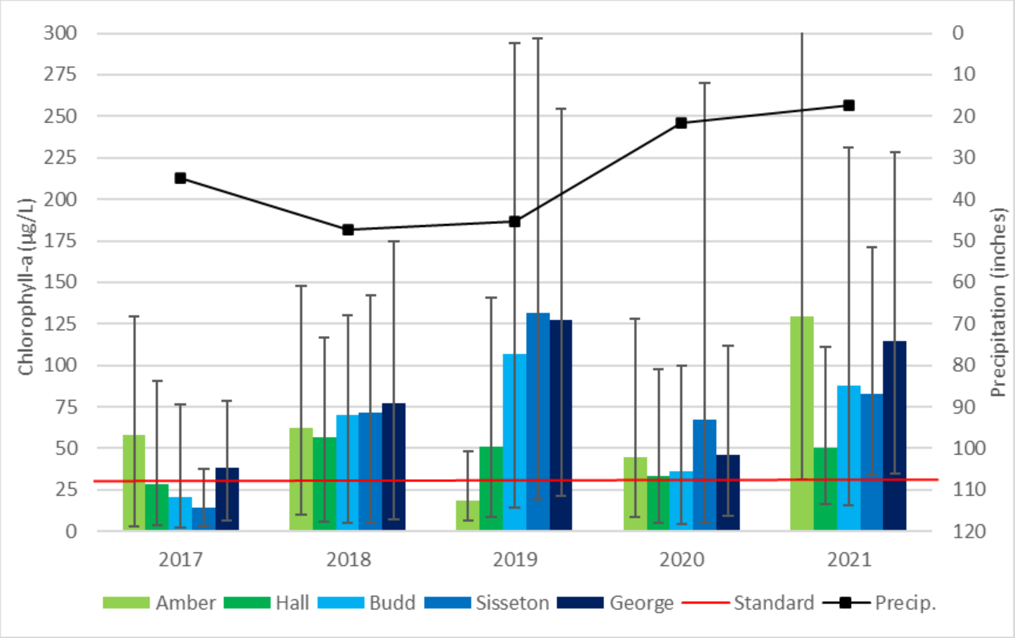
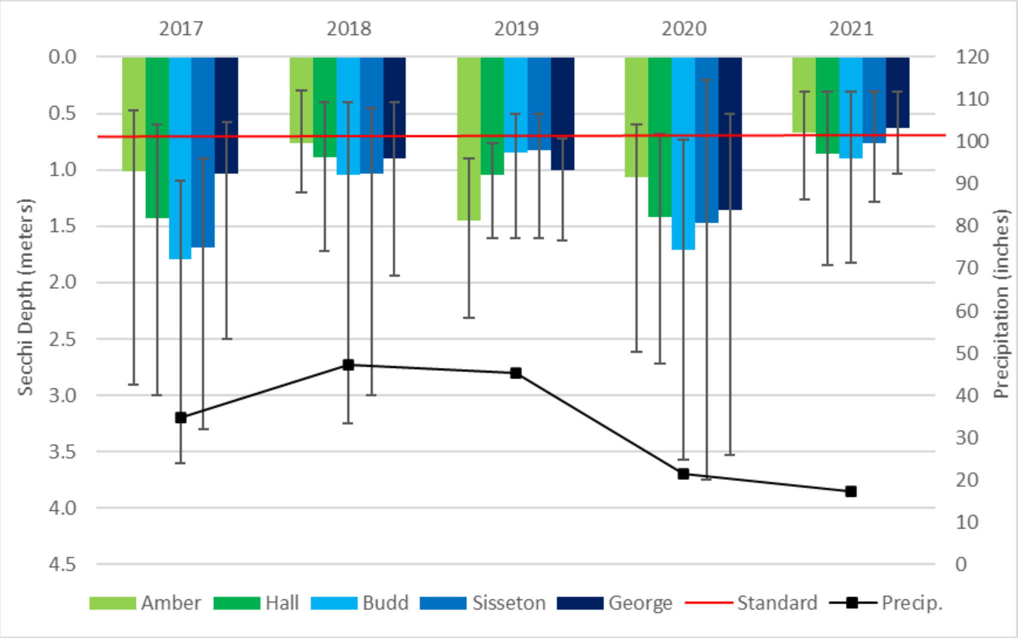


Figure 10. Fairmont Chain of Lakes priority lake summer growing season mean Secchi depth and annual precipitation (2017–2021). Error bars represent maximum and minimum summer growing season Secchi depth measurements.



2.5.2.3 Seasonal Water Quality Dynamics

Similar to other shallow, eutrophic lakes in southern Minnesota, the Fairmont Chain of Lakes exhibit strong seasonal patterns in TP, chl-*a*, and Secchi depth. Appendix B presents several figures (mainly box plots and bar charts) that help illustrate and visualize some of the seasonal water quality patterns in the

Fairmont Chain of Lakes. While some of these dynamics are more pronounced in certain years and/or lakes, below is brief summary of some of the overarching seasonal trends that were observed from 2017 through 2021:

- Spring and early summer conditions are generally characterized by high runoff and external inputs of sediment, nitrogen, and phosphorus to the lakes (see discussion in Section 2.4 and Appendix A).
- Although external loading is highest during spring and early summer, much of the sediment and particulate phosphorus loads that are delivered to the lakes settle out rapidly, particularly the lakes with larger direct drainage areas (e.g., Amber and Hall Lakes). This, combined with low water temperatures and high flushing rates, results in low surface water TP and chl-*a* concentrations, and high Secchi depths in spring and early summer (Figures 67 through 76 in Appendix B).
- As water temperatures increase in mid-summer, thermal stratification begins to develop and anoxic conditions (i.e., DO<2.0 mg/L) can also develop at the sediment-water interface which can lead to phosphorus release from the sediment. Dissolved oxygen (DO) profiles collected in 2018 indicate anoxic conditions were observed at the sediment-water interface at some point between early June and mid-August in all the priority lakes except George (Figures 77 through 81 in Appendix B).
- Thermal stratification in the priority lakes typically begins to weaken and break down by early to mid-August which results in phosphorus-rich deep water mixing into the surface water.
- Surface TP and chl-*a* concentrations in the priority lakes peak in August and September when temperatures are high, flushing rates are low, and thermal stratification starts to break down and/or weaken (Figures 51, 53, 55, 57, 59, and 67 through 76 in Appendix B).
- Although few water quality measurements have been collected in late September and October, it appears that high TP and chl-*a* concentrations continue into at least the early fall throughout the Fairmont Chain of Lakes. (Figures 51, 53, 55, 57, 59, and 67 through 76 in Appendix B).

2.5.2.4 Nitrogen Data

Although phosphorus is often considered the limiting nutrient in most Minnesota lakes, nitrogen is an essential nutrient for algal and aquatic plant growth. While TN (which is calculated as nitrate/nitrite + total Kjeldahl nitrogen [TKN]) has not been monitored in the Fairmont Chain of Lakes, nitrate concentrations were monitored in Hall, Budd, Sisseton, and George from 2017 through 2021 due to drinking water contamination concerns. In-lake nitrate concentrations in these lakes peaked in April and May and occasionally approached the 10 mg/L MCL for drinking water (individual lake maximums ranged from 5.3 through 7.8 mg/L; Figure 63 Appendix B). Nitrate concentrations began to decline in late spring/early summer and were typically at or near minimum detection limits (i.e., <0.04 mg/L) by early July. TKN (i.e., organic nitrogen + ammonia) was monitored in Amber, Hall, Budd, Sisseton, and George Lakes in 2001, 2002, and 2017 (Figure 64 in Appendix B). Results show summer TKN concentrations were highest in George (range = 0.9 to 3.0 mg/L; mean = 2.0 mg/L), followed by Amber (TKN range = 0.8 to 2.5 mg/L; mean TKN = 1.7 mg/L), Sisseton (range = 0.8 to 2.4 mg/L; mean = 1.7

mg/L), Budd (range = 0.9 to 2.2 mg/L; mean = 1.5 mg/L), and Hall (range = 0.7 to 1.8 mg/L; mean = 1.3 mg/L). Studies have found that aquatic plant coverage and the number of plant species in lakes tend to decline when TN levels exceed ~2.0 mg/L (Sagrario et al. 2005; MPCA 2005a). All the priority lakes in the Fairmont Chain of Lakes have exhibited TKN and/or nitrate concentrations above 2.0 mg/L during certain times of the year. More spring and summer in-lake TN measurements are needed throughout the Fairmont Chain of Lakes to better understand if/how nitrogen levels are impacting eutrophication (i.e., algae growth), aquatic plants, and other biota.

2.5.3 Fox and Big Twin Lakes water quality

For Fox Lake, data at site 101 were used to represent overall lake water quality conditions because this site has the most consistent data record, and it is in the lake's deep spot at 20 feet. The data summary presented in Table 10 differs from the MPCA's 2019 impairment assessment summary because the 2019 assessment pooled surface water quality data from all monitoring sites from 2009 through 2018. The impairment assessment summary includes a 2009 sample from a very shallow monitoring site (likely less than two feet deep) with noticeably worse water quality data than data from other sites on other dates.

Although Fox Lake meets the phosphorus standard, the lake does not meet the chl-*a* or Secchi depth standards (Table 10), and chl-*a* and Secchi have worsened in recent years (Figure 11). Long-term Secchi data along the south shore shows fluctuating transparency over time and a recent trend of decreasing transparency (Figure 12). Data from the University of Minnesota's Lake Browser were used to supplement the water quality analysis in Figure 11 and Figure 12.

Temperature and DO depth profiles for Fox Lake are available from 2018, during which surface water temperatures warmed enough in July and August, relative to bottom water temperatures, to lead to thermal stratification and anoxic conditions in bottom waters in July and August (Figure 13). Although phosphorus in bottom waters was not monitored in 2018, data from 2007 and 2008 indicate that bottom water phosphorus was not elevated with respect to surface waters on the days that were monitored (Figure 14). However, phosphorus recycling from sediments in shallow lakes often occurs intermittently throughout the growing season and might not have been captured in the monitoring record.

Big Twin Lake meets the shallow lake eutrophication standards for phosphorus and Secchi depth and borderline meets the chl-*a* standard (Table 10). The lake was listed as impaired in 2010. Although water quality conditions have improved compared to the 2010 initial assessment, the 2019 assessment concluded that the lake nutrient impairment should remain because it is close to exceeding standards (Figure 15). Data from the University of Minnesota's Lake Browser were used to supplement the water quality analysis in Figure 15.

Temperature and DO depth profiles for Big Twin Lake are available from 2018, during which the water column did not thermally stratify; low DO concentrations measured in bottom waters may reflect conditions at the sediment-water interface (Figure 16). Although phosphorus in bottom waters was not monitored in 2018, data from 2007 and 2008 indicate that bottom water phosphorus was at times slightly elevated with respect to surface waters (Figure 17), indicating that phosphorus recycling from sediments may occur intermittently in Big Twin Lake.

Table 10. Fox Lake (site 46-0109-00-101) and Big Twin Lake (site 46-0133-00-101) water quality summary.

Parameter	Fox Lake (2017–2018)	Big Twin Lake (2017-2018)
TP (µg/L)	78 (n=8)	54 (n=8)
Chl-*a* (µg/L)	77 (n=8)	29 (n=8)
Secchi (m)	0.64 (n=8)	0.88 (n=12)

Figure 11. Fox Lake growing season means of TP, chl-*a*, and Secchi.

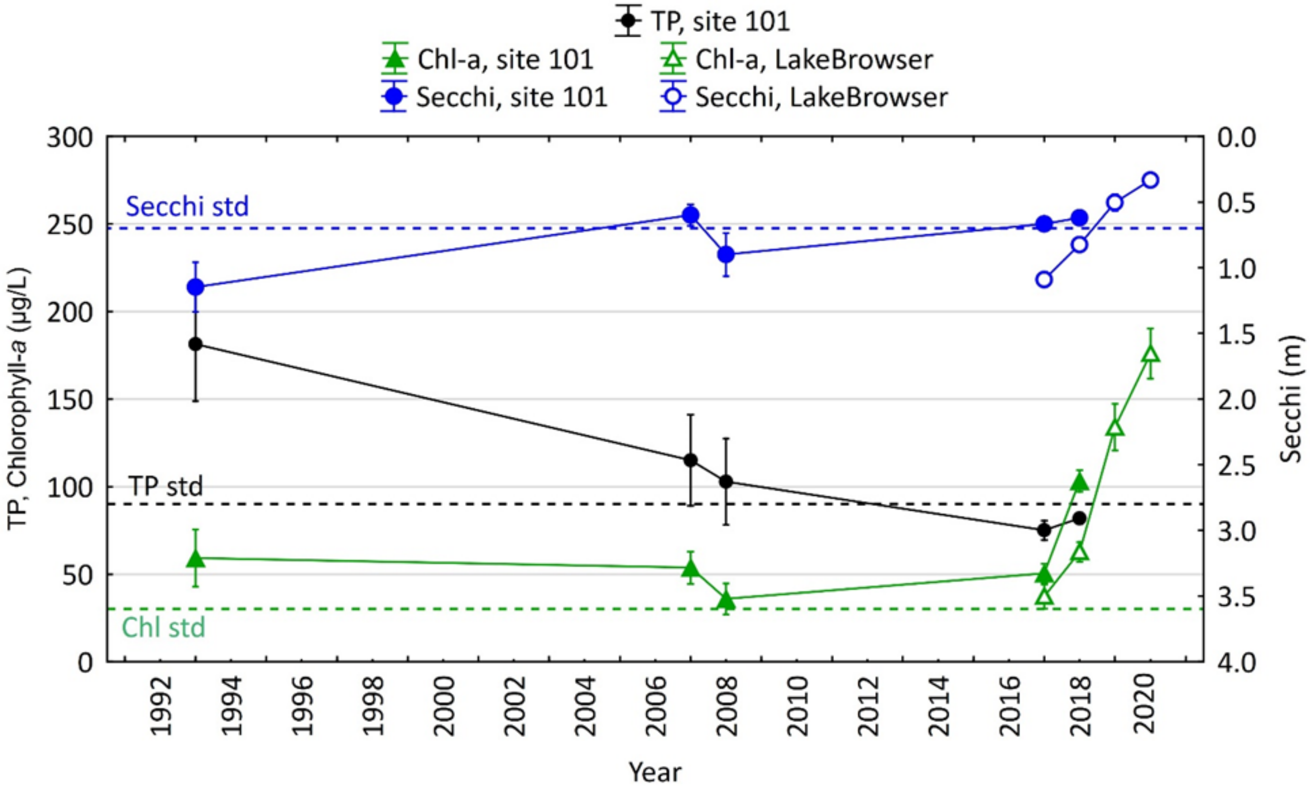


Figure 12. Fox Lake long-term growing season mean Secchi depth data.

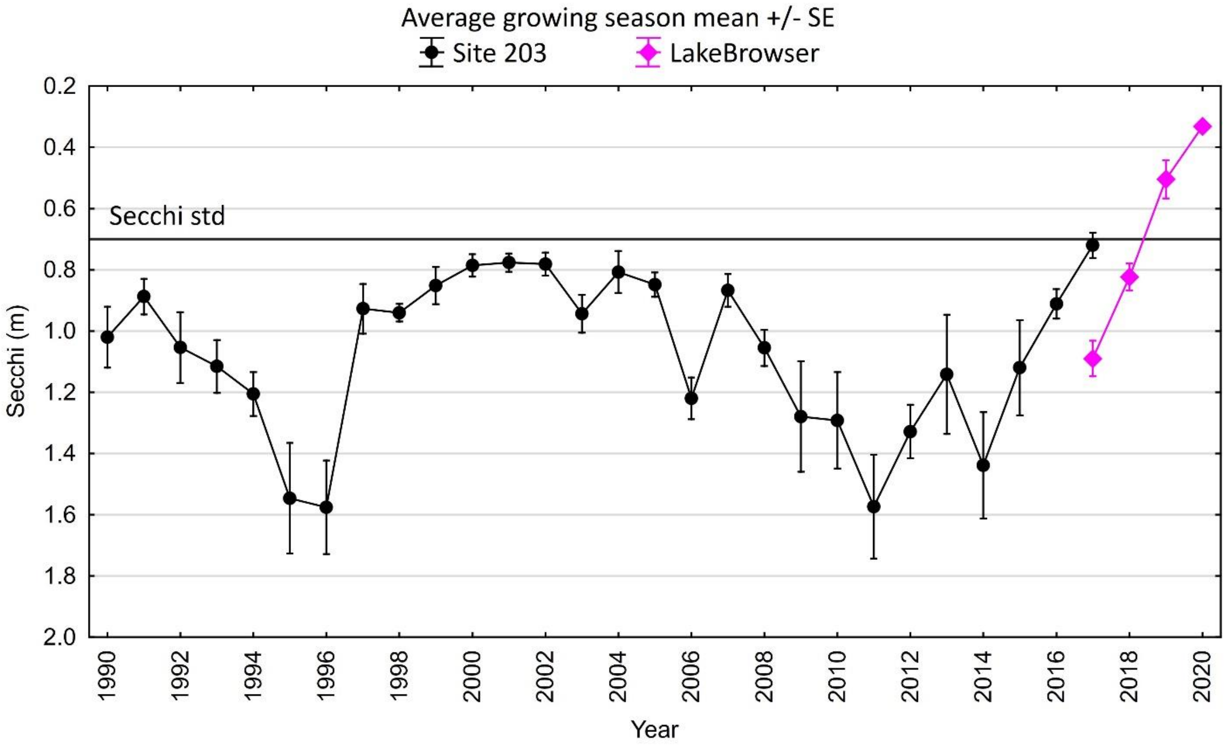


Figure 13. Fox Lake 2018 dissolved oxygen depth profiles at site 101.

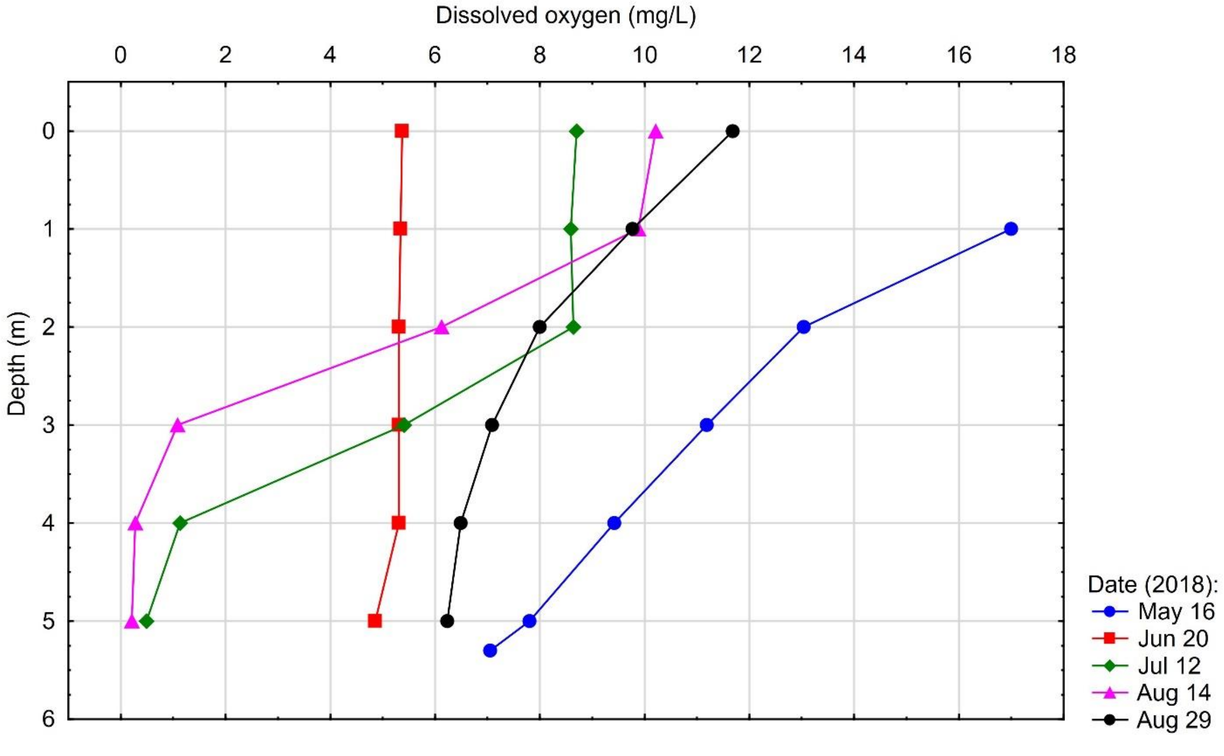


Figure 14. Fox Lake 2007–2008 surface vs. bottom phosphorus concentrations at site 101.

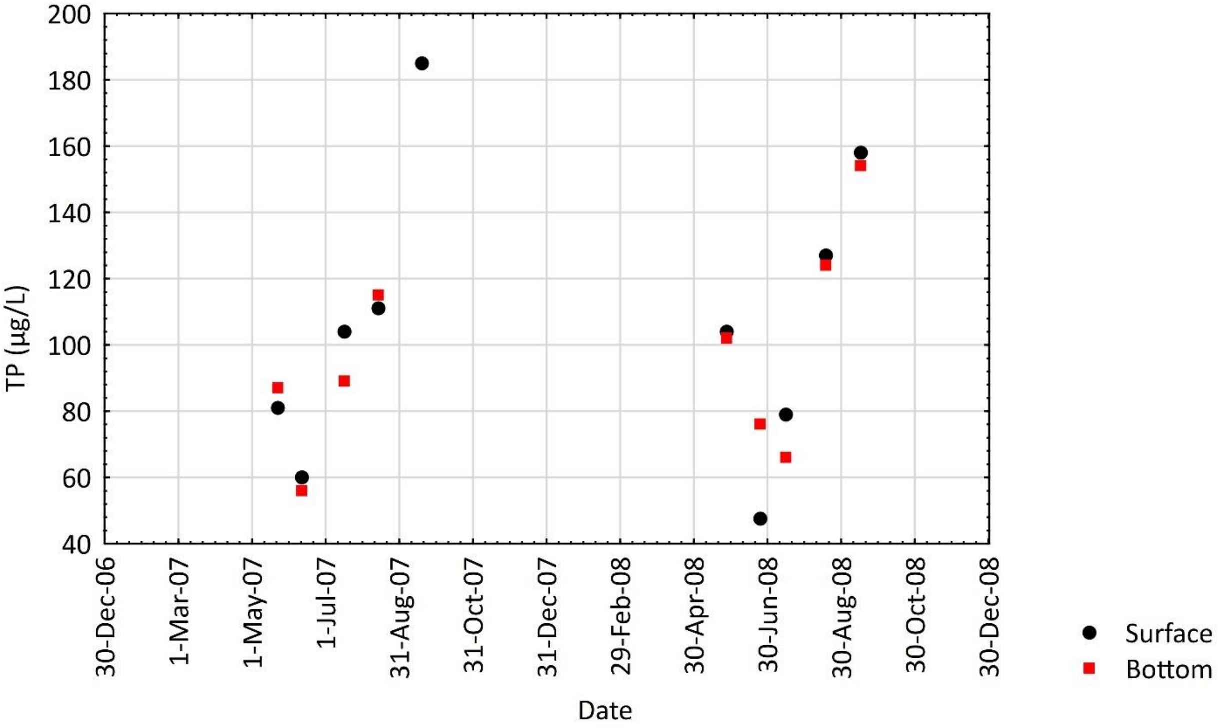


Figure 15. Big Twin Lake growing season means of TP, chl-*a*, and Secchi, site 101.

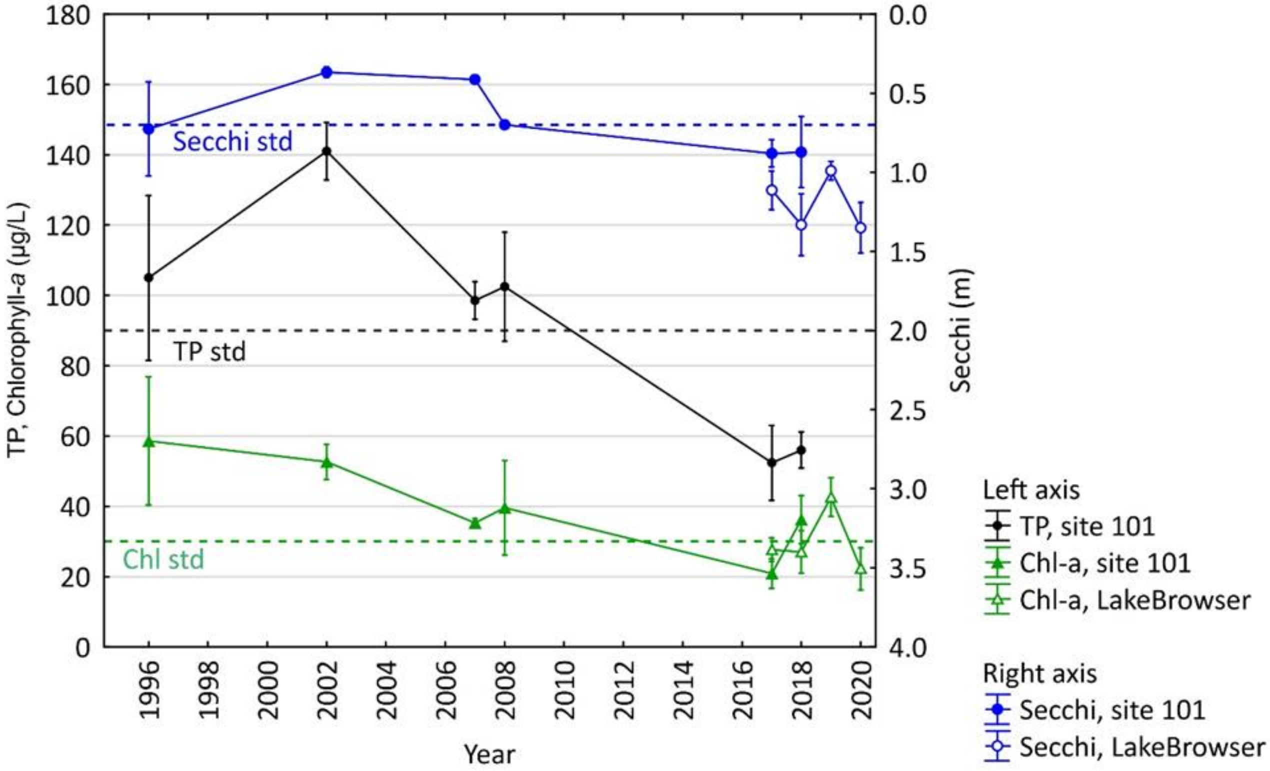


Figure 16. Big Twin Lake 2018 dissolved oxygen depth profiles at site 101.

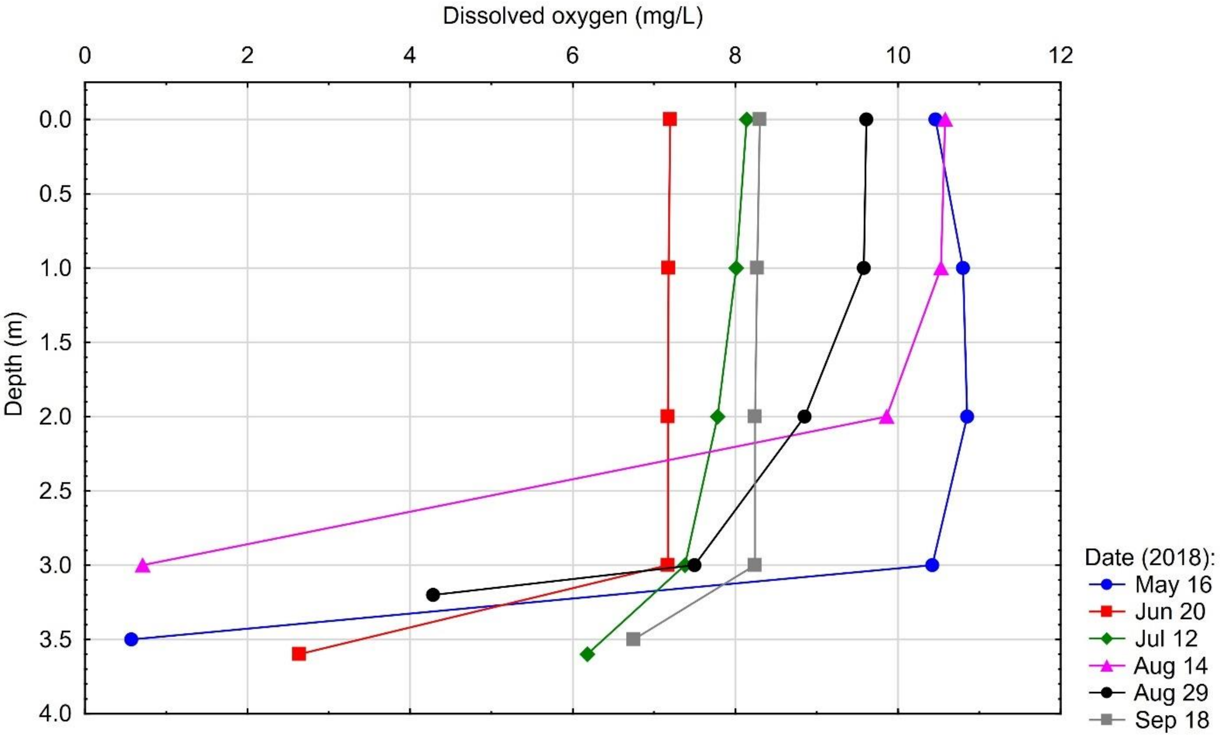
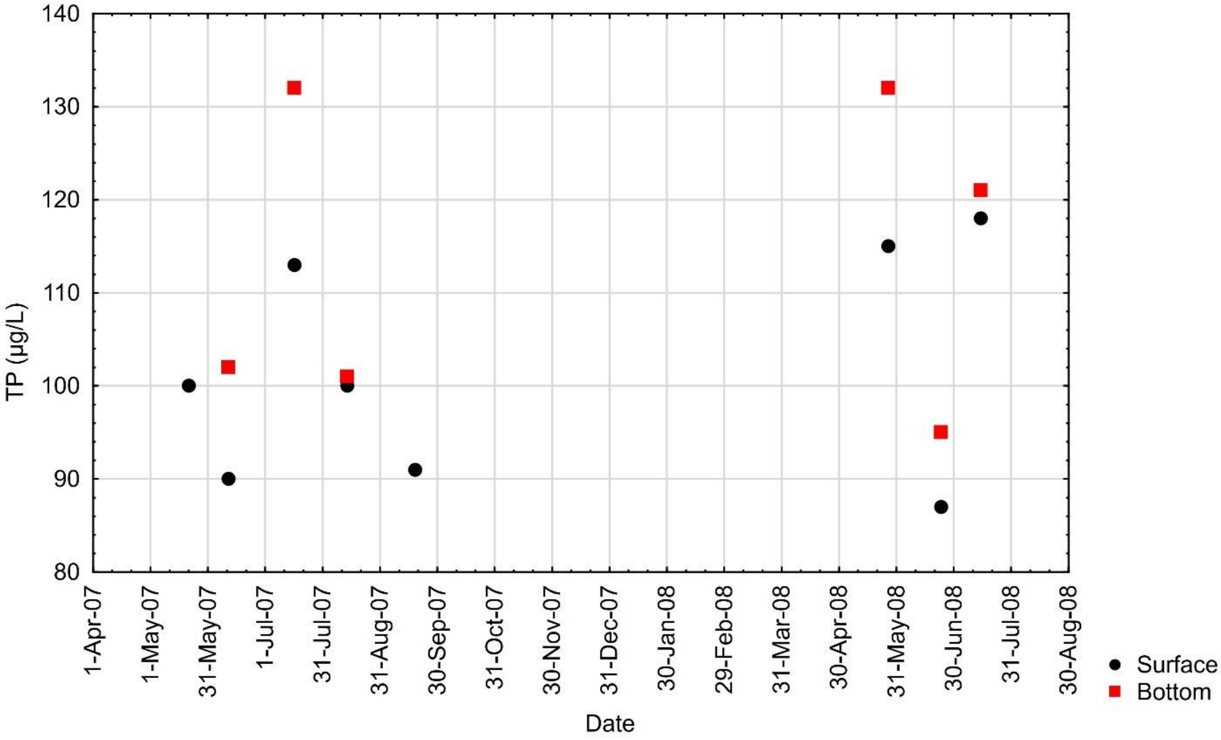


Figure 17. Big Twin Lake 2007–2008 surface vs. bottom phosphorus concentrations at site 101.



2.6 Fisheries summary

The Fairmont Chain of Lakes is a popular fishing destination for anglers in southwest Minnesota. There are no major barriers between the lakes in the Fairmont Chain of Lakes, so fish can move relatively freely throughout the chain during high water levels. The priority lakes in the Fairmont Chain of Lakes are primarily managed by the DNR for walleye and muskellunge, and secondarily for several species including black crappie, yellow perch, bluegill, and channel catfish. Willmert Lake, which is the only lake upstream of the priority lakes that is managed by the DNR, is primarily managed for northern pike and secondarily for yellow perch, walleye, and black crappie. The DNR continually monitors and tracks fish communities in all the priority lakes using various methods including standard surveys (i.e., trap and gill net surveys) as well as assessing the health of the entire fish community (i.e., index of biological integrity). Results of both techniques are described below in more detail.

2.6.1 Routine trap and gill net surveys

2.6.1.1 Fairmont Chain of Lakes

Although several fisheries surveys and assessments were conducted by the DNR prior to 1980, the DNR in 1984 initiated a regular schedule (i.e., four to eight year intervals) of trap and gill net surveys for each managed lake in the Fairmont Chain of Lakes: Amber, Hall, Budd, George, and Willmert. The purpose of the trap and gill net surveys is to provide a relatively broad overview of the fish community and track changes over time (DNR 2017). Since 2000, the five DNR managed lakes in the Fairmont Chain of Lakes have been individually sampled three to four times for a total of 21 survey events. Results of the DNR trap and gill net surveys, which include the raw survey numbers and brief narrative summaries, are available online through the Minnesota DNR LakeFinder.

The DNR trap and gill net survey results and summaries for the Fairmont Chain of Lakes were downloaded and reviewed for this study to characterize fish communities, evaluate potential spatial and/or temporal trends, and compare fisheries trends to other changes and management actions that have occurred within the lakes and their watersheds. In general, the DNR assessment reports indicate that fish communities in the Fairmont Chain of Lakes have undergone several changes over the last 40 years. Below is a summary of some of the important changes and trends noted in the DNR reports:

- Beginning in the mid-1980s, survey numbers for several key gamefish species, including walleye, bluegill, white crappie, and yellow perch, began to decline.
- Also, during the 1980s, catch rates increased for several less desirable fish species such as black bullhead, common carp, and freshwater drum. It is unclear whether the increase in the less desirable species caused the decrease in gamefish by destroying vegetation and by predation or if the decrease in gamefish allowed the less desirable species to fill a void that was left when the gamefish numbers decreased.
- Historically, some of the shallower basins in the Fairmont Chain of Lakes have been susceptible to winterkills. Willmert Lake, for example, has experienced 12 documented winterkills over the last half century, however the most recent documented winterkill was the winter of 2000–2001. It is suspected that mild winters over the past 20+ years have reduced the frequency and severity of winterkill in in the Fairmont Chain of Lakes.

- In or around 2012, yellow bass were illegally introduced to the Fairmont Chain of Lakes and have since established a self-sustaining population. Although yellow bass are native to Minnesota, this species tends to become very abundant in a fish community and can outcompete other desirable fish, such as yellow perch. Recent surveys indicate that yellow bass are one of the most abundant panfish in several of the Fairmont lakes.
- In 2016, muskellunge were introduced by the DNR to the Chain of Lakes to provide an additional predator species and biological control for undesired species. It will likely take at least 5 to 10 years for muskellunge to become a noticeable member of the fish community.

Despite some of the changes noted above, a total of 18 fish species have been sampled throughout the Fairmont Chain of Lakes since 2000, making it one of the more diverse fish communities in the region. Unfortunately, the lack of a long-term water quality data record does not allow for comparison of fish community trends to water quality trends.

2.6.1.2 Fox and Big Twin Lakes

The DNR manages Fox Lake primarily for muskellunge and walleye (which are both stocked in the lake) and secondarily for crappie. The lake is one of two lakes in the Windom fisheries management area that provide muskellunge angling opportunities. In the most recent DNR fisheries survey in 2020, the walleye population was noted as in below average health. Other species include common carp and bigmouth buffalo. Bigmouth buffalo were very abundant in 2020; under these conditions, bigmouth buffalo can compete with other fish species for limited food resources and can disturb lake bottom sediments, leading to poor water quality. Bigmouth buffalo are a primary target for the commercial fishery on the lake.

The DNR manages Big Twin Lake primarily for walleye and secondarily for black crappie. In addition to walleye fingerling stocking, walleye reproduce naturally in the lake in certain years. Data from the most recent DNR fisheries survey in 2020 indicate a robust walleye population. Channel catfish rates have increased since the early 2000s; the channel catfish population could compete for prey with other top predators and affect populations such as walleye. Other species sampled include common carp and black bullhead. Big bluegill, which are often associated with aquatic vegetation, have been caught in the lake.

2.6.2 Fish-based index of biological integrity

A common misconception is that if a lake supports a quality gamefish population (e.g., high abundance or desirable size structure of a popular gamefish species), it should be considered a healthy lake. This is not necessarily true because both game and nongame fish species must be considered when holistically evaluating fish community health. Oftentimes, the smaller nongame fishes serve ecologically important roles in aquatic ecosystems and are generally the most sensitive to human-induced stress. To better evaluate the entire fish community, the DNR uses a fish-based lake index of biological integrity (FIBI) scoring system to assess lakes throughout the State of Minnesota. The FIBI assessments utilize fish community data collected from a combination of trap nets, gill nets, beach seines, and backpack electrofishing. From these data, an FIBI score can be calculated for each lake that provides a measure of overall fish community health based on species diversity and composition. If biological impairments are found, stressors to the fish community must be identified. More information about the sampling and assessment process can be found at the DNR lake index of biological integrity website.

Six of the priority lakes in this study have been sampled and assessed using the FIBI: Amber, Hall, Budd, Sisseton, Fox, and Big Twin (George Lake was not assessed). Results of the FIBI assessments indicate all six assessed lakes scored below the FIBI impairment threshold established for similar lakes and therefore do not support aquatic life use and are considered “impaired.” A Stressor Identification (SID) Report was completed in 2022 for the six impaired lakes in this study, as well as four other lakes in the Blue Earth River Watershed (DNR 2022), to identify primary stressors to the fish communities and to provide general strategies to help address the stressors. The SID report identified the following stressors as probable causes of stress to aquatic life in the FIBI impaired lakes:

- Eutrophication—excess nutrients (Amber, Hall, Budd, Sisseton, Fox, Big Twin)
- Physical habitat alteration—high dock density, low aquatic plant diversity, common carp present, potential fish barriers at some flow conditions, historic dredging, low shoreline health scores (Amber, Hall, Budd, Sisseton, Fox)

The SID report also identified several potential stressors that could be affecting aquatic life but are considered inconclusive at this time until more data and supporting evidence are collected. The inconclusive causes of the FIBI impairments include:

- Physical habitat alteration (Big Twin)
- Altered interspecific competition—common carp, stocking activities, commercial fish removals (Amber, Hall, Budd, Sisseton, Fox, Big Twin)
- Pesticide application—rotenone treatment in 1967, copper sulfate treatments from 1921 through 1979, pesticide impairment for Dutch Creek (Amber, Hall, Budd, Sisseton, Fox, Big Twin)

2.7 Vegetation conditions

Submerged aquatic vegetation (SAV) are critical to shallow lakes, providing spawning and cover for fish, habitat for macroinvertebrates, refuge for prey, and stabilization of sediments. Declines in the abundance and diversity of SAV can be an indication of a shifting water quality state. As disturbances increase, sensitive SAV species are lost from the system and often replaced with less desirable species (e.g., aquatic invasive species) or no SAV at all.

There is very little historic information regarding vegetation in the Fairmont Chain of Lakes. Anecdotal information suggests there used to be more vegetation in several of the lakes in the early 1980s than there is today. A DNR fish survey conducted in 1984 noted sago pondweed as “common.” The DNR survey reports since 2000 have documented very little or sporadic submerged vegetation throughout the chain. This general lack of vegetation creates less habitat for zooplankton, small fish species, and top predators which are critical for maintaining good water quality conditions in shallow lakes. Lakes that are devoid of vegetation are also more susceptible to wind resuspension of sediments, high turbidity levels, increased internal phosphorus recycling, and decreased sedimentation and nutrient retention.

Vegetation notes available for Fox Lake from the DNR fisheries survey indicate curly-leaf pondweed is present in the lake and was first documented in 2006. Curly-leaf pondweed can become abundant in Fox Lake in the southeast portion of the lake. There is no vegetation information available for Big Twin Lake.

2.8 Shoreline conditions

2.8.1 Fairmont Chain of Lakes

Lakeshore habitat assessments were conducted during the FIBI and SID process for five lakes in the Fairmont Chain of Lakes: Willmert, Amber, Hall, Budd, and Sisseton. The primary tool used in the assessments was the DNR Score the Shore Rapid Assessment (Perleberg et al. 2019) which were performed by DNR staff during the summers of 2017 and 2018. Score The Shore is a protocol developed to rapidly assess the quantity and integrity of lakeshore habitat. The survey is designed to assess differences in habitat between lakes and to detect changes over time. Score The Shore surveys require visual observation of lands accessible by boat. The intent of this survey is to assess habitat, not to inspect for violations. Data are not tied to individual properties and are not displayed at the individual lot level. During the surveys, three lakeshore zones (upland/shoreland, shoreline, and aquatic) are assessed independently at each site. Within each zone, surveyors score specific features related to habitat, which are then summed for an overall Zone Habitat Score. Higher scores indicate a greater amount of habitat. Lower scores indicate a low percent of the site remains natural and a higher amount has been physically disturbed or altered by humans. The feature scores within each zone are summed for an overall Site Habitat Score. This scoring process provides a simple method of ranking sites based on the percent of each site that is in a natural condition versus the percent of the site that has been altered. A lakewide score is calculated using the mean Site Habitat Score. Scores range from 0 to 100 and lakes with a high percentage of unaltered habitat score higher than lakes that have been highly altered. More information about the methods used for the Score the Shore surveys can be found in the Minnesota Lake Plant Survey Manual (Perleberg et al. 2019). The DNR also used dock density (based on Google imagery from 2016–2021) to evaluate the level of disturbance occurring along the shoreline of the lakes in the Fairmont Chain of Lakes.

Results of the DNR Score the Shore and dock density assessments are presented in Table 11. The Score the Shore surveys consisted of 30–35 survey sites per lake evenly spaced 100 meters around each lake. Score the Shore scores generally decrease from upstream (Willmert Lake) to downstream (Budd Lake) through the chain as lakeshore development and dock density increases. Hall and Budd Lakes received the lowest scores largely due to their high dock density and highly developed shorelines in the heart of the city of Fairmont. Dock densities exceeding 16 docks per mile can significantly affect fish communities and habitat (Jacobson et al. 2016, Dustin 2017). The surveys for Budd and Hall also noted that vegetation has been removed from at least a portion of the shore frontage either in a small percent of all the canopy layers or from a large percent of at least one canopy layer (e.g., shrub layer has been removed but trees and natural ground cover remain high). Willmert Lake, located approximately two miles south of the city of Fairmont, has the least developed shoreline of the surveyed lakes and received the highest score. Although located within the city of Fairmont, Amber and Sisseton Lakes received moderate scores due to a few large, undeveloped parcels with well-buffered, low dock density shorelines owned by the City of Fairmont on the west side of each lake. Overall, the Amber and Sisseton scores are very close to the mean score for lakes across the state of Minnesota (74). Score the Shore results for Hall and Budd Lakes were below the statewide mean, while Willmert Lake was well above the mean.

Table 11. DNR Score the Shore Survey results for selected lakes in the Fairmont Chain of Lakes.

Category	**Willmert**	**Amber**	**Hall**	**Budd**	**Sisseton**
Dock density (#/mile)	4	19	29	48	17
Survey sites	34	34	33	35	30
Percent developed	41%	71%	94%	100%	97%
Shoreland zone score	32 High	18 Low	11 Very Low	13 Very Low	24 Moderate
Shoreline zone score	32 High	28 High	20 Low	17 Low	23 Moderate
Aquatic zone score	31 High	26 Moderate	24 Moderate	22 Moderate	25 Moderate
TOTAL SCORE	95 High	72 Moderate	55 Low	52 Low	72 Moderate

2.8.2 Fox and Big Twin Lakes

DNR Score the Shore survey results for Fox and Big Twin Lakes are presented in Table 12. The surveys consisted of 91 survey sites for Fox Lake and 50 sites for Big Twin Lake. In general, Fox Lake received lower scores than Big Twin Lake mainly due to significantly higher dock density and shoreline development. Big Twin Lake, with a dock density of 4.1 docks per mile of shoreline, has the third lowest density of the 10 lakes assessed in the Blue Earth River Watershed Lake SID Report (DNR 2022). Overall, the Fox Lake score was slightly below the statewide mean score of 74 while the score for Big Twin Lake was right at the statewide mean.

Table 12. DNR Score the Shore Survey results for Fox and Big Twin Lakes.

Category	**Fox**	**Big Twin**
Dock density (#/mile)	12.9	4.1
Survey sites	91	50
Percent developed	69%	52%
Shoreland zone score	14 Very Low	19 Low
Shoreline zone score	26 Moderate	27 Moderate
Aquatic zone score	27 Moderate	28 High
TOTAL SCORE	67 Moderate	74 Moderate

2.9 Fairmont Chain of Lakes management history

The Fairmont Chain of Lakes has a long history of management that goes back over 100 years. Initially, limiting the severity of algae blooms to protect drinking water for the city of Fairmont was the primary management focus for the Fairmont Chain of Lakes. Copper sulfate was applied to several lakes in the chain for 58 years (1922 through 1979) to reduce excessive algal growth. The copper sulfate treatments had several short-term and long-term effects that were documented extensively in Hanson and Stefan (1984). Short-term effects of the copper sulfate treatments included:

- Immediate, although temporary, killing of algae
- DO depletion by decomposition of dead algae
- Accelerated phosphorus recycling from the lake bed and recovery of the algal population within 7 to 21 days
- Occasional fish kills due to oxygen depletion by decomposition of dead algae

Longer-term effects of the copper sulfate treatments included:

- Copper accumulation in the sediments
- Tolerance adjustments of certain species of algae to higher copper sulfate dosages
- Shift of species from green to blue-green algae and from game fish to “rough fish”
- Disappearance of macrophytes
- Reduction in benthic macroinvertebrates

Over time management in the Fairmont Chain of Lakes expanded beyond the copper sulfate treatments to activities focused on enhancing and protecting the fish community and improving water quality to support boating, swimming, and other recreational activities. Table 13 is a timeline of management activities that have occurred throughout the Fairmont Chain of Lakes over the last century. Unfortunately, gaps in the long-term water quality data record (see Section 2.5.2) do not allow us to evaluate the water quality response and success of each of these management actions. As management continues on the Fairmont Chain of Lakes and their drainage area, it is critical that an effectiveness monitoring program be developed to evaluate BMPs and to inform adaptive management of the lakes.

Table 13. Timeline of lake management activities in the Fairmont Chain of Lakes.

Year(s)	Management activity	Lake(s)	Description
1922–1979	Copper sulfate treatments	Amber, Hall, Budd, Sisseton	Approximately 1.5 million kilograms (~1,650 tons) of copper sulfate applied from 1922-1979 to several lakes in the chain by the Fairmont Lakes Commission to protect drinking water. High concentrations of copper in the sediments, oxygen depletion resulting from the copper treatments, and lack of cost effectiveness prompted the Commission to recommend the suspension of treatments in 1979 (Stefan et al. 1981).

Year(s)	Management activity	Lake(s)	Description
1965	Sanitary sewer system installed	Amber, Hall, Budd, Sisseton, George	Beltline sewer system installed around lakes within the city of Fairmont that eliminated lakeshore septic systems (Stefan et al. 1981).
1966–1967	Dredging	George	Sediment dredging conducted in George Lake to increase volume by approximately 57% (Martin County Environmental Services and MPCA 2003).
1967	Fisheries reclamation	All	Rotenone treatment and subsequent stocking done by DNR to reclaim fish community. DNR records indicate only a partial kill of black bullheads was achieved and other undesirable species (e.g., common carp, bigmouth buffalo, freshwater drum) continued to be abundant (Source: DNR LakeFinder).
1968–1970	Dredging	Sisseton	Sediment dredging conducted in Sisseton Lake to increase volume by approximately 91% (Martin County Environmental Services and MPCA 2003).
1970–2022	Regular fish stocking	Amber, Hall, Budd, Sisseton, George	Regular stocking program started by DNR in 1970 for managed lakes throughout the chain. Stocking has typically occurred every one to four years on each managed lake. Historically, walleye have been the primary stocked species with occasional stockings of northern pike, bluegill, and black crappie (Source: DNR LakeFinder and historic reports).
1971–1980	Dredging	Budd	Periodic sediment dredging conducted in Budd Lake over a nine-year period to increase volume by approximately 34% (Martin County Environmental Services and MPCA 2003).
1981–1999	Dredging	Hall	Periodic sediment dredging conducted in Hall Lake over an 18-year period to increase volume by approximately 60% (Martin County Environmental Services and MPCA 2003).
2002	Aeration	Budd	City of Fairmont installed four SolarBee pond circulators on Budd Lake to enhance mixing to precipitate phosphorus, and in turn, reduce algal production (Martin County Environmental Services and MPCA 2003).
2012	Yellow bass illegally stocked	All	Yellow bass first detected in the Fairmont Chain of Lakes in 2012. Recent DNR surveys indicate they have become the most abundant panfish species in some of the lakes in the chain. DNR hopes that future survey work will continue to shed light on the potential interactions among yellow bass and other panfish species (Source: DNR LakeFinder).
2015–2018	Bluegill stocking	Amber, Hall, Budd, Sisseton, George	Bluegill were purchased and stocked by the Fairmont Lakes Foundation in the fall of 2015 and 2018 (Source: DNR LakeFinder).
2016–2018	Muskellunge stocking	Amber, Hall, Budd, Sisseton, George	In 2016 DNR initiated fingerling stocking of Muskellunge to the Fairmont Chain of Lakes to provide another top predator and biological control for undesired species. A

Year(s)	Management activity	Lake(s)	Description
			second fingerling stocking was conducted in the fall of 2018 (Source: DNR LakeFinder).
2019-2022	Water Storage and Habitat Improvement	Hall (Dutch Creek)	Lessard-Sams awarded the City of Fairmont $1,390,000 in funds from the Clean Water, Land and Legacy amendment funds to restore floodplain wetlands along Dutch Creek, create spawning habitat for northern pike in the Fairmont Chain of Lakes, and create native upland habitat.

3. 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 lakes in this study, including watershed runoff, upstream lakes, feedlots, wastewater, internal recycling, 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.

This section provides a description of the modeling methods used to evaluate watershed phosphorus sources along with a brief description of the potential sources of phosphorus to the priority lakes. More detailed information of estimated phosphorus loads from specific sources to each priority lake can be found in Section 5.

3.1 Watershed modeling approach

3.1.1 Fairmont Chain of Lakes

Previous runoff and water quality modeling efforts in the Fairmont Chain of Lakes drainage area include:

- The City of Fairmont Simple Estimator (SE) Model
- The Dutch Creek and Hall Lake Soil and Water Assessment Tool (SWAT) Model developed by Tetra Tech (2018)
- The Blue Earth River Watershed HSPF Model and Scenario Application Manager (SAM version 2.10) originally developed by RESPEC (2014) and Tetra Tech (2015, 2016) and updated by MPCA in 2022 (3/31/2022 model version)

The Fairmont SE model was developed by City staff in 2021 and includes the entire city of Fairmont municipal boundary. The SE is an Excel-based tool that is commonly used by municipalities in Minnesota to estimate flow, phosphorus loads, and load reductions associated with implementation of BMPs (link to Minnesota Stormwater Manual SE page). The City's 2021 zoning district GIS layer was used to define land cover for the model with some modifications for areas that, for example, are zoned as commercial but are currently being used for agricultural production. The City also used their most up to date (as of 2021) stormwater BMP, stormsewer, and subwatershed GIS data and information to route the flow of water through the model and develop other necessary model inputs. The Fairmont SE model files were supplied by the City to the MPCA for use in this study. The model files were reviewed by MPCA and consolidated to only include areas within the city of Fairmont municipal boundary that drain to the priority lakes. The consolidated model was set up to estimate annual flow volumes and phosphorus loads to the priority lakes from nonagricultural land covers (i.e., residential, commercial, industrial, park, etc.) within the City's municipal boundary from 2017 through 2021.

The Dutch Creek and Hall Lake SWAT Model and the Blue Earth River Watershed HSPF Model both cover the drainage areas for all lakes within the Fairmont Chain of Lakes. The modeling period for the SWAT model covers 2000 through 2017, while the HSPF model runs from 1996 through 2017. Please see the

Dutch Creek and Hall Lake SWAT Modeling Report (Tetra Tech 2018) and the Blue Earth River Watershed TMDL Report (MPCA 2023) for more information on these models.

As discussed in Section 2.5.2, intensive monitoring of the priority lakes in the Fairmont Chain of Lakes began in 2017 and continued through 2021. Continuous flow and water quality monitoring of Dutch Creek (S003-000) also began in 2017 and continued through 2021 (see Section 2.4). Thus, a spreadsheet model (referred to going forward as the Fairmont Chain of Lakes Watershed Loading Model) was created to “extend” the SWAT/HSPF models through 2021 and leverage the Dutch Creek monitoring data and the Fairmont SE model. Below is a brief description of the methods and process used to develop the Fairmont Chain of Lakes Watershed Loading Model:

- Average annual flow and phosphorus land use loading rates (1996 through 2017) for all agricultural and rural (i.e., areas outside of city of Fairmont municipal boundary) land use types were extracted from the Blue Earth River Watershed HSPF model. HSPF land use loading rates were selected over SWAT rates to be consistent with the Blue Earth TMDL and WRAPS reports and because HSPF rates were easily accessible using SAM version 2.10.
- Using the HSPF-derived average annual land use loading rates as a starting point, rates were adjusted upward or downward within the drainage area to Dutch Creek monitoring station S003-000 to match monitored flow volumes and phosphorus loads (see Section 2.4 and Appendix A). Independent loading rate adjustments were made for each year in which flow volumes and loads were monitored (i.e., 2017, 2018, 2019, 2020, and 2021) and adjustments within a given year were consistent across all land use types (i.e., same percent increase or decrease).
- Global adjustments were made to all land use loading rates within the Fairmont Chain of Lakes drainage area (minus the nonagricultural land covers within the city of Fairmont municipal boundary) using the same rate adjustments made to the Dutch Creek station S003-000 drainage area.
- Annual land use loading rates for all nonagricultural land use types within the city of Fairmont municipal boundary were extracted from the Fairmont SE model and incorporated into the Fairmont Chain of Lakes Watershed Loading Model spreadsheet.

3.1.2 Fox and Big Twin Lakes

For Fox and Big Twin Lakes, the MPCA’s Hydrologic Simulation Program–Fortran (HSPF) model application of the Blue Earth River Watershed (RESPEC 2014; Tetra Tech 2015; Tetra Tech 2016; and updated by MPCA in 2022) was used to estimate runoff volumes and phosphorus loads from each lake’s drainage area. Please see the TMDL report (Section 3.7.1.2) for a brief description of how the HSPF model was used to estimate watershed runoff to Fox and Big Twin Lakes. Model documentation contains additional details about the model development and calibration. Phosphorus loading information was exported from the HSPF-SAM model of the Blue Earth River Watershed.

3.2 Phosphorus source summary

3.2.1 Rural watershed runoff

Precipitation that falls in a rural area flows across the land surface and/or through sub-surface drain tiles, 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 rural runoff may include soils, fertilizer, vegetation, release from wetlands, livestock, 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.

Watershed runoff volumes and phosphorus loads for the rural portions (i.e., outside the city of Fairmont boundary) of the Fairmont Chain of Lakes drainage area were estimated using the Fairmont Chain of Lakes Watershed Loading Model (Section 3.1). The Blue Earth River Watershed HSPF model was used as the primary tool to assess rural watershed phosphorus sources for Fox and Big Twin Lakes (Section 3.1).

3.2.2 Urban watershed runoff

The city of Fairmont (population 10,042; MS400239) is subject to the MPCA's Municipal Separate Storm Sewer System (MS4) Permit program. MS4s are defined by the U.S. Environmental Protection Agency (EPA) as stormwater conveyance systems owned or operated by an entity such as a state, city, township, county, district, or other public body having jurisdiction over disposal of stormwater or other wastes. See the Blue Earth TMDL (MPCA 2023) for more information regarding the MS4 program and requirements.

Urbanized areas can be a source of phosphorus to lakes through decaying vegetation (leaves, grass clippings, lawns, etc.), domestic and wild animal waste, soil and deposited particulates from the air, road salt, and oil and grease from vehicles. Although land cover in the Fairmont Chain of Lakes drainage area is predominantly cultivated crops, all five priority lakes are located within the city of Fairmont (population 10,042) municipal boundary. The city of Fairmont represents approximately 22% (6,270 acres) of the Fairmont Chain of Lakes drainage area, although only about 40% of this area is considered developed (i.e., residential, commercial, industrial park, parkland, etc.; see Section 2.3). As of 2021, there was still approximately 2,500 acres of undeveloped cropland within the city of Fairmont municipal boundary that drains to the Fairmont Chain of Lakes.

Runoff volumes and phosphorus loads from developed areas within the city of Fairmont were estimated using the City's SE model which was incorporated into the greater Fairmont Chain of Lakes Watershed Loading Model as discussed in Section 3.1.

3.2.3 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 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 Blue Earth River Watershed TMDL Report (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 (see Section 2.3). 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.

3.2.4 Fertilizer

Chemical fertilizers and manure are the dominant forms of fertilizer in the Fairmont Chain of Lakes drainage area (MPCA 2020a). Phosphorus fertilizers tend to be blends or mixes with nitrogen fertilizers. Typical phosphorus chemical fertilizers include monoammonium phosphate (MAP), diammonium phosphate (DAP), and phosphate (P_2O_5) (MDA 2002). Phosphorus was applied at an estimated 61 lbs of phosphorus per acre (USDA NASS 2017; Tetra Tech 2018; MPCA 2020a). Kaiser et al. (2011) recommends that soils be tested for phosphorus prior to planting to ensure optimal application rates. The survey also concluded that 53% of farmers applied fertilizer in the spring prior to planting, 43% was applied the previous fall, and the remainder was side dressed. Phosphorus may be applied to soybeans at lower rates than applied to corn (Kaiser et al. 2011), but farmers in the area mainly apply commercial phosphorus every other year to corn (MDA 2002).

Manure from livestock operations is often land-applied to crop fields. Manure may be land-applied as a liquid via draglines or as a solid using a spreader (USDA NASS 2017; Tetra Tech 2018; MPCA 2020a). Permitted livestock operations (e.g., CAFOs) have requirements for manure application, especially when the livestock operator land-applies manure on their own crop fields (State of Minnesota 2014). A manure management plan must be developed for all permitted feedlots. All farmers applying manure are required to observe state-mandated setbacks from water features as well. For feedlots with NPDES permits, surface applied solid manure is prohibited during the month of March. Winter application of manure (December through February) requires fields to be approved in their manure management plan, and the feedlot owner/operator must follow a standard list of setbacks and BMPs. Winter application of surface applied liquid manure is prohibited except for emergency manure application as defined by the NPDES permit. "Winter application" refers to application of manure to frozen or snow-covered soils, except when manure can be applied below the soil surface. Minnesota regulations also require manure applicators to follow feedlot permits when they apply manure obtained from feedlots (State of Minnesota 2014).

According to analysis of the 2012 Census of Agriculture by Gronberg et al. (2017), several livestock species produce manure in Martin County. Hogs are the main producers, responsible for over 90% of the county's manure nutrient production. In the Fairmont Chain of Lakes drainage area, manure is typically land-applied in the fall, after harvest, and on corn and soybean fields that are planted the following spring per the Martin County SWCD. Manure is also land-applied during the winter when livestock operations run out of manure storage capacity. In Minnesota, livestock operations must have a 9-month storage capacity (State of Minnesota 2014).

Phosphorus loading from chemical fertilizers and manure was not explicitly estimated for this study. However, inputs from these sources are implicit in the cropland land use loading rates used in the Fairmont Chain of Lakes Watershed Loading Model which were adjusted and calibrated to monitored phosphorus loads in the Dutch Creek Subwatershed (see Section 3.1).

3.2.5 Subsurface sewage treatment systems

subsurface sewage treatment system (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. Common limitations that contribute to failure include seasonal high water table, fine-grained soils, bedrock, and fragipan (i.e., altered subsurface soil layer that restricts water flow and root penetration). Septic systems can fail hydraulically through surface breakouts or hydrogeologically from inadequate soil filtration. Failure potentially results in higher levels of pollutant loading to nearby surface waters.

Septic systems that are conforming and are appropriately sited still discharge small amounts of phosphorus. Failing septic systems do not protect groundwater from contamination; these systems are seepage pits, cesspools, drywells, leaching pits, or other pits, and any system with less than the required vertical separation distance. Septic systems that discharge untreated sewage to the land surface or directly to streams are considered imminent threats to public health and safety (ITPHS) and can contribute phosphorus directly to surface waters. ITPHS typically include straight pipes (i.e., no treatment), effluent ponding at ground surface, effluent backing up into home, unsafe tank lids, electrical hazards, or any other unsafe condition deemed by a certified SSTS inspector. Therefore, not all the ITPHSs discharge pollutants directly to surface waters.

County-wide estimated percentages of SSTSs that are failing to protect groundwater range from 11 to 35%, and systems that are categorized as an ITPHS range from 12 to 28% (Table 14). Rates of noncompliant SSTS overall have been decreasing in the watershed.

Table 14. Average SSTS failure and ITPHS rates by county (2010–2019 average).
Rates are provided by counties to MPCA and are estimates only; the data do not represent verified compliance status.

County name	Failing	ITPHS
Blue Earth County	28%	12%
Cottonwood County	35%	28%
Faribault County	– [a]	21%
Freeborn County	32%	16%
Jackson County	47%	15%
Martin County	11%	16%
Watonwan County	19%	17%

a. Data not available.

All the shoreline properties surrounding Amber, Hall, Budd, Sisseton, and George Lake fall within the city of Fairmont municipal boundary and are connected to the City's sanitary sewer system. For Fox and Big Twin Lakes, it was assumed that SSTSs from shoreline properties have the potential to contribute phosphorus to these lakes. The number of shoreline properties was estimated from aerial photography, and compliance status was estimated from conversations with Martin County staff (Table 15). 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 25% of the Fox Lake residences and 5% of the Big Twin Lake residences are seasonally occupied.

Table 15. Septic system inventory.

Lake	Estimated number of conforming SSTS	Estimated number of nonconforming SSTS
Big Twin	18	1
Fox	94	5

3.2.6 Permitted wastewater dischargers

Fairmont Water Treatment Plant (WTP, permit #MN0045527) was the only permitted wastewater discharger in the Fairmont Chain of Lakes drainage area. This facility, which was located approximately one mile west of Hall Lake along Dutch Creek, was the site of the city's former water supply facility. The facility consisted of three settling basins that were historically used as discharge ponds for lime sludge. In 2013, the City of Fairmont constructed a new water treatment system and therefore, beginning that year, no longer utilized the discharge ponds at the former site in their water treatment process. The current permit for the old Fairmont WTP ponds contains requirements for quarterly monitoring of any discharge (including TP) from the ponds along with annual reporting of facility closure progress. Decommissioning of the settling basins, completed in August of 2021, included periodic dewatering of the ponds leading up to this point in 2019, 2020, and 2021. Discharge monitoring reports (DMRs) for Fairmont WTP indicate TP discharge from the ponds to Dutch Creek from the 2019 through 2021 dewatering activities were small and ranged from <1 to 3.8 lbs per year. The last reported discharge from the facility was in June 2021. The City of Fairmont is expected to apply for termination of the permit.

3.2.7 Internal phosphorus recycling

Internal phosphorus recycling, often referred to as "internal loading," is a common occurrence in eutrophic and hypereutrophic shallow lakes throughout central and southern Minnesota. Phosphorus contained in the sediment of lakes originates as an external phosphorus load that settles out of the water column to the lake bottom. Typically, a significant amount of the external load to the Fairmont Chain of Lakes is delivered during snow melt and spring and early summer runoff. During this time, low water temperatures and high flushing rates limit the amount of algae growth and biological activity within the lakes. A similar pattern exists in Fox Lake and Big Twin Lake, except hydrologic residence times are much longer and therefore flushing rates are not as high. As water temperatures increase in mid-summer (e.g., late June and July), shallow lakes can become thermally stratified during quiescent periods and biological activity increases, which leads to higher rates of algae growth and bacterial decomposition. As this happens, oxygen is consumed by bacteria, and anoxic conditions (i.e., low DO) can develop at the sediment-water interface which leads to the release of phosphorus from the lake sediments. The phosphorus that is released from the sediments is in a soluble form that is readily available to algae for uptake. In shallow lakes like those in the Fairmont Chain of Lakes, phosphorus that has accumulated near the sediment-water interface can be readily mixed into the surface waters following wind events and as stratification begins to weaken in the late summer. Internal phosphorus recycling is especially problematic in shallow lakes during dry and hot summers, when lower base flows provide less dilution for P loads recycled from lake bottom sediments. Further, algae growth rates and sediment decomposition rates are elevated during dry and hot summers due to higher water temperatures and longer hydraulic residence times (Walker 2011).

There are multiple lines of evidence from the data analyses (Section 2.5) and lake models (Section 4.1) developed for this study that suggest internal phosphorus recycling occurs within the Fairmont Chain of Lakes:

- Surface TP concentrations in all five priority lakes increase from June through August each year despite generally decreasing flows, external TP concentrations, and external TP loads during this time period (Section 2.4, Section 2.5, and Figures 67 to 71 in Appendix B).
- 2021 mean summer TP concentrations for four of the five priority lakes (Amber, Hall, Budd, and George) were higher than previous summers (2017 through 2020) despite extremely low rainfall totals, runoff volumes, external TP concentrations, and external TP loads in 2021 (Figure 8).
- Although temperature and DO profile data is rather limited, surface TP concentration spikes have been observed in most of the lakes when thermal stratification weakens and/or breaks down in late summer (see Section 2.5 and Figures 67 to 71 in Appendix B).
- Phosphorus settling/retention rates in the BATHTUB models had to be reduced from default values to calibrate the Budd, Sisseton, and George models to observed values. See Section 4.1 for further discussion.

The data record in Fox Lake and Big Twin Lake is sparser than in the Fairmont Chain of Lakes. However, data suggest that internal recycling of phosphorus may occur in these two lakes intermittently throughout the growing season (Section 2.5.3).

This study does not attempt to explicitly quantify the amount of phosphorus that is recycled within the priority lakes due to a general lack of data to confidently estimate this. Because internal phosphorus recycling reflects recycling of loads that originally entered the lake from the watershed, the amount of P recycling is expected to vary with external load. As discussed in Section 4.1, internal phosphorus recycling is implicitly accounted for by the process used to develop and calibrate the lake BATHTUB models. If the local partners wish to further investigate internal phosphorus recycling in the Fairmont Chain of Lakes, it is recommended that additional data be collected such as high-frequency temperature and DO profiles, hypolimnetic phosphorus samples, and/or sediment cores.

3.2.8 Common carp

Lake eutrophication can lead to, or allow for, the dominance of less desirable fish species such as common carp (MPCA 2005; Lechelt and Bajer 2016). When present in high densities, common carp can further exacerbate poor water quality in lakes by destroying/uprooting aquatic vegetation and resuspending/recycling TP from lake sediments. Studies have demonstrated how adult carp can increase turbidity, TSS, TP, and negatively affect macrophyte abundance through various direct and indirect processes (Parkos et al. 2003). Research suggests that negative impacts of common carp on turbidity and vegetation begin to occur at densities of around 89 lb/acre (Bajer et al. 2009). To our knowledge, common carp density has not been assessed in the priority lakes. Although the gear used in the DNR trap and gill net surveys tends to underrepresent common carp abundance due to high net avoidance, these surveys can provide a relative means to track carp trends and changes over time within a lake and compare catch rates to other lakes. Appendix C presents several figures showing changes in carp catch rates and average weights over time throughout the Fairmont Chain of Lakes. Some of the key takeaways from the DNR survey data include:

- For Willmert and Amber Lakes, common carp catch rates were moderate (i.e., within the normal range of similar lakes) throughout the 1970s and 1980s and then increased to at or above the upper normal range throughout much of the 1990s (Figures 82 and 83 in Appendix C). Common carp catch rates in both lakes peaked in 2001 following a significant winter kill event and have decreased in nearly every survey since 2001. During the most recent surveys (2018) common carp catch rates for both lakes were near the median of similar lakes in the region. Common carp average weights, on the other hand, have steadily increased in both lakes since the 2001 winterkill and were at or above the upper normal range during the 2018 survey. This suggests that while total carp numbers in Willmert and Amber may be on the decline, several large carp remain in these lakes.
- Common carp catch rates for Hall, Budd, Sisseton, and George Lakes have been steadily decreasing from peak values in 1989 that were well above the upper normal range for similar lakes (Figures 84-87 in Appendix C). During the most recent surveys, common carp catch rates were within the normal range for Hall, Budd, and Sisseton, while George was still slightly above the upper normal range. Similar to Willmert and Amber, common carp average weights have steadily increased in Hall, Budd, Sisseton, and George. Average weights were above the upper normal range in all four lakes during the most recent survey.
- When comparing lakes across the chain, Willmert and Amber have historically had the highest common carp catch rates but lowest average weight (Figure 88 through Figure 90 in Appendix C). Conversely, Budd and Sisseton tend to have the lowest catch rates and highest average weights.
- Common carp were sampled in the Fox Lake and Big Twin Lake DNR fisheries surveys. However, observations by DNR staff suggest that carp densities are not excessively high in these lakes.

Similar to internal phosphorus recycling, this study does not attempt to quantify the water quality impacts of common carp on the priority lakes. Given the moderate to high common carp catch rates and average weights in the Fairmont Chain of Lakes, it is possible, if not likely, that common carp have some impact on water quality conditions throughout the chain. The primary process by which common carp affect water quality in lakes is through resuspension of bottom sediments which, in turn, can increase internal phosphorus recycling and reduce phosphorus sedimentation and retention. Thus, phosphorus recycling by common carp is implicitly accounted for in the BATHTUB model calibration process for the priority lakes (Section 4.1).

3.2.9 Atmospheric deposition

Phosphorus is bound to atmospheric particles that settle out of the atmosphere and are deposited directly onto surface water. Phosphorus loading from atmospheric deposition to the surface area of the impaired lakes was estimated using the average for the Minnesota River basin (0.37 lbs per acre per year, Barr Engineering 2007).

3.2.10 Upstream lakes

The Fairmont Chain of Lakes is a series of closely linked flow-through lakes with large upstream contributing areas. There is likely very little, if any, phosphorus settling and retention within the short, shallow channels that connect the priority lakes. Flow is relatively constant through the chain and therefore outflow from one lake can have significant water quality impacts on the next lake in the chain. Phosphorus loading from the immediate upstream lake was explicitly included in the BATHTUB models by multiplying the upstream lake's outflow volume by its average summer growing season TP concentration.

4. Establishing water quality improvement targets and goals

The ultimate goal of this study is to improve water quality conditions in the priority lakes. To achieve this, individual water quality improvement targets for each lake were established and then phosphorus load reduction goals were estimated. Below is an overview of the process used to develop the lake water quality models (Section 4.1), establish in-lake and watershed TP concentration targets (Section 4.2), and set phosphorus load reduction goals to meet these targets (Section 4.3). This section concludes with a brief discussion of another nutrient, nitrogen, that likely impacts water quality in the Fairmont Chain of Lakes (Section 4.4).

4.1 Lake water quality model development

A spreadsheet version of the lake model BATHTUB (Walker 1987) was established for each priority lake to model lake water quality conditions (i.e., phosphorus concentration, chl-*a* concentration, and Secchi transparency) and establish phosphorus targets and reduction goals. BATHTUB is a steady state model that predicts eutrophication response in lakes based on empirical formulas developed for nutrient balance calculations and algal response (Walker 1987). The model was developed by the U.S. Army Corps of Engineers and has been used extensively in Minnesota and across the Midwest for lake nutrient TMDLs. Several models (subroutines) are available for use within the BATHTUB model, and the Canfield-Bachmann model was used to predict phosphorus settling/retention and the lake response to TP loads in all lakes except for Fox Lake. For Fox Lake, the second-order phosphorus model was used to model the response to phosphorus loads. The BATHTUB model requires flow and phosphorus loading inputs from the lake's drainage area, upstream lakes, and atmospheric deposition. Lake morphometric data (Table 4) and estimated mixed depth are also required by the model.

4.1.1 Fairmont Chain of Lakes

The BATHTUB models for the Fairmont Lakes were calibrated to the summer mean lake phosphorus concentration, consisting of all data collected during the intensive monitoring period from 2017 through 2021 (Section 2.5.2). A seven-month averaging period (i.e., April through October) was used to model each priority lake in the Fairmont Chain of Lakes due to short hydraulic and nutrient residence times (Walker 1987, 2006). A majority of the precipitation in the Fairmont Chain of Lakes (~88%) occurs between March and October with the remainder (~12%) falling mostly as snow between November and February (MPCA 2020a), which further justifies applying a seven-month averaging period. Modeled phosphorus loads from watershed sources (Section 3.1), atmospheric deposition (Section 3.2.9), and upstream lake loads (Section 3.2.10) were input to the BATHTUB models, which were then calibrated by adjusting the phosphorus sedimentation calibration factor as recommended in the BATHTUB Version 6.1 Online Documentation (Walker 2006). For the George Lake BATHTUB model, the 2017 through 2021 mean TP concentration greatly exceeded the BATHTUB-predicted steady state TP concentration even when the phosphorus sedimentation calibration factor was set to zero (i.e., no net TP settling/retention). Thus, for George Lake, an explicit phosphorus load, referred to as "internal recycling /unidentified load," was added to calibrate the model. The additional load for George Lake may be attributed to excessive internal phosphorus recycling, sediment resuspension from common carp and wind, and/or other sources (e.g., watershed loads) that could not be quantified with the available data and models. It is also possible that a portion of the additional load needed to calibrate the George Lake model are the result of one (or more) of the sources being under-represented by the available data and models.

It is important to point out that internal phosphorus recycling was not explicitly included as a loading source in the Fairmont Chain of Lakes BATHTUB models because it reflects recycling of phosphorus that originally entered the lakes from the watershed (Walker 2006). Thus, internal phosphorus recycling rates are expected to vary with external load. In long-term steady-state models such as BATHTUB, including internal phosphorus recycling as a separate loading source in the model could produce a model that is less reliable for evaluating response to future changes in external load (Walker 2006). An alternative approach for lakes with high external phosphorus loads is to adjust the phosphorus sedimentation calibration factor so that model predicted concentrations meet observed values as described above.

4.1.2 Fox and Big Twin Lakes

The BATHTUB models for Fox and Big Twin Lakes were calibrated to the average 2017–2018 lake phosphorus concentrations, which was the only data collected in the 10-year period of 2012 through 2021 (Table 10). An annual averaging period (i.e., January through December) was used due to the longer residence times compared to the Fairmont Chain of Lakes. Modeled watershed runoff, SSTS loads, and atmospheric deposition were input to the BATHTUB models. The Big Twin model was calibrated by adjusting the phosphorus calibration factor to reflect the lower phosphorus retention observed when internal phosphorus recycling is high. The Fox Lake model needed minimal calibration; the phosphorus calibration factor was adjusted slightly.

4.2 Water quality improvement targets

4.2.1 Fairmont Chain of Lakes

As discussed in Section 2.5.2, Hall, Budd, and Sisseton Lakes currently meet the 90 µg/L WCBP shallow lake TP standard based on data collected from 2017 through 2021. Two of the priority lakes in this study, Amber and George, failed to meet the WCBP shallow lake TP standard from 2017 through 2021 and therefore TMDLs were developed for the entire chain of lakes as part of the Blue Earth River Watershed TMDL Report (MPCA 2023). All five of the Fairmont Chain of Lakes priority lakes exceed the 30 µg/L WCBP chl-*a* standard for shallow lakes. Because Hall, Budd, and Sisseton currently meet water quality standards for TP, in-lake TP concentration targets below the 90 µg/L standard are needed for these lakes to ensure George Lake meets the TP standard. The following criteria were considered in establishing water quality improvement targets for the Fairmont Chain of Lakes priority lakes:

1. Establish in-lake targets for all lakes that will allow Amber and George to meet the 90 µg/L WCBP standard.
2. Set in-lake targets that will reduce the frequency of occurrence (FOC) of nuisance algae blooms (defined here as individual chl-*a* measurements at or above 30 µg/L; MPCA 2005) throughout the priority lakes.

3. Set in-lake and watershed targets for all lakes that are realistic and achievable.
4. If possible, establish in-lake targets that result in consistent watershed targets/goals across the Fairmont Chain of Lakes drainage area.

Although criteria to protect the public water supply was not included as part of this study, chapter three of the *Minnesota Lake Quality Assessment Report: Developing Nutrient Criteria* (MPCA 2005) includes a section on considerations for establishing in-lake targets for domestic water supply lakes. This section does not propose specific in-lake targets for domestic water supply lakes in Minnesota; however, the authors recommend that in-lake TP concentrations be maintained as low as possible and that an appropriate target for the Fairmont Chain of Lakes may be 70 µg/L or lower (MPCA 2005).

Figure 18 shows the range in summer growing season nuisance algae bloom FOC for the Fairmont Chain of Lakes priority lakes at various mean summer TP concentration intervals. These data suggest nuisance algae blooms rarely occur when summer mean TP concentrations are below 40 µg/L. While eliminating nuisance algae blooms throughout the Fairmont Chain of Lakes would be ideal, the load reductions required to reduce mean in-lake TP levels below 40 µg/L TP would be extremely costly and likely not feasible. Studies suggest that watershed BMPs aimed at trapping, settling, filtering, and infiltrating runoff and subsurface drainage have a wide range of TP load reductions with median values ranging from 25% to 50% (Osgood 2017; RESPEC 2017). Setting watershed TP reduction targets and goals that exceed this range would be difficult to achieve without significant improvements in BMP efficiencies and/or significant shifts in land cover to pre-settlement conditions. Neither of these are expected to change significantly in the foreseeable future due to the importance of agriculture and farming in maintaining the region’s economy. Thus, it would not be realistically feasible to set watershed TP targets that require load reductions that exceed the upper end of this range.

Figure 18. Summer nuisance algae bloom FOC under various mean summer TP conditions for the Fairmont Chain of Lakes priority lakes. Solid green bars represent the mean FOC of all priority lakes (all available data from 2002 through 2021) and error bars represent the maximum and minimum FOC values for individual lakes.

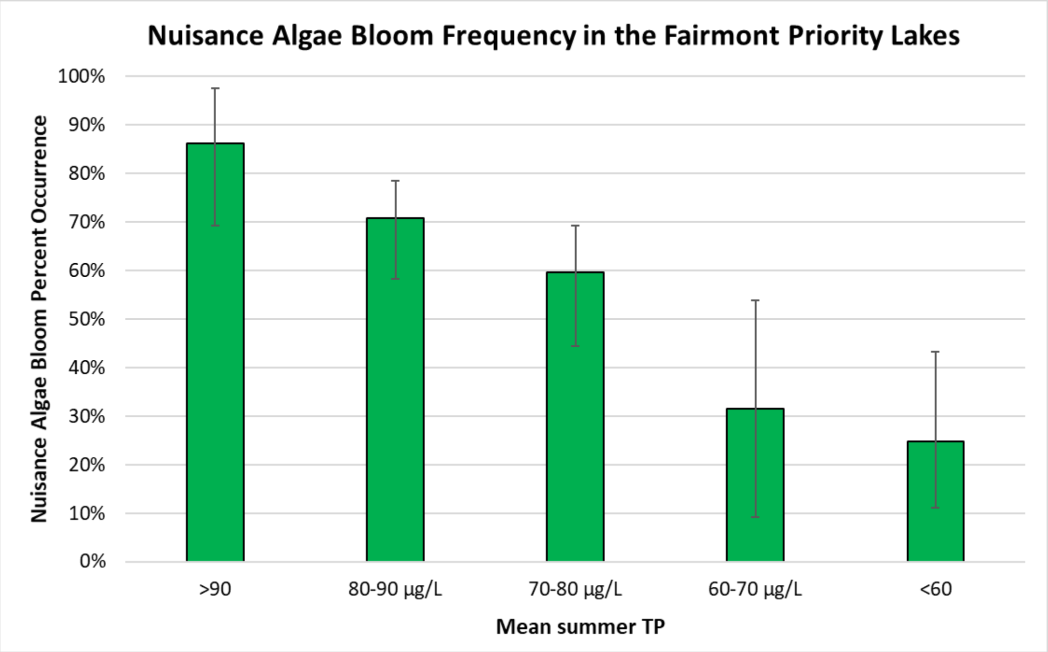


Table 36 in Appendix D presents the modeling approach used to evaluate different in-lake and watershed target scenarios. In general, the modeling exercise showed that each lake would require its own watershed TP target if all five priority lakes were held to the same in-lake TP target. Setting five different watershed TP targets would be confusing, complicating, and present several logistical challenges for watershed managers. Further, there is inherent uncertainty and variability in the watershed data and models used in this study that prohibit us from confidently assigning individual watershed targets for each lake. Thus, a series of model scenarios were run to identify an optimal watershed runoff TP concentration target for the entire Fairmont Chain of Lakes drainage area that achieves the criteria outlined above. Through this approach, the following watershed and in-lake targets were identified.

- All priority lakes: proposed mean annual watershed runoff TP concentration target of 183 µg/L.
- Amber and George: in-lake summer mean TP concentration target of 90 µg/L. This proposed target aligns with the WCBP shallow lake TP standard and, if met, would result in significant TP reductions to downstream lakes and streams. It was demonstrated through the BATHTUB modeling exercise (Table 36 in Appendix D) that both lakes can achieve the 90 µg/L in-lake TP target if all upstream lakes meet their in-lake TP targets and all watershed sources meet the 183 µg/L watershed TP target described above (Table 16). Meeting the watershed and in-lake TP targets would require watershed TP reductions of approximately 25% for Amber and 35% for George.
- Hall and Budd: proposed in-lake summer mean TP concentration target of 65 µg/L. This target is below the 70 µg/L upper end potential goal mentioned in MPCA 2005 and, if met, would reduce nuisance algae bloom FOC and result in significant TP reductions to downstream lakes. Modeling suggests that both lakes can achieve the 65 µg/L in-lake TP target if upstream lakes meet their proposed in-lake TP targets and the 183 µg/L watershed TP target is met. Watershed TP inputs would need to be reduced by approximately 26% in Hall and 39% in Budd for both lakes to meet their proposed in-lake and watershed TP targets.
- Sisseton: proposed in-lake summer mean TP concentration target of 75 µg/L. This target is slightly above the 70 µg/L upper end potential goal mentioned in MPCA 2005. Justification for a slightly higher in-lake TP target for Sisseton includes its location downstream of the city of Fairmont water supply intake, shallow nature (max depth of 18 ft which is shallower than Hall and Budd Lakes), and very high modeled watershed TP reductions (>68%) needed to meet the 65 µg/L in-lake TP target proposed for Hall and Budd. More achievable watershed TP reductions (~22%) would be required for Sisseton to meet the 75 µg/L in-lake target proposed here. Meeting the 75 µg/L in-lake target should result in lower nuisance algae bloom FOC for Sisseton and significant TP load reductions to George Lake. The modeling suggests that Sisseton should achieve the 75 µg/L in-lake TP target as long as the 183 µg/L watershed TP target is met, and Budd Lake meets its proposed 65 µg/L in-lake TP target.

Table 16. Proposed in-lake and watershed TP concentration targets for the Fairmont Chain of Lakes priority lakes.

Condition	Amber	Hall	Budd	Sisseton	George
Current watershed TP (2017–2021)	245 µg/L	247 µg/L	298 µg/L	236 µg/L	280 µg/L
Proposed watershed TP target	183 µg/L				
Current in-lake TP (2017–2021)	107 µg/L	79 µg/L	75 µg/L	85 µg/L	145 µg/L
Proposed In-lake TP Target	90 µg/L	65 µg/L	65 µg/L	75 µg/L	90 µg/L
Modeled in-lake TP if proposed watershed TP target and upstream in-lake TP targets are met	88 µg/L[1]	65 µg/L	62 µg/L[1]	72 µg/L[1]	90 µg/L
Current nuisance algae bloom FOC[2]	70%	68%	60%	71%	75%
Expected nuisance algae bloom FOC range at TP target[3]	58%–70%	9%–54%	9%–54%	44%–69%	58%–75%

[1] Modeled in-lake TP is lower than the proposed in-lake TP target therefore providing some margin of safety (MOS) that the proposed in-lake target for this lake, and all lakes downstream, will be met if/when the proposed watershed TP target is met.

[2] Calculated based on chl-*a* measurements from 2002 and 2017–2021.

[3] Range estimated based on TP and chl-*a* data used in Figure 18.

4.2.2 Fox and Big Twin Lakes

Fox and Big Twin Lakes currently meet the 90 µg/L WCBP shallow lake TP standard based on data collected in 2017 and 2018 (Table 10). Alternative TP concentration targets below the 90 µg/L standard were established to reduce algae and eutrophication to improve and protect aquatic recreation and biota:

- The Fox Lake TP concentration target for this study is 65 µg/L. The 2017–2018 average TP concentration of 78 µg/L is associated with a high chl-*a* concentration, and reductions in TP should reduce the frequency of algal blooms in Fox Lake.
- The Big Twin Lake TP target of 45 µg/L is derived from the simulated TP concentration when chl-*a* meets the WCBP lake criterion of 22 µg/L. Although the 2017–2018 TP and Secchi met the shallow lake criteria, the chl-*a* concentration was hovering at the criterion. Reductions in TP should reduce the frequency of algal blooms in Big Twin Lake.

4.3 Phosphorus reduction goals

With the proposed watershed and in-lake TP targets defined, the BATHTUB models were used to establish phosphorus load and reduction goals for each priority lake in the Fairmont Chain of Lakes using the following approach:

- Allocations for upstream lakes are based on the upstream lake meeting the in-lake TMDL targets (Amber and George) and the proposed in-lake water quality improvement targets (Hall, Budd, Sisseton) described in Section 4.2 and Table 16.
- Watershed load allocations for each priority lake were developed assuming all watershed sources will meet the proposed runoff TP concentration target of 183 µg/L.
- No changes in load from atmospheric deposition were assigned since this source is generally low compared to other sources and difficult to manage.
- For George Lake, the unidentified load (see discussion in Section 4.1) was reduced significantly (~77%) in order to meet the 90 µg/L TMDL target after the upstream lake and watershed load allocations were established as described above.

For Fox and Big Twin Lakes, phosphorus load targets and reduction goals were set using average annual watershed runoff TP concentration targets of 161 µg/L and 135 µg/L, respectively, and assuming all SSTS being compliant.

The total load to each lake in the TMDL (for Amber and George Lakes) and water quality improvement target model scenarios (for the remaining lakes) represents the loading capacity, and the percent reduction needed to meet the target was calculated as the existing load minus the loading capacity divided by the existing load. The estimated percent reduction provides a rough approximation of the overall reduction needed for the lakes to meet the targets proposed in this report. BATHTUB model inputs and outputs are presented in Appendix D. The final load allocations and reduction goals for each priority lake are presented in Section 5.

4.4 Nitrogen

While the primary focus of this study is reducing phosphorus since it is typically the limiting nutrient in lakes, studies have demonstrated that nitrogen loading to lakes can affect eutrophication and should not be overlooked. As discussed in Section 2.5.2, nitrogen inputs from Dutch Creek to the Fairmont Chain of Lakes can be high, particularly during spring and early summer. Further, nitrate and TKN concentrations in all five priority lakes have, at times, exceeded levels that may affect aquatic plants. More nitrogen monitoring data is needed throughout the Fairmont Chain of Lakes to better understand its impact on drinking water, eutrophication, aquatic plants, and other biota. Specific nitrogen targets and watershed load reduction goals for the priority lakes could be considered in the future as more data are collected. Nitrogen reductions alone may not be successful in reducing nuisance algae blooms because certain algae (e.g., blue-green algae) are able to fix atmospheric nitrogen (Wetzel 2001). However, reduction in nitrogen loading in conjunction with the phosphorus load reductions presented in this report is likely the best approach for reducing algal growth and the FOC of nuisance algal blooms (MPCA 2005).

5. Load reductions to meet water quality targets

5.1 Amber Lake (46-0034-00)

The majority of the phosphorus loading to Amber Lake is from cropland runoff throughout the lake's direct drainage area (Table 17). Outflow from Willmert Lake is the second largest loading source followed by developed areas, grassland/pasture, and atmospheric deposition. Forest/shrub and wetlands and open water represent less than 1% of the seasonal load to Amber Lake. While some monitoring data was collected in Willmert Lake in 2017 and 2018, more monitoring of Willmert and the other lakes upstream of Amber (i.e., Mud and North Silver Lakes) is needed to better evaluate their loading and impacts to Amber Lake.

Table 17. Phosphorus source summary for Amber Lake.

Source		Area (acres)	Areal TP load (lb/acre/season [a])	TP concentration (µg/L)	TP load (lb/season[a])	% load
Upstream lake (Willmert) [b]		3,603	0.20	93	610	12%
Watershed runoff from noncity areas	Cropland and feedlot	6,401	0.60	265	3,856	78%
	Grassland and pasture	219	0.25	149	54	1%
	Developed	286	0.24	106	70	1%
	Forest and shrub	108	0.06	42	6	<1%
	Wetland and open water	567	0.06	48	36	<1%
Watershed runoff from city area	Developed [c]	261	0.36	262	95	2%
	Cropland	273	0.60	263	163	3%
	Wetlands and ponds [c,d]	26	–	–	–	–
Atmospheric deposition		182	0.37	59	68	1%
Total		*11,926*	*0.42*	*197*	*4,958*	*100%*

a. Model averaging period is April through October and therefore does not include P loading during winter months (i.e., November through March).
b. Assumes TP of 93 µg/L for Willmert Lake (2017–2018 growing season mean).
c. Developed areas and wetlands/ponds within the city of Fairmont boundary were modeled using the City of Fairmont Simple Estimator (see Section 3.1). All cropland land covers within the city boundary and all land covers outside the city boundary were modeled using the Fairmont Chain of Lakes Watershed Loading Model (see Section 3.1).
d. Does not include Amber Lake surface area. Simple Estimator default rates assume zero net flow and TP loading from wetlands, ponds, and open water areas.

The in-lake TP target for Amber is the WCBP 90 µg/L shallow lake standard. To achieve this target, a TP load reduction of approximately 1,110 lb/season is needed, which represents an overall 22% reduction in the current phosphorus load to the lake (Table 18). The lake and watershed models suggest that a majority of this load (~91%) will need to come from the rural (i.e., non-city) portions of Amber Lake's drainage area. Since approximately 81% of the overall phosphorus load comes from cropland runoff, restoration of Amber Lake should focus on BMPs to reduce sediment and phosphorus loads from these areas. Although minimal data exist, in-lake TP concentrations and phosphorus loading to Willmert Lake will also need to be reduced for Amber to meet its in-lake TP target.

Table 18. Amber Lake phosphorus loading goals.
Loading targets apply Apr–Oct.

P source		Existing P load (lb/season [a])	Target P load (lb/season [a])	Target P load reduction (lb/season [a])	Target P load reduction (%)
Watershed runoff [b]	City area	258	180	78	30%
	Non-City area	4,022	3,013	1,009	25%
Atmospheric deposition		68	68	0	0%
Upstream Lake (Willmert) [c]		610	587	23	4%
	Total	*4,958*	*3,848*	*1,110*	*22%*

a. Model averaging period is April through October and therefore does not include P loading during winter months (i.e., November through March).
b. The watershed runoff target P load was established using a runoff TP concentration target of 183 µg/L for both city and non-city areas.
c. The upstream lake target P load assumes Willmert Lake will meet the 90 µg/L WCBP shallow lake standard.

5.2 Hall Lake (46-0031-00)

Similar to Amber, a majority of the phosphorus loading to Hall Lake comes from cropland runoff (67%; Table 19). Outflow from Amber Lake, which currently exceeds the 90 µg/L WCBP TP standard, represents approximately 26% of Hall Lake's seasonal phosphorus load and is the second largest loading source followed by developed areas (4%) and atmospheric deposition (2%). Wetlands and open water areas, and forest/shrub land represent less than 1% of the seasonal load to Hall Lake. As discussed in Section 3.2.6, the Fairmont WTP settling ponds were decommissioned in August 2021.

Table 19. Phosphorus source summary for Hall Lake.

Source		Area (acres)	Areal TP load (lb/acre/season [a])	TP concentration (µg/L)	TP load (lb/season[a])	% load
Upstream Lake (Amber) [b]		11,926	0.22	107	2,575	26%
Watershed runoff from non-city Areas	Cropland and feedlot	9,930	0.61	268	6,024	61%
	Grassland and pasture	250	0.25	150	62	<1%
	Developed	463	0.27	117	127	1%
	Forest and shrub	135	0.06	42	8	<1%
	Wetland and open water	345	0.06	48	22	<1%
Watershed runoff from city area	Developed [c]	889	0.38	214	341	3%
	Cropland and feedlot	1,189	0.48	214	576	6%
	Wetlands and ponds [c,d]	112	–	–	–	–
	Fairmont WTP [e]	–	–	–	–	–
Atmospheric deposition		548	0.37	59	204	2%

Source	Area (acres)	Areal TP load (lb/acre/season [a])	TP concentration (µg/L)	TP load (lb/season[a])	% load
Total	*25,787*	*0.39*	*176*	*9,939*	*100%*

a. Model averaging period is April through October and therefore does not include loading during winter months (i.e., November through March).
b. Assumes TP of 107 µg/L for Amber Lake (2017–2021 growing season mean).
c. Developed areas and wetlands/ponds within the city of Fairmont boundary were modeled using the City of Fairmont Simple Estimator (see Section 3.1). All cropland land covers within the city boundary and all land covers outside the city boundary were modeled using the Fairmont Chain of Lakes Watershed Loading Model (see Section 3.1).
d. Does not include Hall Lake surface area. Simple Estimator default rates assume zero net flow and TP loading from wetlands, ponds, and open water areas.
e. Fairmont WTP was decommissioned in August 2021 (see Section 3.2.6). Prior to decommissioning DMR records from 2017 through 2021 indicate this facility contributed approximately 1 lb of TP per season to Hall Lake at a mean concentration of ~45 µg/L.

The in-lake water quality target for Hall Lake is 65 µg/L TP. To achieve this target, a TP load reduction of approximately 2,277 lb/season (~23%) is needed (Table 20). It is estimated that approximately 76% of the load reduction required for Hall Lake (~1,726 lb/season) will need to come from the rural (i.e., non-city) portions of Hall Lake's drainage area, which includes most of the Dutch Creek Subwatershed. Since a significant portion of the phosphorus load to Hall Lake comes from cropland runoff, restoration should focus on BMPs to reduce sediment and phosphorus loads from these areas. It is estimated that reducing phosphorus loads to Amber Lake to meet the 90 µg/L WCBP standard will lead to a phosphorus load reduction to Hall Lake of approximately 418 lb/season. Implementation of stormwater BMPs throughout the developed areas surrounding Hall Lake should also be evaluated since this source represents a sizeable portion of the current load to the lake.

Table 20. Hall Lake phosphorus loading goals.
Loading targets apply Apr–Oct.

P source		Existing P load (lb/season [a])	Target P load (lb/season [a])	Target P load reduction (lb/season [a])	Target P load reduction (%)
Watershed runoff [b]	City area	917	785	132	14%
	Non-City area	6,243	4,517	1,726	28%
Atmospheric deposition		204	204	0	0%
Upstream Lake (Amber) [c]		2,575	2,157	418	16%
Fairmont WTP [d]		–	–	–	–
	Total	*9,939*	*7,663*	*2,276*	*23%*

a. Model averaging period is April through October and therefore does not include loading during winter months (i.e., November through March).
b. The watershed runoff target P load was established using a runoff TP concentration target of 183 µg/L for both city and non-city areas.
c. The upstream lake target P load assumes Amber Lake will meet the 90 µg/L WCBP shallow lake standard.
d. Fairmont WTP was decommissioned in August 2021 and therefore will no longer be a phosphorus source to Hall Lake (see Section 3.2.6 and Table 19).

5.3 Budd Lake (46-0030-00)

The Hall Lake Watershed represents a majority of the Budd Lake Watershed (97% by area), and therefore a majority of the phosphorus loading to Budd Lake is from Hall Lake (92%; Table 21). All of Budd Lake's 523-acre direct watershed is located within the city of Fairmont and most of this area is developed (~95%). Thus, nearly all of the phosphorus loading from the direct watershed comes from developed areas (285 lb/season) while only a small portion comes from cropland runoff (13 lb/season). Atmospheric deposition accounts for approximately 2% of the seasonal TP load to Budd Lake.

Table 21. Phosphorus source summary for Budd Lake.

Source		Area (acres)	Areal TP load (lb/acre/season [a])	TP concentration (µg/L)	TP load (lb/season[a])	% load
Upstream Lake (Hall) [b]		25,787	0.16	79	4,170	92%
Watershed runoff from city area	Developed [c]	498	0.57	302	285	6%
	Cropland and feedlot	25	0.53	241	13	<1%
	Wetlands and ponds [c,d]	0	–	–	–	–
Atmospheric deposition		228	0.37	59	85	2%
Total		*26,538*	*0.17*	*82*	*4,553*	*100%*

a. Model averaging period is April through October and therefore does not include loading during winter months (i.e., November through March).

b. Assumes TP of 79 µg/L for Hall Lake (2017–2021 growing season mean).

c. Developed areas and wetlands/ponds within the city of Fairmont boundary were modeled using the City of Fairmont Simple Estimator (see Section 3.1). All cropland land covers within the city boundary and all land covers outside the city boundary were modeled using the Fairmont Chain of Lakes Watershed Loading Model (see Section 3.1).

d. Does not include Budd Lake surface area. Simple Estimator default rates assume zero net flow and TP loading from wetlands, ponds, and open water areas.

The in-lake water quality target for Budd Lake is 65 µg/L TP. To achieve this target, a TP load reduction of approximately 845 lb/season (~19%) is needed (Table 22). It is estimated that approximately 86% of this load reduction could be achieved if phosphorus loading to Hall Lake is reduced to meet the 65 µg/L in-lake TP target proposed in this report. Implementation of stormwater BMPs throughout the developed areas surrounding Budd Lake will also be needed for Budd Lake to meet its in-lake TP target.

Table 22. Budd Lake phosphorus loading goals.

Loading targets apply Apr–Oct.

P source		Existing P load (lb/season [a])	Target P load (lb/season [a])	Target P load reduction (lb/season [a])	Target P load reduction (%)
Watershed runoff [b]	City area	298	183	115	39%
	Non-City area	–	–	–	–
Atmospheric deposition		85	85	0	0%
Upstream Lake (Hall) [c]		4,170	3,440	730	18%
Total		*4,553*	*3,708*	*845*	*19%*

a. Model averaging period is April through October and therefore does not include loading during winter months (i.e., November through March).

b. The watershed runoff target P load was established using a runoff TP concentration target of 183 µg/L for both city and non-city areas.

c. The upstream lake target P load assumes Hall Lake will meet the 65 µg/L water quality improvement concentration target identified in this report (see Section 4.2).

5.4 Sisseton Lake (46-0025-00)

Budd Lake and its upstream contributing area represents a majority of the drainage area to Sisseton Lake (~93% by area). As a result, most of the phosphorus loading to Sisseton Lake is from Budd Lake (80%; Table 23). However, Sisseton does have a sizeable direct drainage area (~1,834 acres) of which 81% is within the city of Fairmont and 19% is outside the city boundary. Approximately 513 acres (~35%) of the city of Fairmont direct drainage area is currently developed. Thus, a majority of the phosphorus loading from the city-portion of the direct watershed comes from cropland runoff (477 lb/season; 65%) while developed areas account for 35% (256 lb/season). Grassland and pasture, forest and shrub land, and atmospheric deposition each account for 1% of the seasonal phosphorus load to Sisseton Lake.

Table 23. Phosphorus source summary for Sisseton Lake.

Source		Area (acres)	Areal TP load (lb/acre/season[a])	TP concentration (µg/L)	TP load (lb/season[a])	% load
Upstream Lake (Budd)[b]		26,538	0.15	75	4,052	80%
Watershed runoff from non-city Areas	Cropland and feedlot	300	0.64	287	193	4%
	Grassland and pasture	19	0.24	144	5	<1%
	Developed	19	0.54	194	10	<1%
	Forest and shrub	9	0.06	42	<1	<1%
	Wetland and open water	10	0.06	48	<1	<1%
Watershed runoff from city area	Developed[c]	513	0.50	244	256	5%
	Cropland and feedlot	962	0.50	221	477	9%
	Wetlands and ponds[c,d]	2	–	–	–	–
Atmospheric deposition		138	0.37	59	51	1%
	Total	*28,510*	*0.18*	*86*	*5,045*	*100%*

a. Model averaging period is April through October and therefore does not include loading during winter months (i.e., November through March).
b. Assumes TP of 75 µg/L for Budd Lake (2017–2021 growing season mean).
c. Developed areas and wetlands/ponds within the city of Fairmont boundary were modeled using the City of Fairmont Simple Estimator (see Section 3.1). All cropland land covers within the city boundary and all land covers outside the city boundary were modeled using the Fairmont Chain of Lakes Watershed Loading Model (see Section 3.1).
d. Does not include Sisseton Lake surface area. Simple Estimator default rates assume zero net flow and TP loading from wetlands, ponds, and open water areas.

The in-lake water quality target for Sisseton Lake is 75 µg/L TP. To achieve this target, a TP load reduction of approximately 759 lb/season (~15%) is needed (Table 24). It is estimated that a majority of the load reduction needed for Sisseton Lake will be achieved if Budd Lake is able to meet its 65 µg/L in-lake TP target. Implementation of agricultural and urban stormwater BMPs throughout Sisseton Lake's direct drainage area will also be needed for Sisseton to meet its in-lake TP loading goal.

Table 24. Sisseton Lake phosphorus loading goals.
Loading targets apply Apr–Oct.

P source		Existing P load (lb/season [a])	Target P load (lb/season [a])	Target P load reduction (lb/season [a])	Target P load reduction (%)
Watershed runoff [b]	City area	733	587	146	20%
	Non-City area	209	143	66	32%
Atmospheric deposition		51	51	0	0%
Upstream Lake (Budd) [c]		4,052	3,505	547	13%
	Total	*5,045*	*4,286*	*759*	*15%*

a. Model averaging period is April through October and therefore does not include loading during winter months (i.e., November through March).

b. The watershed runoff target P load was established using a runoff TP concentration target of 183 µg/L for both city and non-city areas.

c. The upstream lake target P load assumes Budd Lake will meet the 65 µg/L water quality improvement concentration target identified in this report (see Section 4.2).

5.5 George Lake (46-0024-00)

The Sisseton Lake drainage area represents a majority of the George Lake Watershed (99% by area), and therefore outflow from Sisseton Lake represents a significant portion (~58%) of George Lake's seasonal phosphorus budget (Table 25). The unidentified load needed to calibrate the George Lake BATHTUB model is the second largest potential source of phosphorus to George Lake (3,381 lb/season; 40%). It is unclear currently what constitutes the drivers of the unidentified load. As discussed in Section 4.1, potential explanations include excessive internal phosphorus recycling, resuspension by wind and/or common carp, and underrepresentation of sources currently accounted for in the George Lake BATHTUB and watershed models (e.g., upstream lakes, watershed inputs). All of George Lake and its 344-acre direct watershed is located within the city of Fairmont and most of it is developed (~82%). As a result, a majority of the loading from the direct watershed comes from developed areas (146 lb/season). Cropland/feedlots and atmospheric deposition are the other sources to George Lake and account for 38 lb/season and 31 lb/season, respectively.

Table 25. Phosphorus source summary for George Lake.

Source		Area (acres)	Areal TP load (lb/acre/season [a])	TP concentration (µg/L)	TP load (lb/season[a])	% load
Upstream Lake (Sisseton) [b]		28,510	0.17	85	4,913	58%
Watershed runoff from city area	Developed [c]	283	0.52	279	146	2%
	Cropland and feedlot	60	0.64	280	38	<1%
	Wetlands and ponds [c,d]	2	–	–	–	–
Atmospheric deposition		83	0.37	59	31	<1%
Unidentified load [e]		–	–	–	3,381	40%
	Total	*28,938*	*0.29*	*144*	*8,509*	*100%*

a. Model averaging period is April through October and therefore does not include loading during winter months (i.e., November through March).

b. Assumes TP of 85 µg/L for Sisseton Lake (2017–2021 growing season mean).

c. Developed areas and wetlands/ponds within the city of Fairmont boundary were modeled using the City of Fairmont Simple Estimator (see Section 3.1). All cropland land covers within the city boundary and all land covers outside the city boundary were modeled using the Fairmont Chain of Lakes Watershed Loading Model (see Section 3.1).
d. Does not include George Lake surface area. Simple Estimator default rates assume zero net flow and TP loading from wetlands, ponds, and open water areas.
e. Unidentified load refers to the additional load that was required to calibrate the George Lake BATHTUB model to 2017–2021 mean monitored in-lake TP concentrations. See Section 4.1 for further discussion.

The in-lake water quality target for George Lake is the 90 µg/L WCBP shallow lake TP standard. To meet this standard, phosphorus loading to George Lake will need to be reduced by approximately 3,238 lb/season (~38%) (Table 27). The George Lake BATHTUB model suggests that the unidentified load will need to be reduced by approximately 80% to meet this load reduction goal. Since such a large portion of the lake's phosphorus budget is unidentified at this time, it is recommended that additional monitoring and modeling be done in George Lake and the other lakes to track and quantify all potential sources to the lakes. Section 6.2 presents several potential monitoring activities that could be considered in the future. The modeling also suggests that improvements to Sisseton Lake would result in significant load reductions to George Lake (~ 569 lb/season). Implementation of stormwater and agricultural BMPs throughout George Lake's direct drainage area will also help George Lake meet state water quality standards.

Table 26. George Lake phosphorus loading goals.
Loading targets apply Apr–Oct.

P source		**Existing P load (lb/season [a])**	**Target P load (lb/season [a])**	**Target P load reduction (lb/season [a])**	**Target P load reduction (%)**
Watershed runoff [b]	City area	184	120	64	35%
	Non-City area	–	–	–	–
Atmospheric deposition		31	31	0	0%
Upstream Lake (Sisseton) [c]		4,913	4,344	569	12%
Unidentified load [d]		3,381	776	2,605	77%
	Total	*8,509*	*5,271*	*3,238*	*38%*

a. Model averaging period is April through October and therefore does not include loading during winter months (i.e., November through March).
b. The watershed runoff target P load was established using a runoff TP concentration target of 183 µg/L for both city and non-city areas.
c. The upstream lake target P load assumes Sisseton Lake will meet the 75 µg/L water quality improvement concentration target identified in this report (see Section 4.2).
d. Unidentified load refers to the additional load that was required to calibrate the George Lake BATHTUB model to 2017–2021 mean monitored in-lake TP concentrations. See Section 4.1 for further discussion.

5.6 Fox Lake (46-0109-00)

The primary identified sources of phosphorus to Fox Lake are cropland runoff, runoff from developed areas, SSTS, and atmospheric deposition (Table 27). Loading from atmospheric deposition is relatively high due to the large lake surface area relative to the size of the watershed. However, reductions in atmospheric deposition are not assumed in the water quality target scenario.

Table 27. Phosphorus source summary for Fox Lake.

Source		TP load lb/yr	TP load %
Watershed runoff	Cropland	1,300	66%
	Pasture	6	<1%
	Developed	130	7%
	Natural (grassland, forest, wetland)	49	3%
SSTS		111	6%
Atmospheric deposition		353	18%
	Total	*1,949*	*100%*

To reach the Fox Lake phosphorus target (65 µg/L), the total load to the lake needs to be reduced by approximately 27%, with a focus on load reductions from watershed runoff (Table 28). Because approximately 66% of the overall phosphorus load comes from cropland runoff, restoration of Fox Lake should focus on BMPs to reduce sediment and phosphorus loads from these areas. The Fox Lake Watershed runoff reduction goal is based on an average annual watershed runoff TP concentration target of 161 µg/L and all SSTS being compliant.

Table 28. Fox Lake phosphorus loading goals.
Loading targets apply Jan–Dec.

Source	Existing TP load lb/yr	Target TP load lb/yr	Estimated load reduction lb/yr	Estimated load reduction %
Watershed runoff	1,485	960	525	35%
SSTS	111	105	6	5%
Atmospheric deposition	353	353	–	0%
Total load	*1,949*	*1,418*	*531*	*27%*

5.7 Big Twin Lake (46-0133-00)

The primary identified sources of phosphorus to the lake are cropland runoff and atmospheric deposition (Table 29). Loading from atmospheric deposition is relatively high due to the large lake surface area relative to the size of the watershed. However, reductions in atmospheric deposition are not assumed in the water quality target scenario.

Table 29. Phosphorus source summary for Big Twin Lake.

Source		TP load lb/yr	TP load %
Watershed runoff	Cropland	264	54%
	Pasture	9	2%
	Developed	9	2%
	Natural (grassland, forest, wetland)	14	3%
SSTS		22	4%
Atmospheric deposition		171	35%
	Total	*489*	*100%*

To reach the Big Twin Lake phosphorus goal (45 µg/L), the total load to the lake needs to be reduced by approximately 27%, with a focus on load reductions from watershed runoff (Table 30). Because approximately 54% of the overall phosphorus load comes from cropland runoff, restoration of Big Twin Lake should focus on BMPs to reduce sediment and phosphorus loads from these areas. The Big Twin

Lake Watershed runoff target is based on an average annual watershed runoff TP concentration target of 135 µg/L and all SSTS being compliant.

Table 30. Big Twin Lake phosphorus loading goals.
Loading targets apply Jan–Dec.

	Existing TP load	Target TP load	Estimated load reduction	
Source	**lb/yr**	**lb/yr**	**lb/yr**	**%**
Watershed runoff	296	166	130	44%
SSTS	22	20	2	7%
Atmospheric deposition	171	171	0	0%
Total load	*489*	*358*	*132*	*27%*

6. Strategies and monitoring

6.1 General strategies to meet water quality improvement targets

6.1.1 Fairmont Chain of Lakes

As demonstrated throughout this report, water quality of the priority lakes is closely linked to the amount of phosphorus delivered to the lakes from their direct drainage areas and upstream lakes. This study estimates that approximately 85% of the current external phosphorus load to the priority lakes comes from cropland runoff. Developed areas represent the next largest external phosphorus source to the Fairmont Chain of Lakes priority lakes (~10% of external sources). The external phosphorus load estimates for this study are consistent with those presented in previous studies and modeling efforts (Stefan and Hanson 1981; Tetra Tech 2018). The lake models developed for this study suggest phosphorus loading to the priority lakes in the Fairmont Chain of Lakes will need to be reduced by at least 25% for each lake to meet the in-lake and watershed TP targets presented in Section 4.2. As discussed in Section 5, reductions will need to come from a variety of areas and sources, including on average:

- 2,800 lb/season from watershed areas outside the city of Fairmont municipal boundary
- 500 lb/season from watershed areas within the city of Fairmont municipal boundary
- 2,600 lb/season from unidentified source(s) (George Lake)

Nutrient reductions will also be needed from the headwater lakes (i.e., Willmert and North Silver Lakes) located upstream of the five priority lakes. More monitoring and modeling are needed for these lakes to identify appropriate targets and load reduction goals. It was demonstrated through modeling that significant phosphorus load reductions to the priority lakes will be achieved (range = 417-730 lb/season) when the immediate upstream lake meets its in-lake and watershed targets. Therefore, working from upstream to downstream and promoting BMPs in the upstream priority lake drainage areas (i.e., Amber and Hall Lakes) are the most appropriate starting points for watershed managers.

There are several models, tools, studies, plans, and initiatives that have evaluated and identified strategies and BMPs to reduce sediment, phosphorus, nitrogen, and other pollutants to the Fairmont Chain of Lakes. Some of these include, but are not limited to, the Fairmont Chain of Lakes SWAT model (Tetra Tech 2018), an Agricultural Conservation Planning Framework (ACPF) model, the Surface Water Intake Protection Plan for the City of Fairmont (MDH 2022), and the 319 Small Watershed Nine Key Element (NKE) Plan for Dutch Creek (MPCA 2020a). Table 31 summarizes the key strategies and BMPs that have been identified for the Fairmont Chain of Lakes. Specific details regarding how these strategies/BMPs were selected and their targeted locations, scales of adoption, estimated reductions, potential costs, etc., can be found in the plans and reports listed in Table 31.

Table 31. Watershed strategies and BMPs to reduce sediment and phosphorus loads to the Fairmont Chain of Lakes.

Strategy type	Lake(s) and/or targeted location(s)	Reference(s)
Offline treatment wetland	Mouth of Dutch Creek	Tetra Tech 2018; MPCA 2020a
Soil health (e.g., reduced tillage, no till/strip till, cover crops)	Prioritize critical areas in Hall Lake watershed identified in NKE plan	MPCA 2020a; MDH 2022
Livestock management (e.g., exclusion fencing, feedlot compliance)	Prioritize operations near riparian areas and where livestock have direct access to streams	MPCA 2020a; MDH 2022
Nutrient management (e.g., fertilizer rates and timed application, targeted nutrient management plans, manure management plans, manure crediting, manure testing and equipment calibration)	Watershed-wide	MPCA 2020a; MDH 2022
Conservation cover (e.g., wetland restorations, filter strips, maintain buffer compliance)	Prioritize critical areas in Hall Lake watershed identified in NKE plan	MPCA 2020a; MDH 2022
Agricultural BMPs (e.g., WASCOBs, grassed waterways, saturated buffers, bioreactors, controlled drainage)	Prioritize critical areas in Hall Lake watershed identified using the ACPF tool developed by Martin SWCD	MPCA 2020a; MDH 2022
Urban stormwater runoff control (e.g., rain gardens)	Prioritize developed areas within city of Fairmont with highest areal P loading rates	This study; Fairmont SE model; MPCA 2020a; MDH 2022
Internal phosphorus recycling (i.e., collect additional data and develop feasibility report within 10 years)	All priority lakes	MPCA 2020a; this study

In addition to the strategies listed in Table 31, the Blue Earth River Watershed SID Report (DNR 2022) identifies several strategies and activities to address the primary stressors to aquatic life in Amber, Hall, Budd, and Sisseton Lakes:

- Follow the nutrient reduction goals identified in this report and the TMDL reports for the Blue Earth River Watershed and continue to implement and promote agricultural BMPs throughout the Fairmont Chain of Lakes Watershed to reduce nutrients, pesticides, and sediment coming from upstream and shoreland sources.
- Promote and maintain riparian areas with the use of shoreline buffers.
- Promote growth of native aquatic vegetation.
- Evaluate upstream and downstream crossings for potential barriers to fish passage and restore connectivity as warranted.
- Monitor common carp to ensure they do not exceed densities that substantially alter physical habitat. If densities are determined to be high enough to be detrimental to physical habitat, removal options could be considered.
- Implement strategies to reduce the spread of nonnative species, including those that are currently absent from Fairmont Chain of Lakes (e.g., Eurasian watermilfoil and zebra mussels).

Finally, as discussed in Section 3.2.7, net effects of internal phosphorus recycling were not explicitly estimated for this study; however, they are implicit in the calibration of the BATHTUB models for Amber, Hall, Budd, and Sisseton. George Lake required an additional unidentified load to calibrate the model, which could be attributed to high rates of internal phosphorus recycling, effects of wind and/or common carp, or other loading sources that were not defined in the development of the BATHTUB model. Although there is evidence that internal phosphorus recycling occurs within the priority lakes, it is assumed that the rate of recycling will decrease as the lake and sediments equilibrate to lower external phosphorus loads. Implementation strategies to decrease internal phosphorus recycling could be considered if in-lake TP and eutrophication response variables do not improve, or are slow to improve, after significant watershed reductions are achieved. These strategies could include, but are not limited to, water level drawdown, sediment dredging, sediment phosphorus immobilization or chemical treatment (e.g., alum), and biomanipulation (e.g., carp management). The MPCA recommends feasibility studies for any lake in which major in-lake management strategies are proposed. The *Minnesota State and Regional Government Review of Internal Phosphorus Load Control* paper (MPCA 2020c) provides more information on internal load BMPs and considerations. *The Dutch Creek and Fairmont Chain of Lakes Section 319 Small Watershed Focus Program NKE* plan (MPCA 2020a) recommends targeted monitoring and data collection to assess internal phosphorus recycling throughout the Fairmont Chain of Lakes in or around year five of the plan. These data will be analyzed in year six of the plan and a report will be produced to determine the extent of internal phosphorus recycling and the feasibility of addressing the results.

6.1.2 Fox and Big Twin Lakes

Similar to the Fairmont Chain of Lakes, land cover in the Fox and Big Twin Lake drainage area is dominated by cropland and therefore many of the same agricultural strategies listed in Table 31 will also apply to these lakes. Key watershed strategies for Fox and Big Twin include implementing practices to improve soil health, livestock and nutrient management, conservation cover, and structural BMPs in critical source areas. Fox and Big Twin Lakes have small watershed to lake area ratios (4.2 and 2.5, respectively) and therefore strategies to protect and improve shoreline and littoral areas are extremely important to improve water quality and promoting healthy biological communities. The Blue Earth River Watershed SID Report (DNR 2022) identified several strategies and activities to address the primary stressors to aquatic life in Fox and Big Twin Lakes:

- Follow the nutrient reduction goals identified in this report and the TMDL reports for the Blue Earth River Watershed and continue to implement and promote agricultural BMPs throughout the lake drainage areas to reduce nutrients, pesticides, and sediment coming from upstream and shoreland sources.
- Promote and maintain riparian areas with the use of shoreline buffers.
- Promote growth of native aquatic vegetation.
- Evaluate upstream and downstream crossings for potential barriers to fish passage and restore connectivity as warranted.

6.2 Monitoring recommendations

Based on the data, analyses, and conclusions provided in this study, the following list of monitoring activities are recommended over the course of the implementation period. These items will help refine and update the watershed and lake models, investigate internal phosphorus recycling, and track response to BMPs as they are implemented throughout the watershed using an adaptive management strategy.

- Continue monitoring and tracking stream flow and pollutant loads in Dutch Creek through the DNR/MPCA Cooperative Stream Gaging program.
- Continue surface water quality monitoring of the Fairmont Chain of Lakes priority Lakes. Monitoring should occur at least one time per month from April/May through October. Although the lake standards require June through September sampling, spring and fall data are also important to evaluate sediment, phosphorus, and nitrogen loading and response over the entire open water season.
- Add TN (i.e., TKN and nitrate/nitrite) to the list of surface water monitoring parameters to better understand how nitrogen affects eutrophication throughout the Fairmont Chain of Lakes priority lakes.
- Collect water column profiles (i.e., temperature, DO, pH) and one hypolimnion (i.e., 0.5 meter from bottom) TP, ortho-phosphorus, and total iron sample during each surface water quality monitoring event. Collecting this information is critical to evaluate how stratification, water column mixing, and internal phosphorus recycling are affecting water quality and seasonal trends throughout the Chain of Lakes.
- Expand the list of monitored lakes to include North Silver, Willmert, and Mud Lakes (if possible). Monitoring these lakes will help paint a clearer picture of water quality conditions throughout the entire Fairmont Chain of Lakes and changes from upstream to downstream through the system.
- Periodically update the watershed model, lake models, and other modeling and assessment tools as data is collected and BMPs are implemented.

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Appendix A: Dutch Creek precipitation, flow, TSS, and TP data analyses

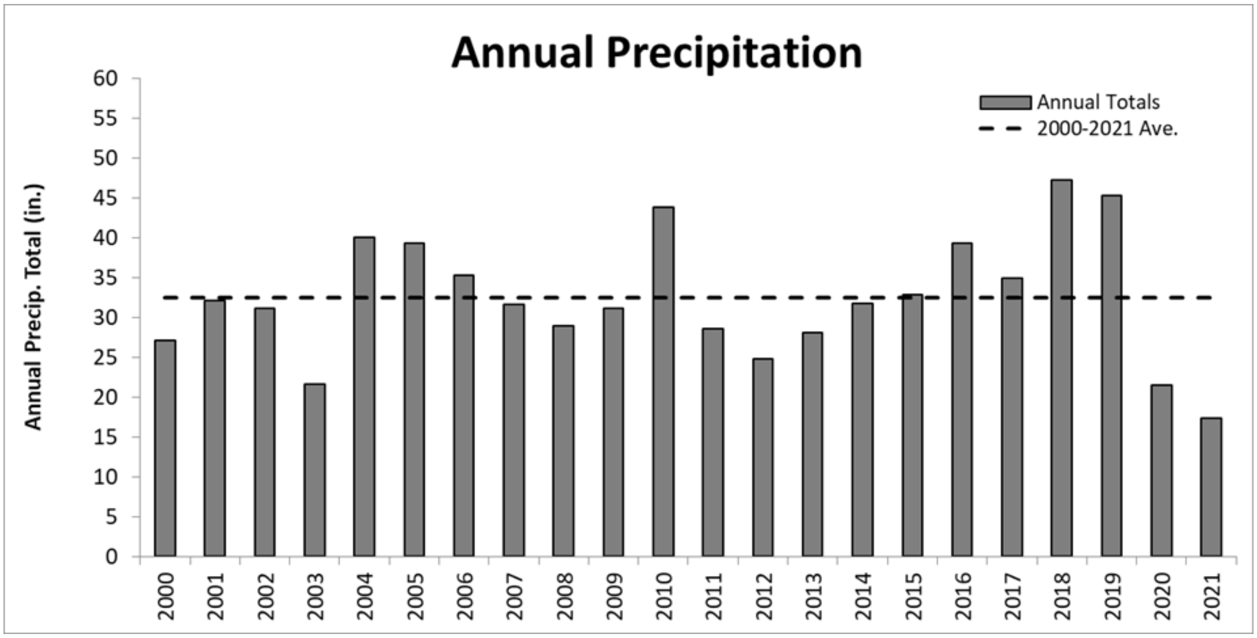


Figure 19. Average annual precipitation near the City of Fairmont.
Data sources: Blue Earth River HSPF model (2000-2017) and local weather stations (2018-2021) downloaded from the Midwestern Regional Climate Center

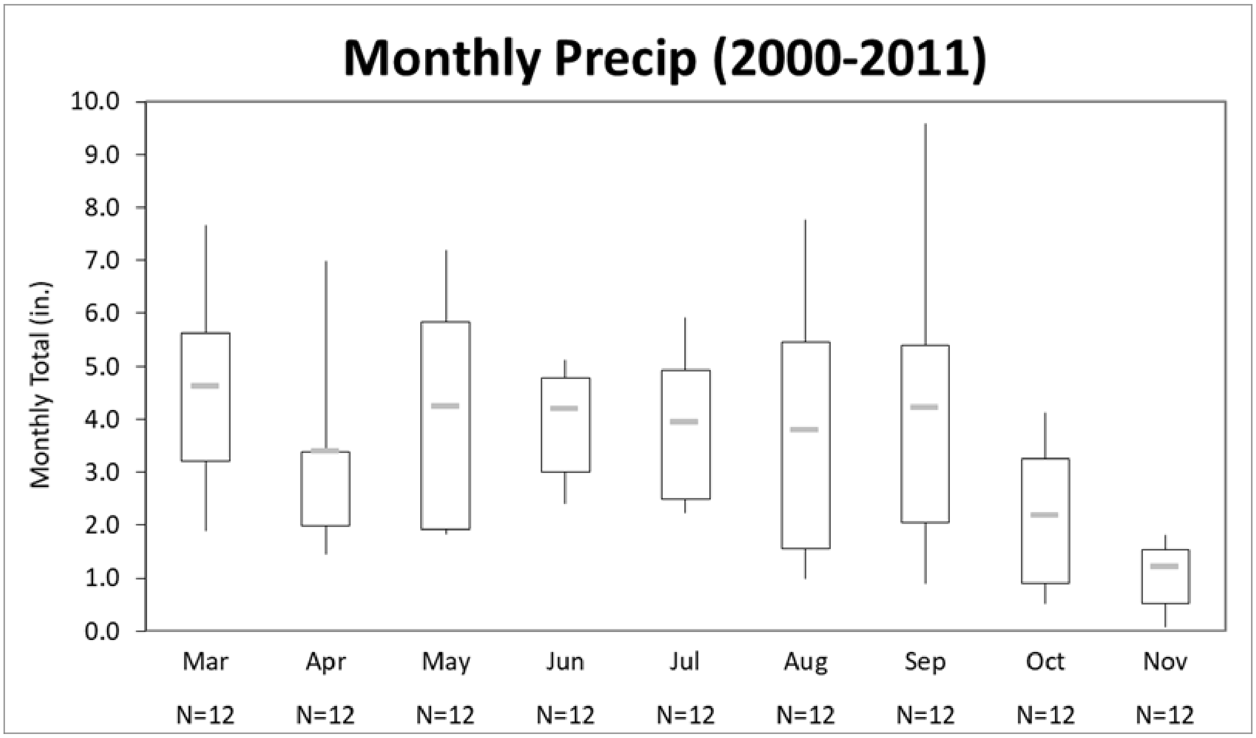


Figure 20. Box plots showing precipitation by month from 2000 through 2011 near the City of Fairmont.

Data source: Blue Earth River HSPF model

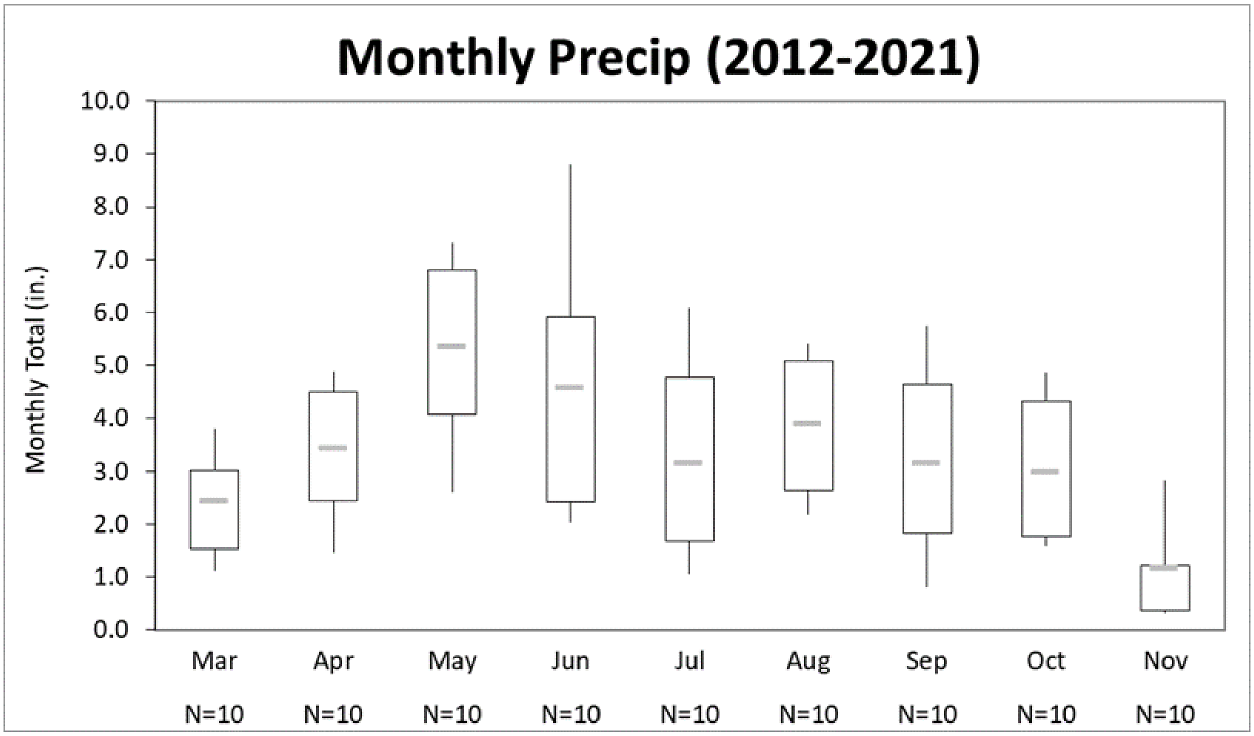


Figure 21. Box plots showing precipitation by month from 2012 through 2021 near the City of Fairmont. Data sources: Blue Earth River HSPF model (2012-2017) and local weather stations (2018-2021) downloaded from the Midwestern Regional Climate Center

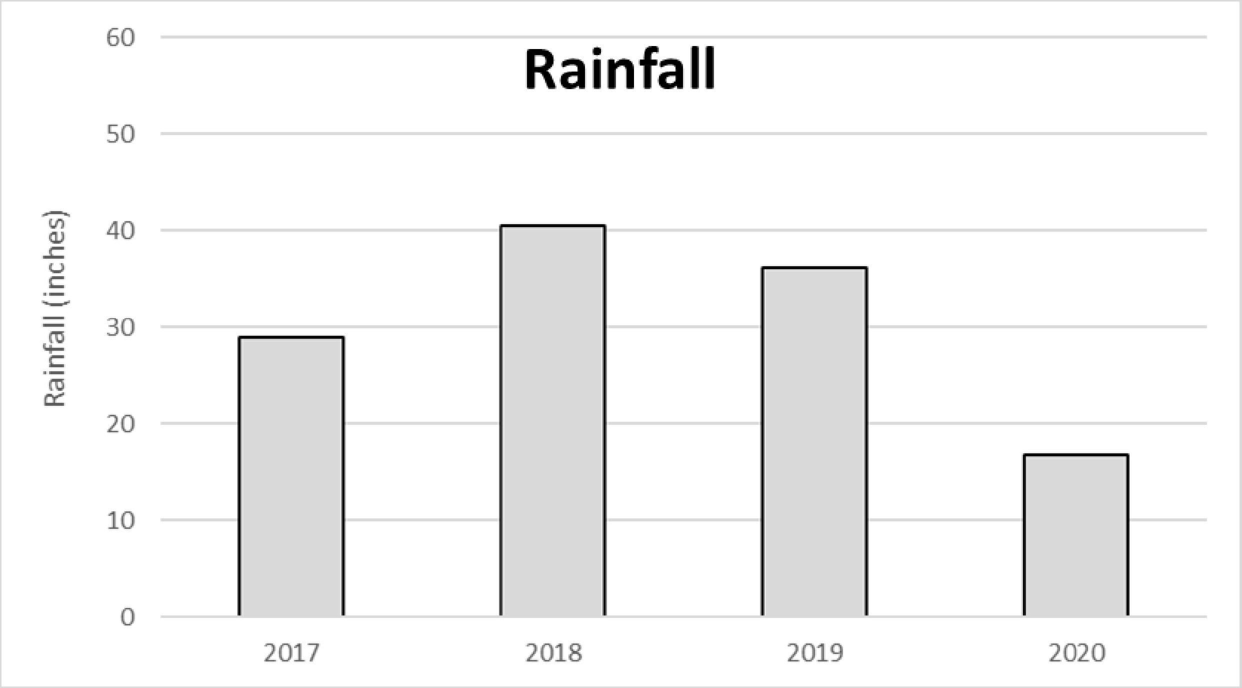


Figure 22. Monitoring season (April through October) rainfall totals near the City of Fairmont from 2017 through 2020.

Data sources: Blue Earth River HSPF model (2000-2017) and local weather stations (2018-2021) downloaded from the [Midwestern Regional Climate Center](https://mrcc.purdue.edu)

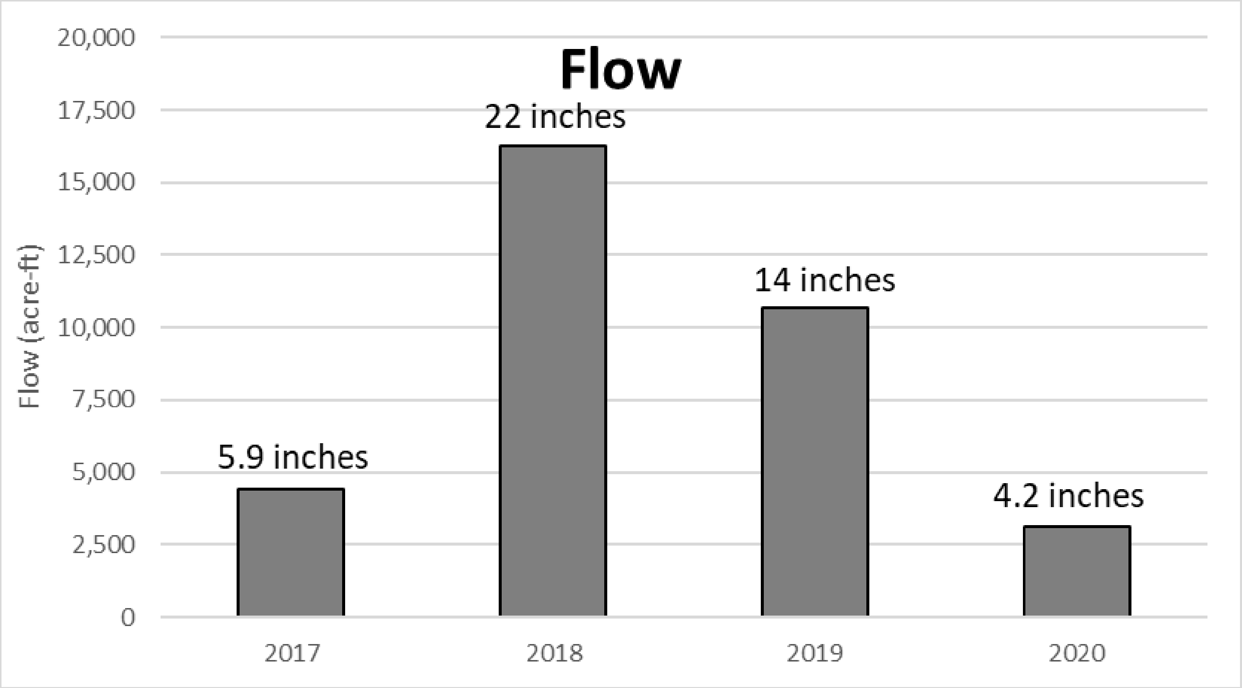


Figure 23. Monitoring season (April through October) monitored flow volume at Dutch Creek Station S003-000 from 2017 through 2020.

Note: monitoring season rainfall totals for each year are included above each bar

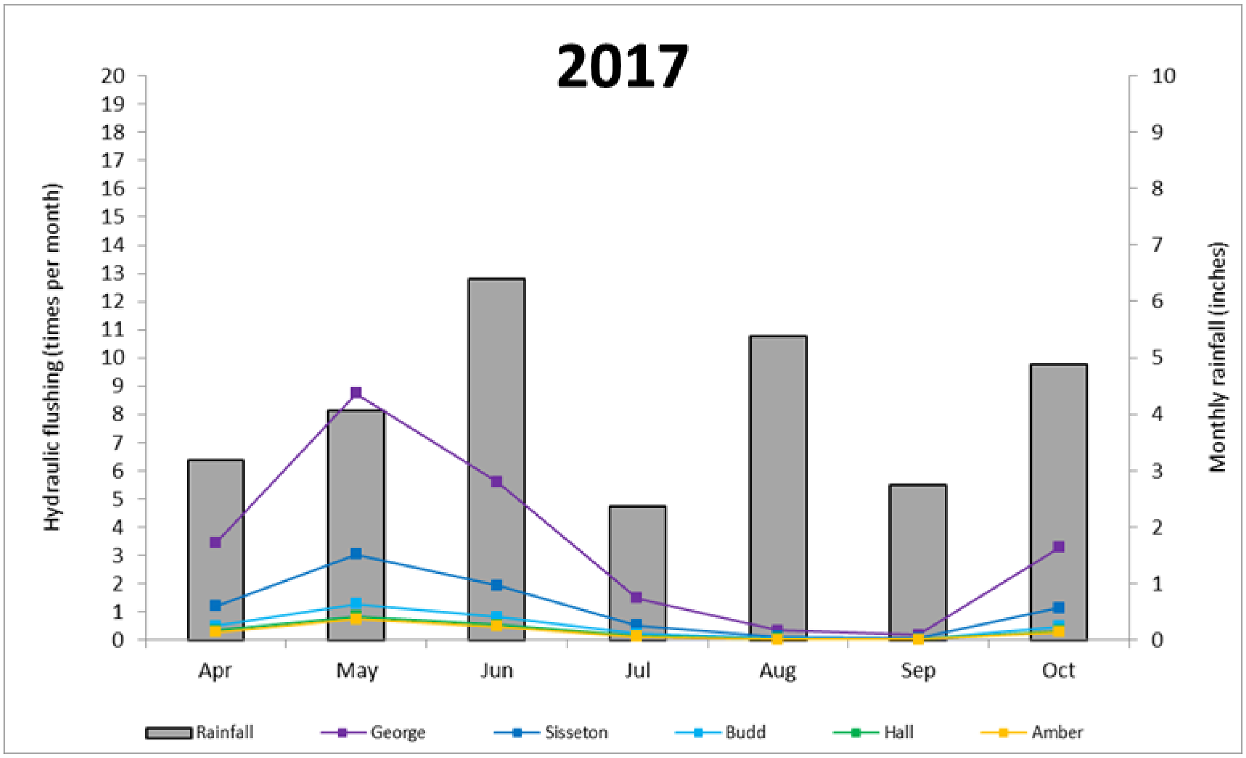


Figure 24. 2017 monthly hydraulic flushing rates for individual lakes in the Fairmont Chain of Lakes (left axis) and monthly total rainfall (right axis, gray bars).

Note: the Fairmont Chain of Lakes Watershed Loading Model (see Section 3.1.1) and Dutch Creek monitoring data were used to estimate flushing rates for individual lakes in the Fairmont Chain of Lakes.

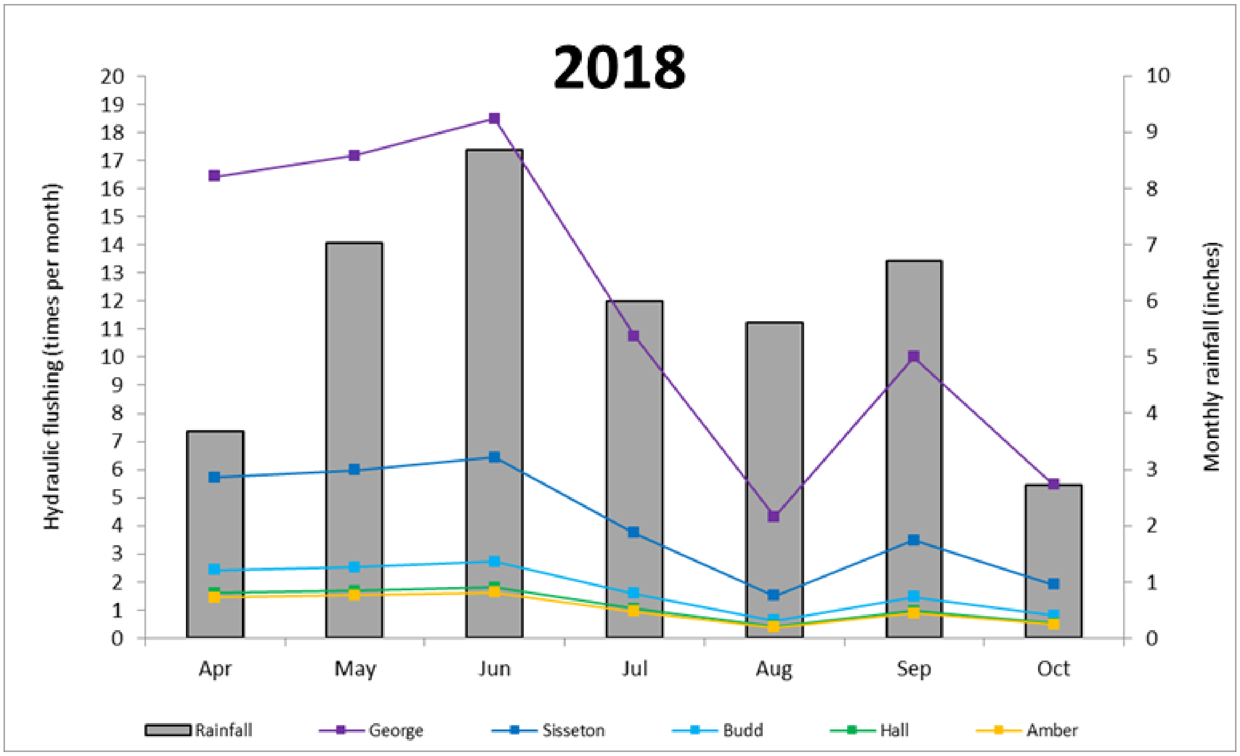


Figure 25. 2018 monthly hydraulic flushing rates for individual lakes in the Fairmont Chain of Lakes (left axis) and monthly total rainfall (right axis, gray bars).

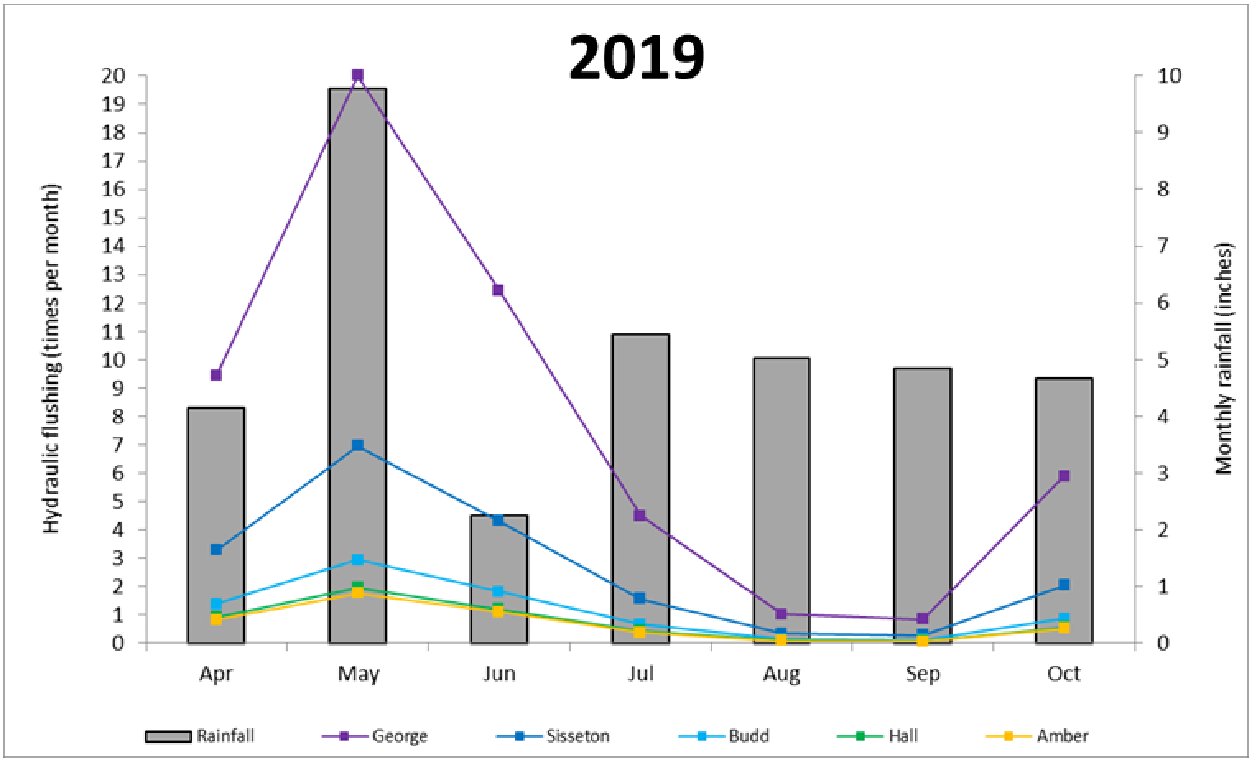


Figure 26. 2019 monthly hydraulic flushing rates for individual lakes in the Fairmont Chain of Lakes (left axis) and monthly total rainfall (right axis, gray bars).

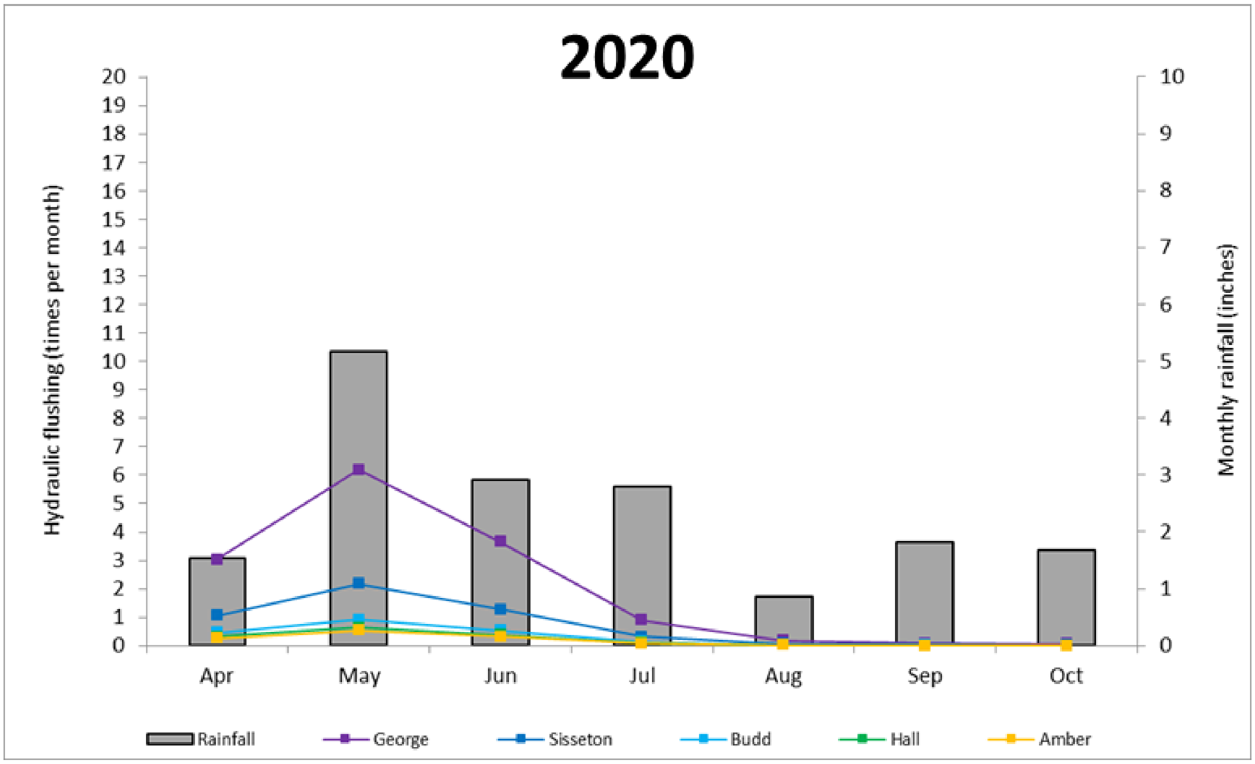


Figure 27. 2020 monthly hydraulic flushing rates for individual lakes in the Fairmont Chain of Lakes (left axis) and monthly total rainfall (right axis, gray bars).

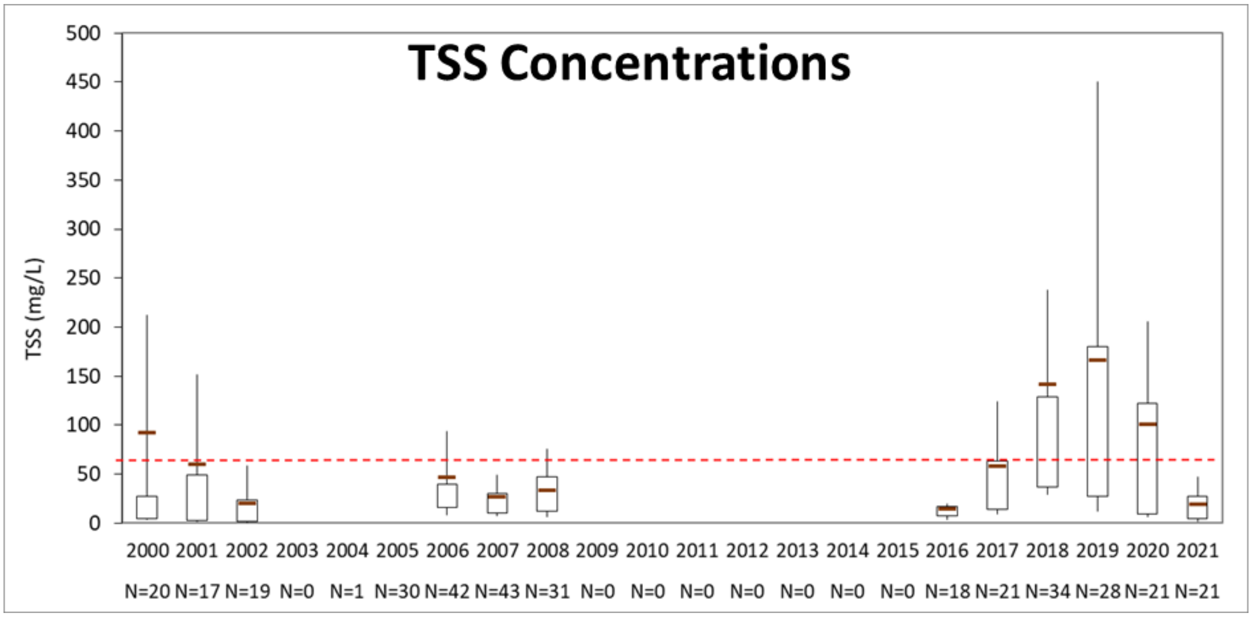


Figure 28. Box plots showing monitored TSS concentrations by year at Dutch Creek station S003-000.

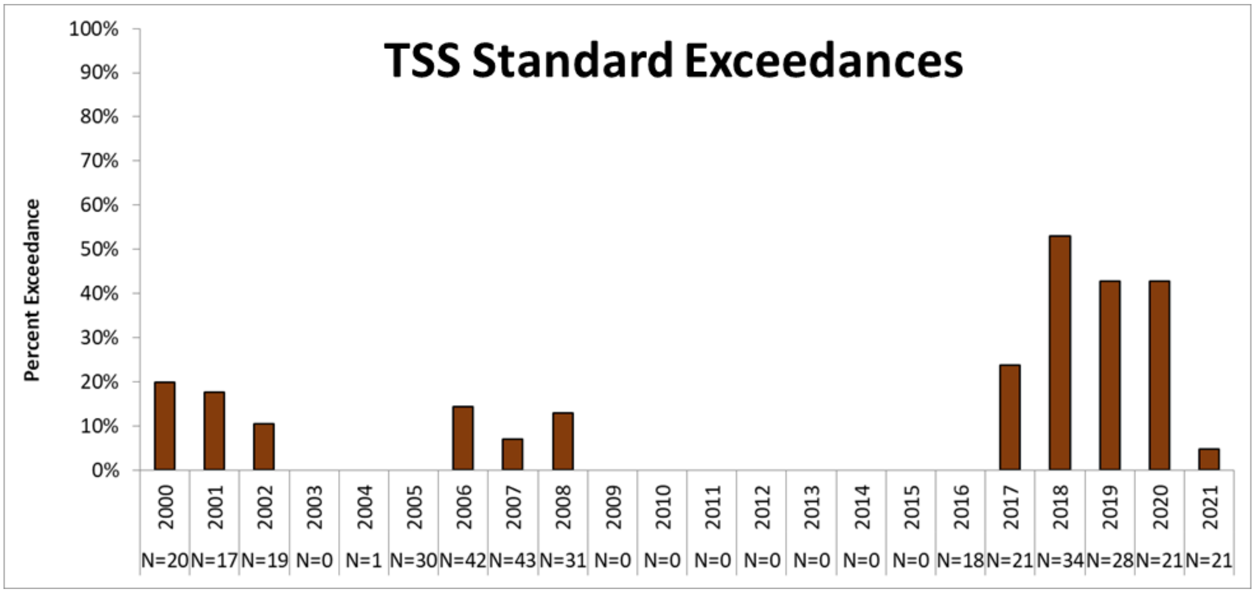


Figure 29. Monitored TSS standard exceedances (i.e., >65 mg/L) by year at Dutch Creek station S003-000

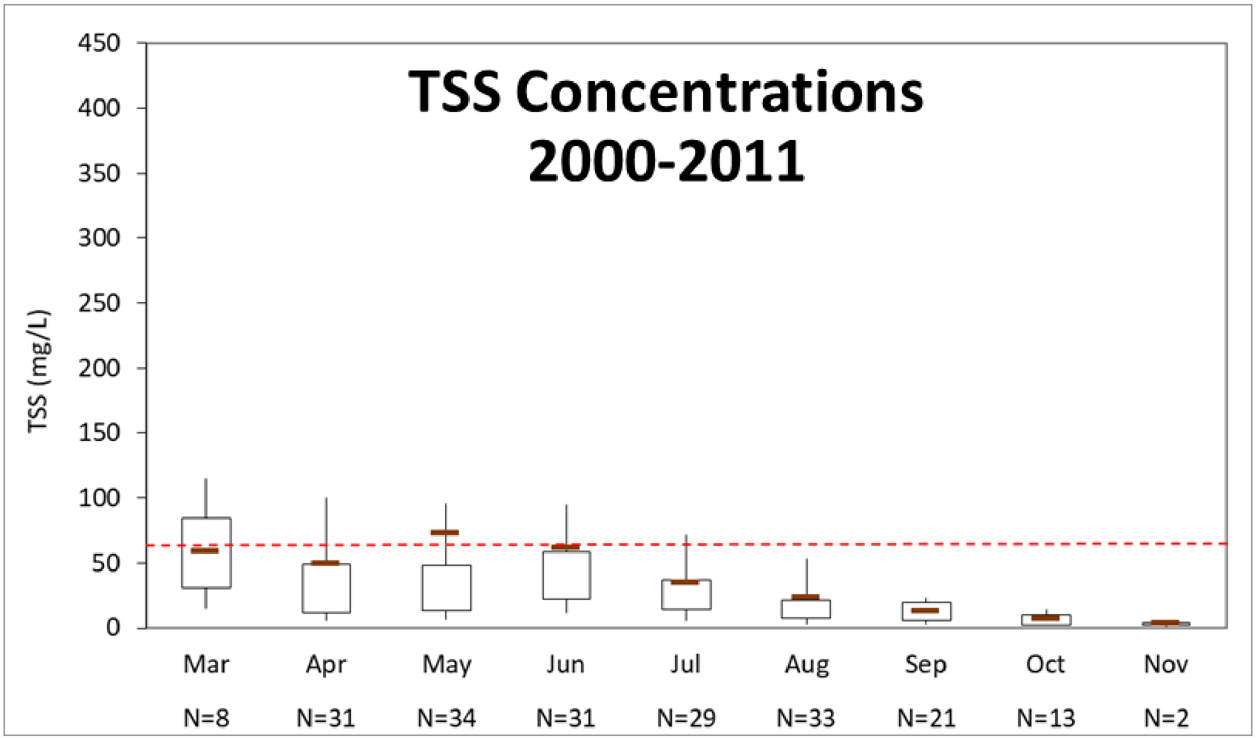


Figure 30. Box plots showing monitored TSS concentrations by month from 2000 through 2011 at Dutch Creek station S003-000.

Note: dotted red line is the 65 mg/L Southern River Nutrient Region TSS standard

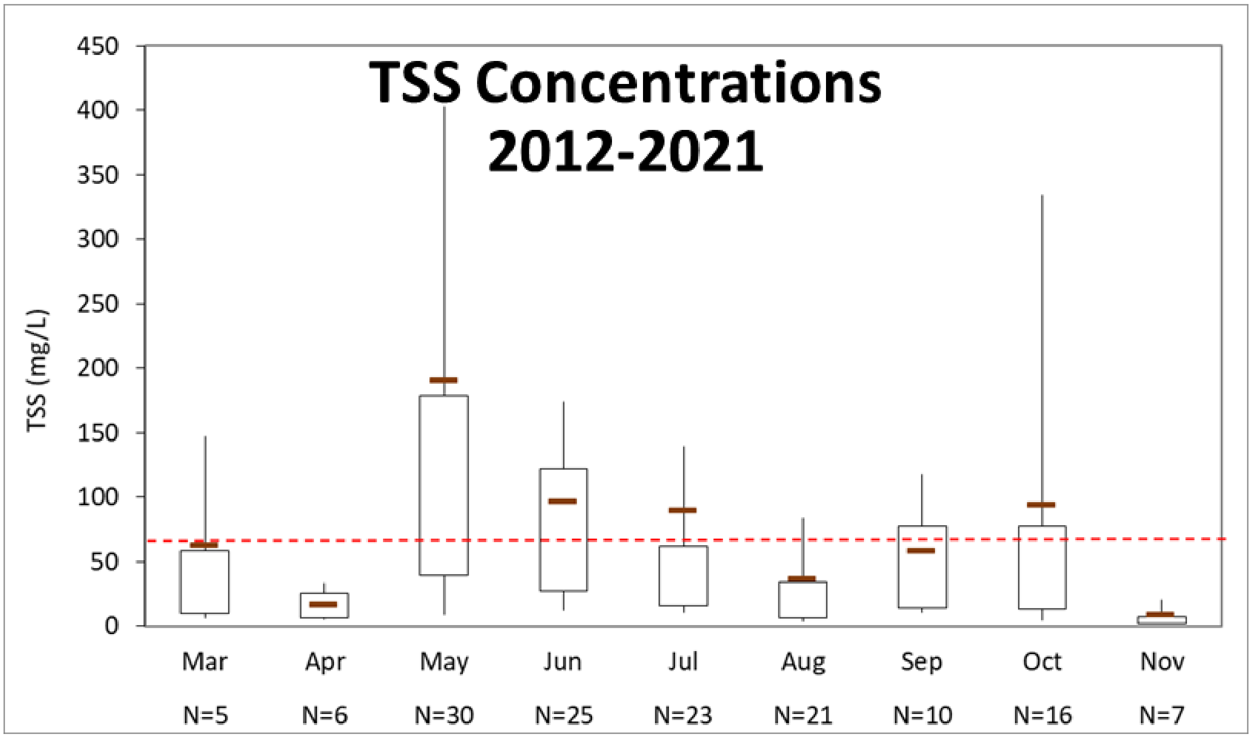


Figure 31. Box plots showing monitored TSS concentrations by month from 2012 through 2021 at Dutch Creek station S003-000.

Note: dotted red line is the 65 mg/L Southern River Nutrient Region TSS standard

Table 32. TSS concentration and annual precipitation statistical comparisons for the 2000-2011 and 2012-2021 monitoring periods.

Parameter	Statistic	2000-2011	2012-2021
TSS	# of Samples (Apr-Sep)	189	123
	% Exceedance of standard (65 mg/L)	14%	37%
	Mean concentration	57 mg/L	112 mg/L
	90th percentile concentration	95 mg/L	212 mg/L
	% Reduction to achieve standard	32%	69%
Precipitation	Mean annual precipitation	32.6 inches	32.3 inches

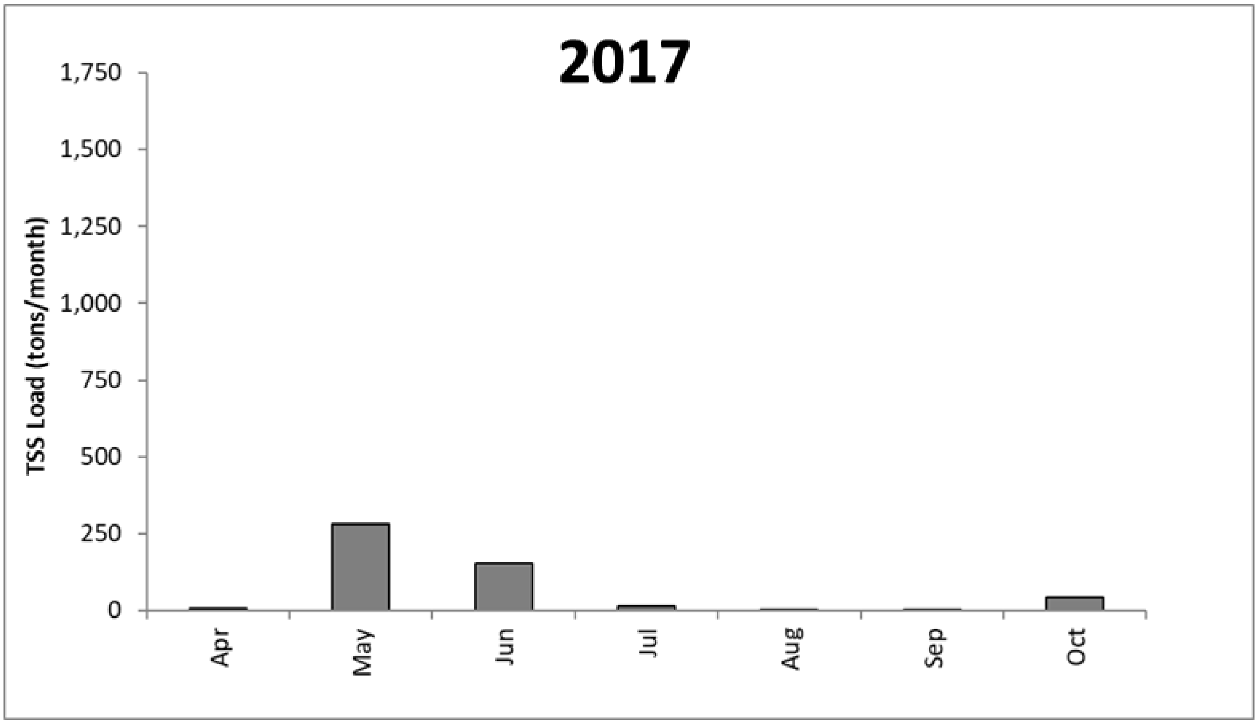


Figure 32. 2017 monthly monitored TSS loads for Dutch Creek Station S003-000.

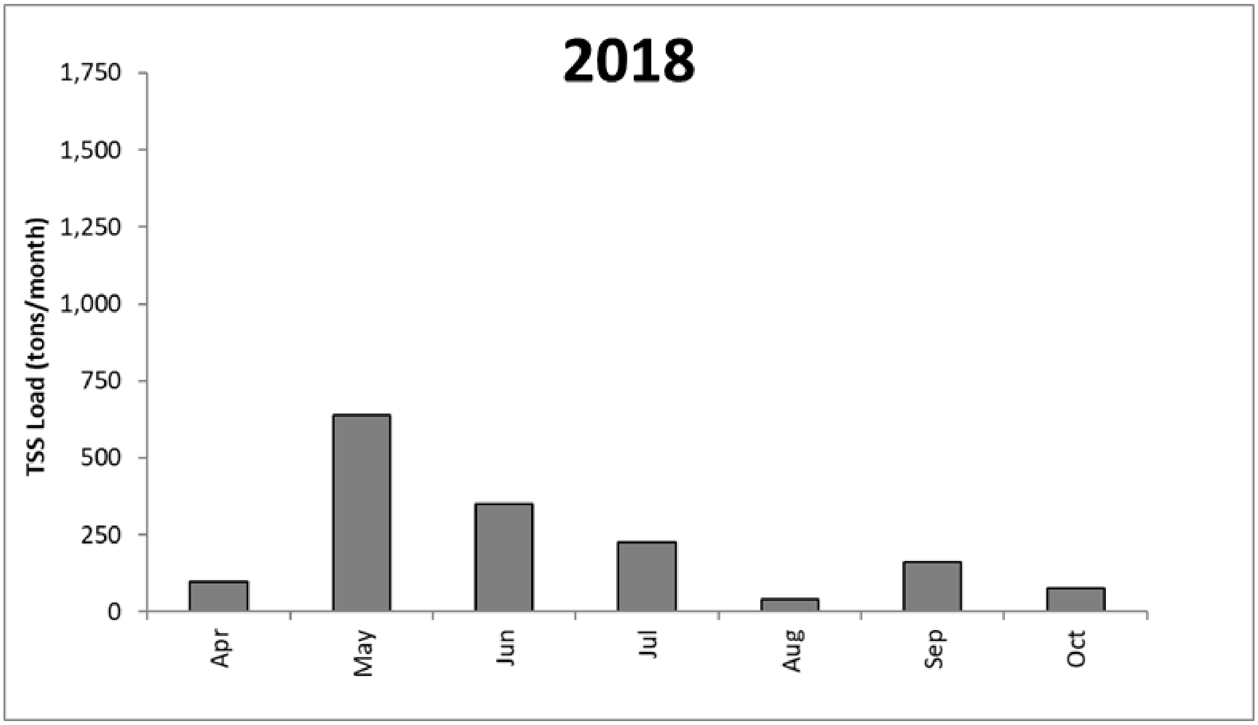


Figure 33. 2018 monthly monitored TSS loads for Dutch Creek Station S003-000.

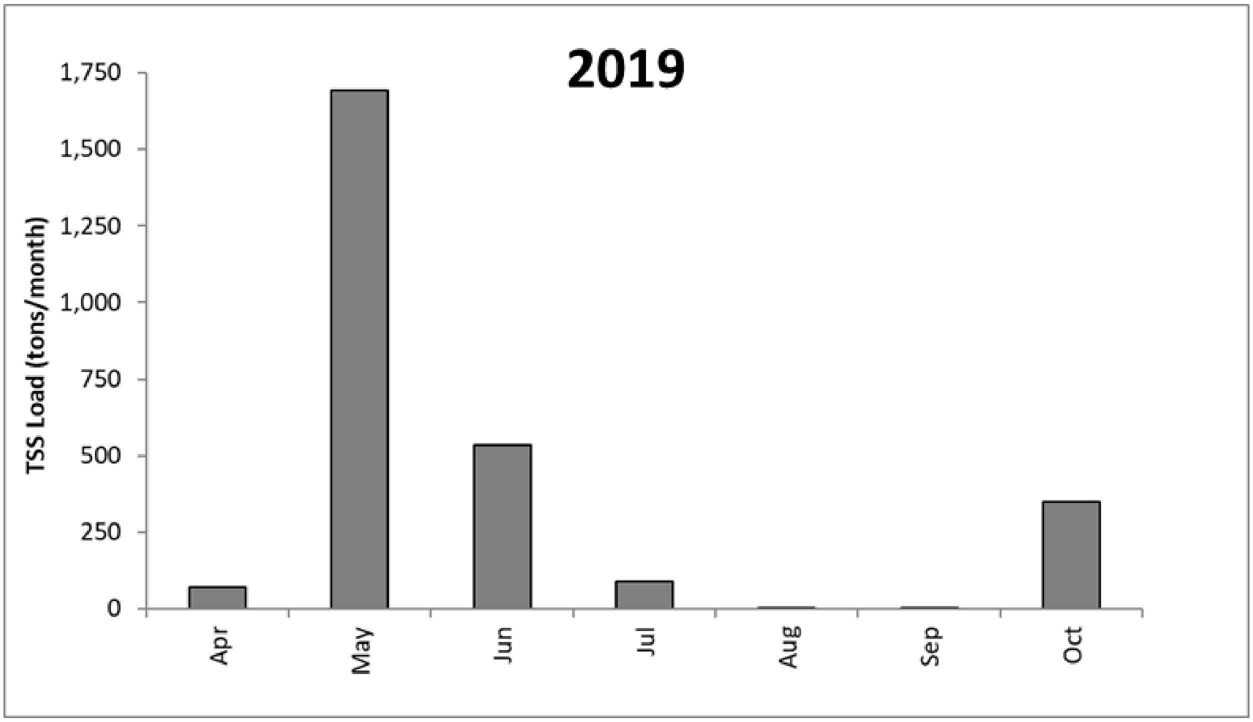


Figure 34. 2019 monthly monitored TSS loads for Dutch Creek Station S003-000.

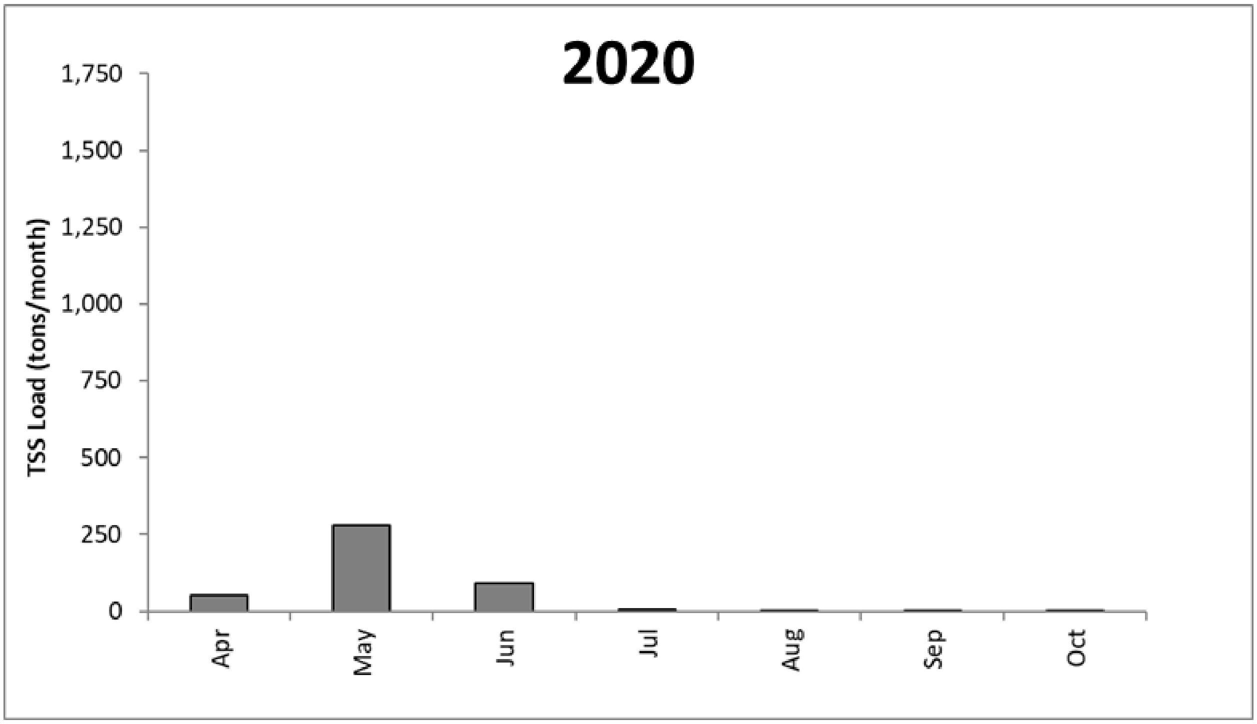


Figure 35. 2020 monthly monitored TSS loads for Dutch Creek Station S003-000.

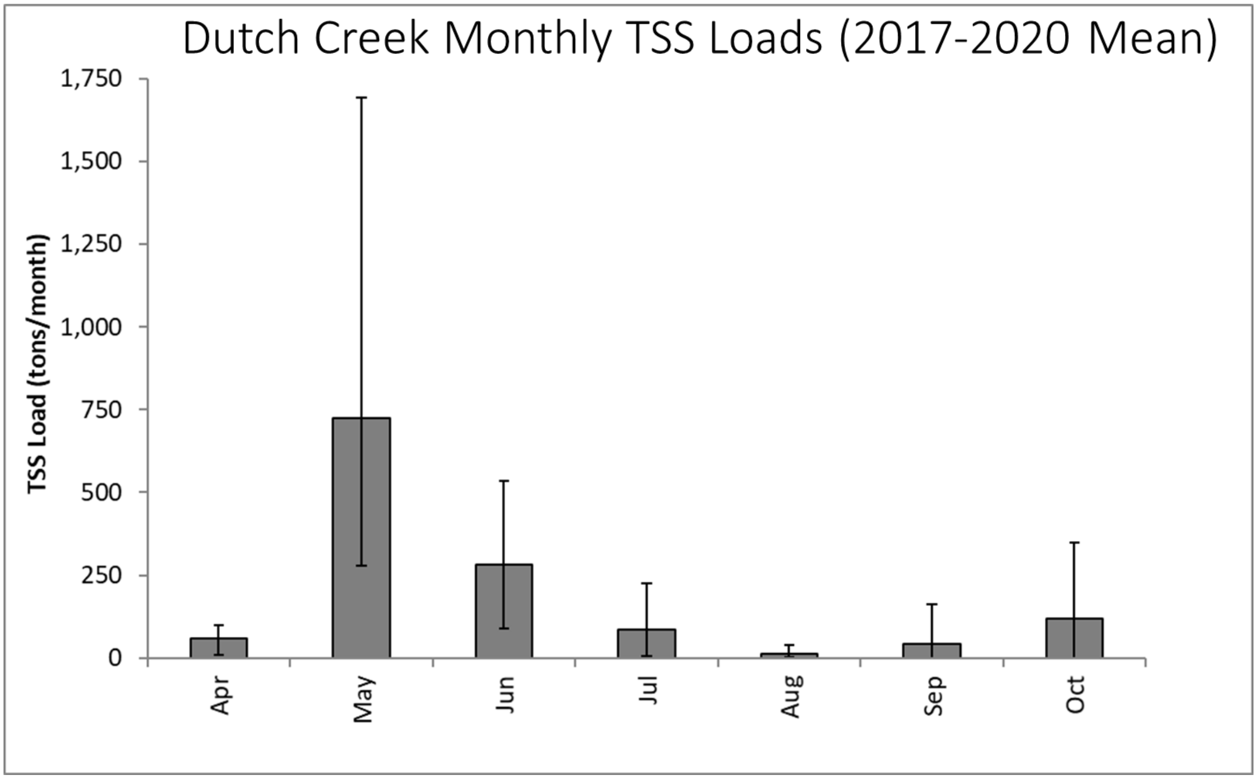


Figure 36. 2017-2020 monthly mean TSS loads for Dutch Creek Station S003-000.

Note: error bars represent the maximum and minimum monthly loads from 2017 through 2020

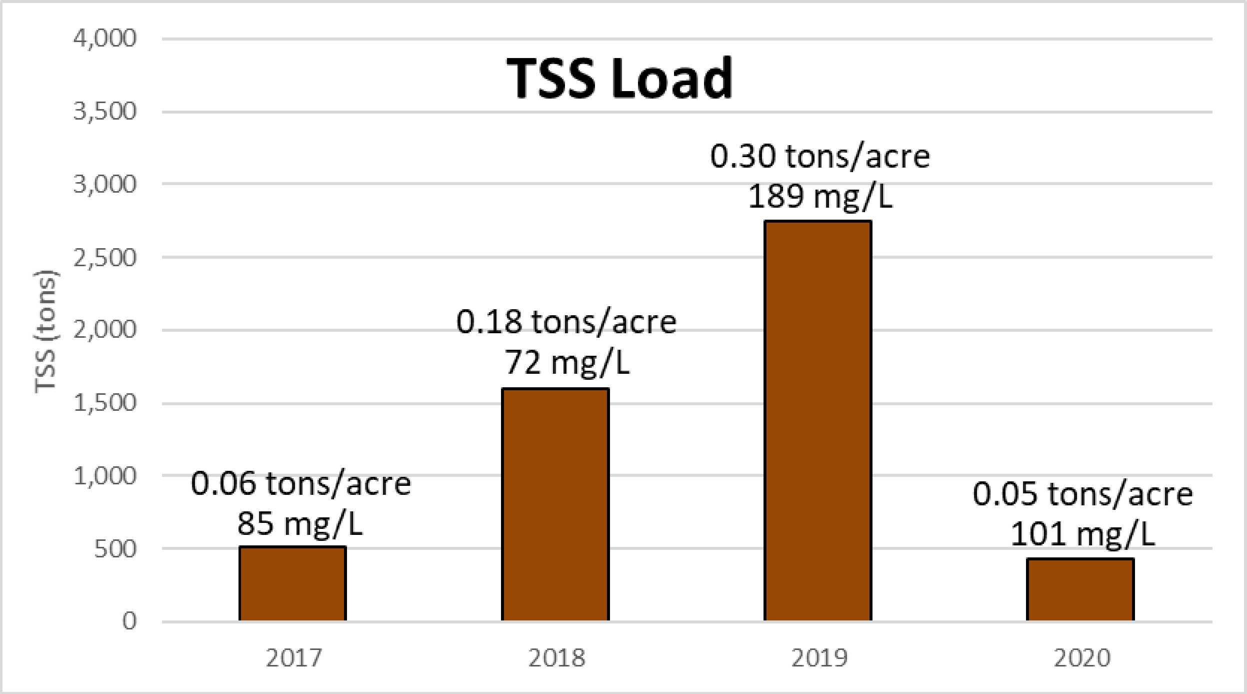


Figure 37. Monitoring season (April through October) monitored TSS load at Dutch Creek Station S003-000 from 2017 through 2020.

Note: flow weighted mean concentration and areal TSS loading rate for each year included above each bar

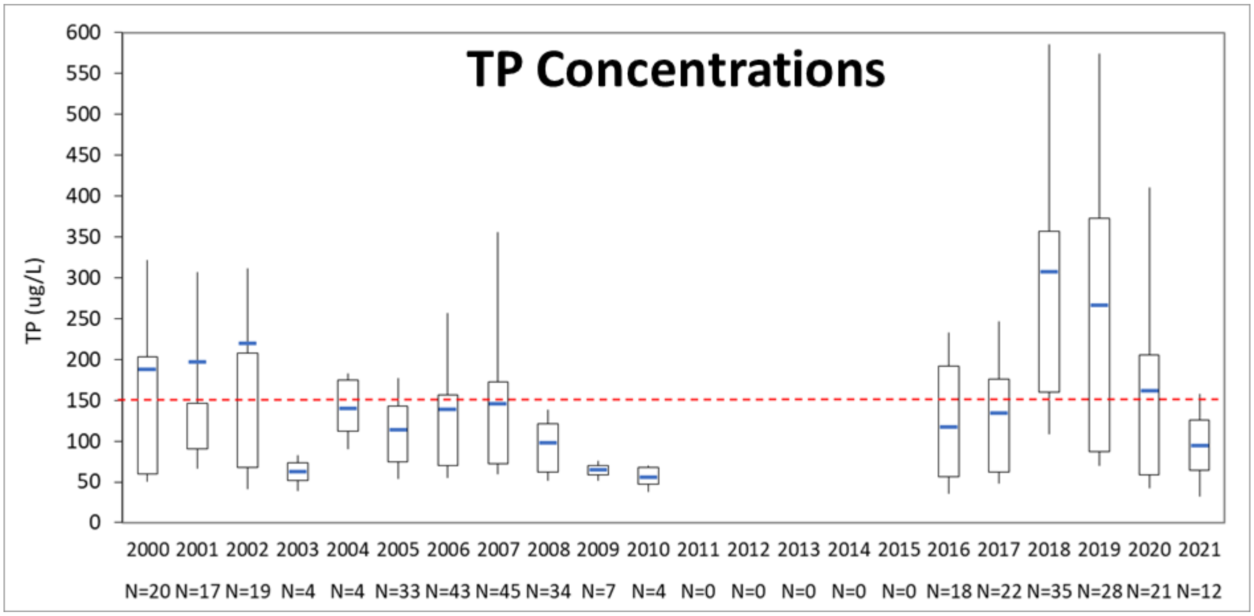


Figure 38. Box plots showing monitored TP concentrations by year at Dutch Creek station S003-000.

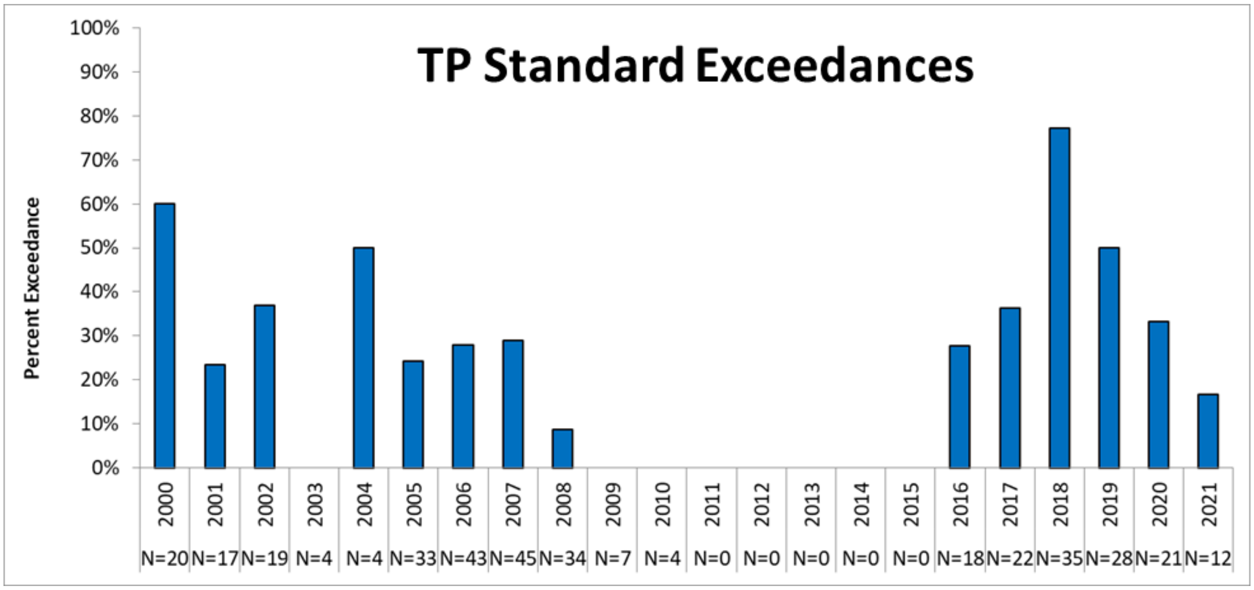


Figure 39. Monitored TP standard exceedances (i.e., >150 µg/L) by year at Dutch Creek station S003-000.

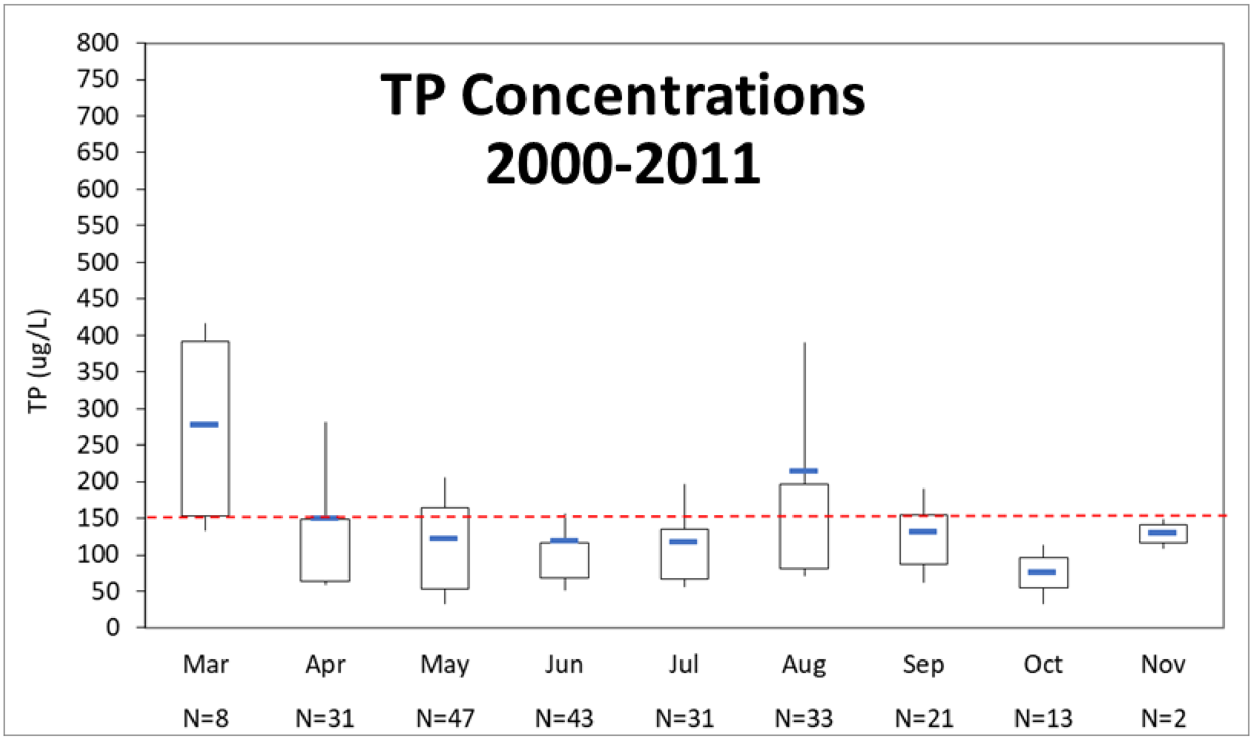


Figure 40. Box plots showing monitored TP concentrations by month from 2000 through 2011 at Dutch Creek station S003-000.

Note: dotted red line is the 150 µg/L Southern River Nutrient Region TP standard

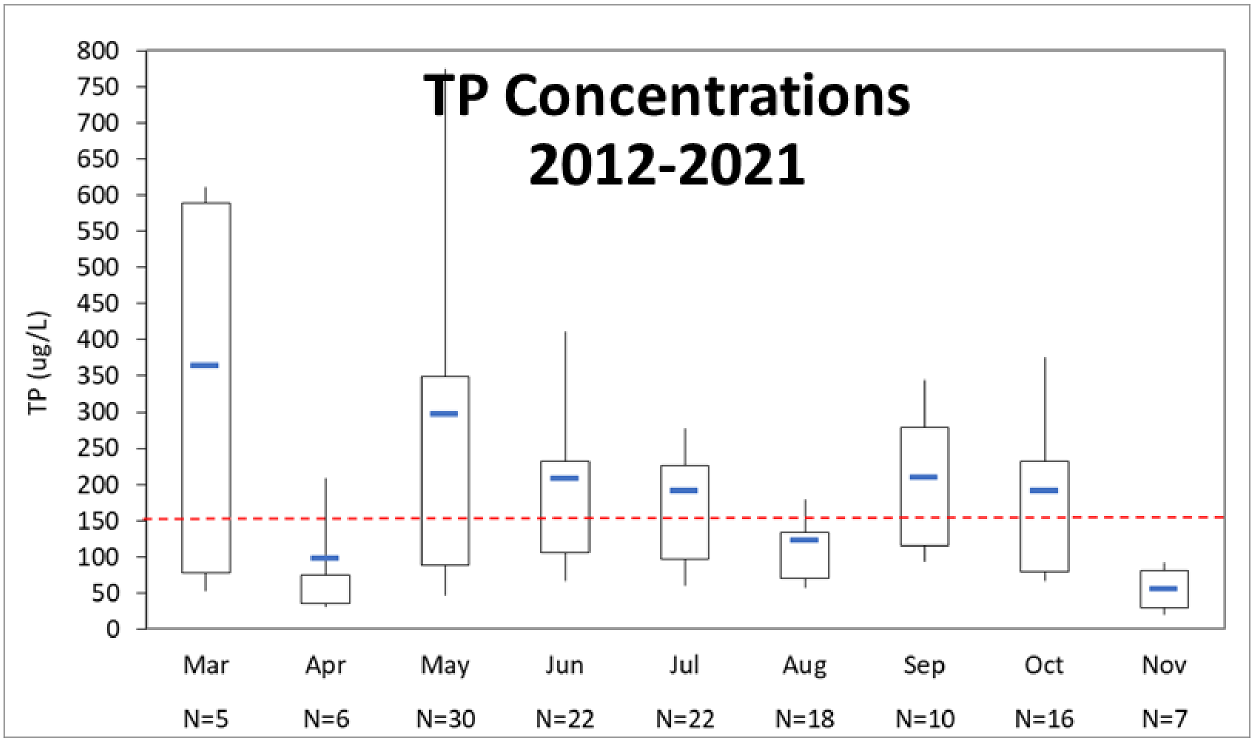


Figure 41. Box plots showing monitored TP concentrations by month from 2000 through 2011 at Dutch Creek station S003-000.

Note: dotted red line is the 150 µg/L Southern River Nutrient Region TP standard

Table 33. TP concentration and annual precipitation statistical comparisons for the 2000-2011 and 2012-2021 monitoring periods.

Parameter	Statistic	2000-2011	2012-2021
TP	# of Samples (All months)	259	117
	% Exceedance of standard (150 µg/L)	26%	53%
	Mean concentration	146 µg/L	238 µg/L
	% Reduction to 150 µg/L	0%	37%
Precipitation	Mean annual precipitation	32.6 inches	32.3 inches

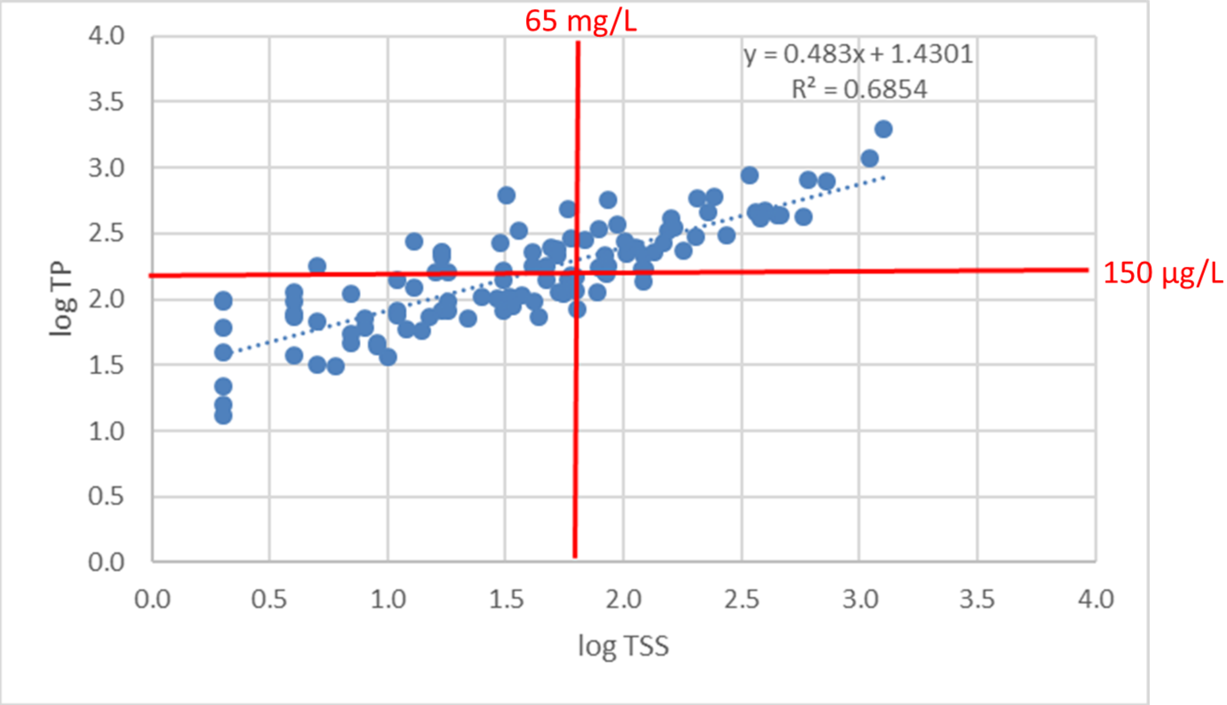


Figure 42. Monitored TSS and TP relationship for Dutch Creek station S003-000.

Note: solid red lines represent the Southern River Nutrient Region TP (150 µg/L) and TSS (65 mg/L) concentration standards

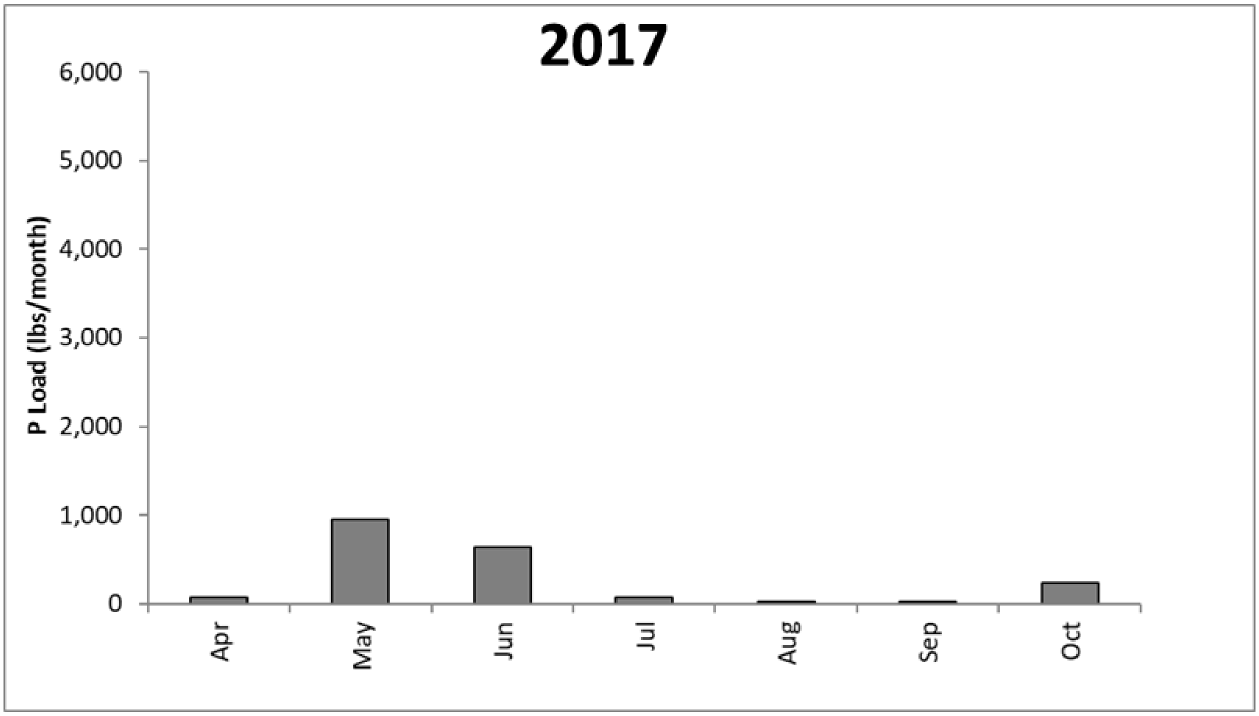


Figure 43. 2017 monthly monitored TP loads for Dutch Creek Station S003-000.

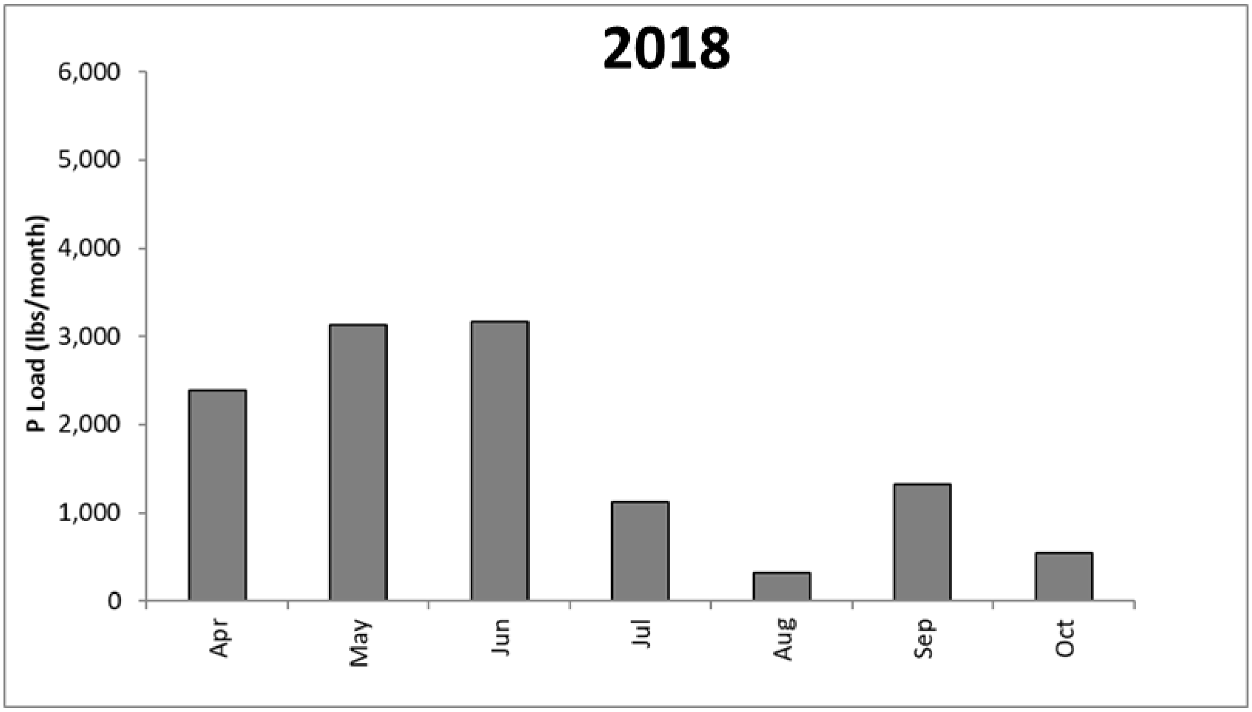


Figure 44. 2018 monthly monitored TP loads for Dutch Creek Station S003-000.

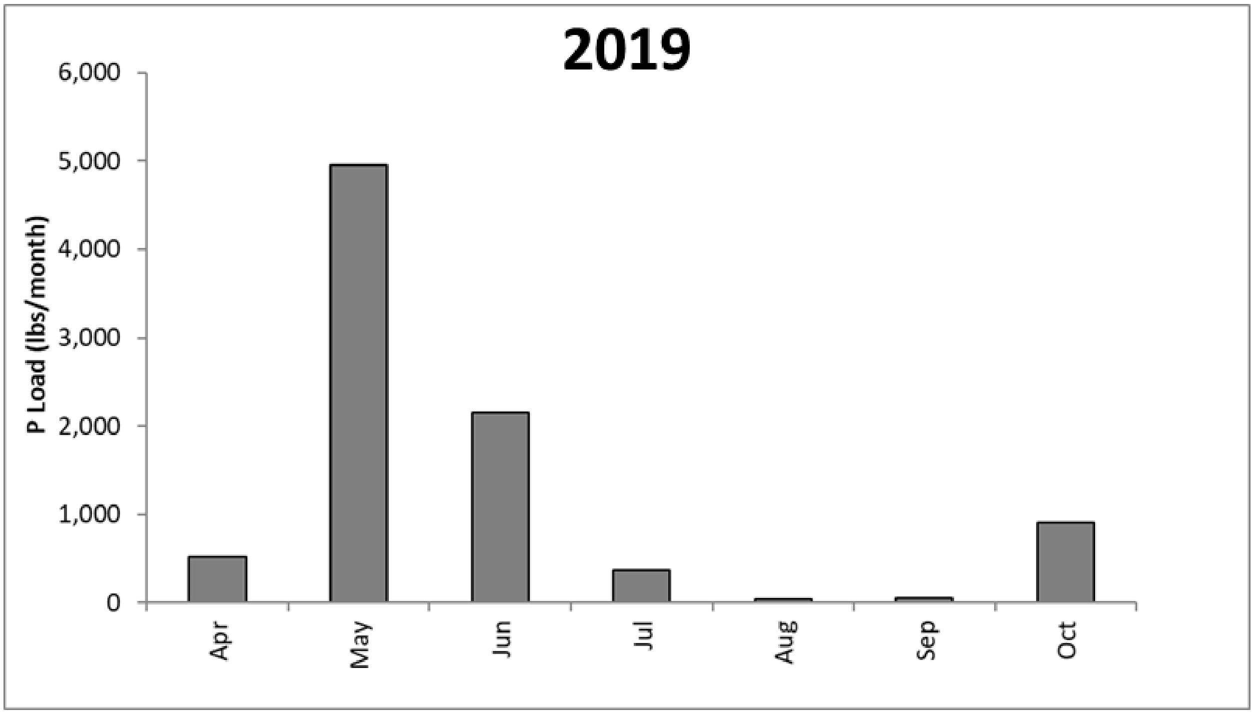


Figure 45. 2019 monthly monitored TP loads for Dutch Creek Station S003-000.

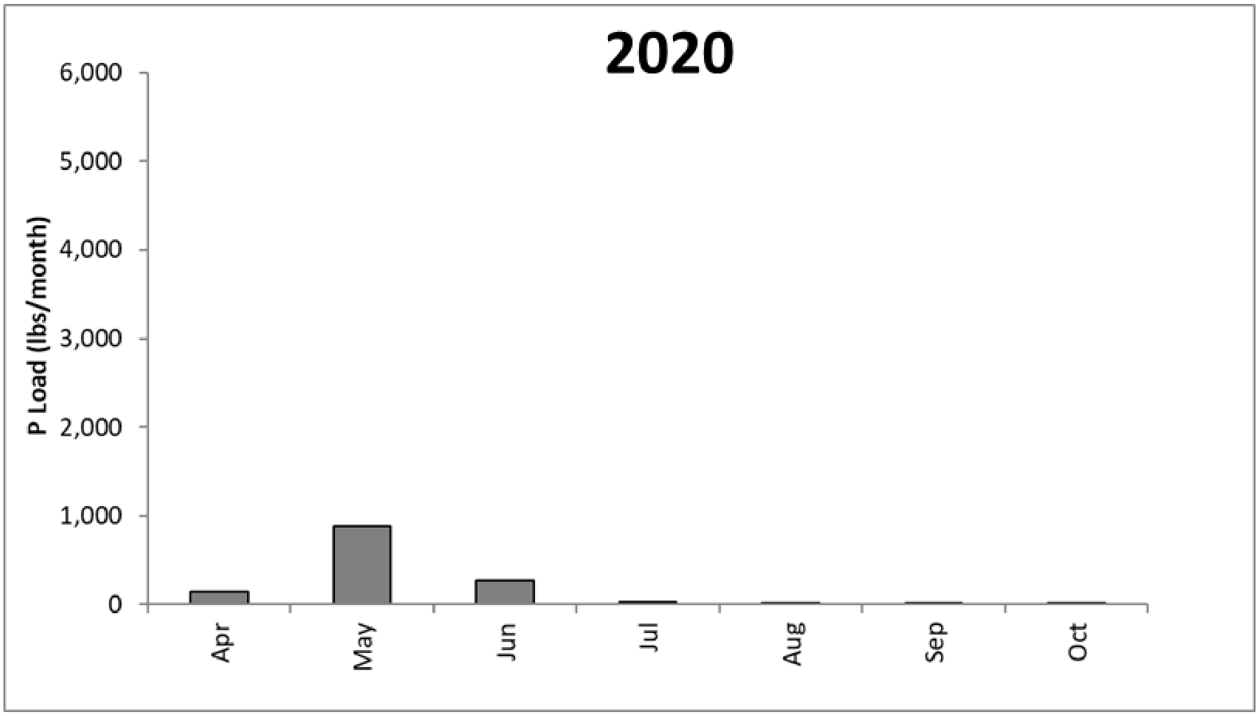


Figure 46. 2020 monthly monitored TP loads for Dutch Creek Station S003-000.

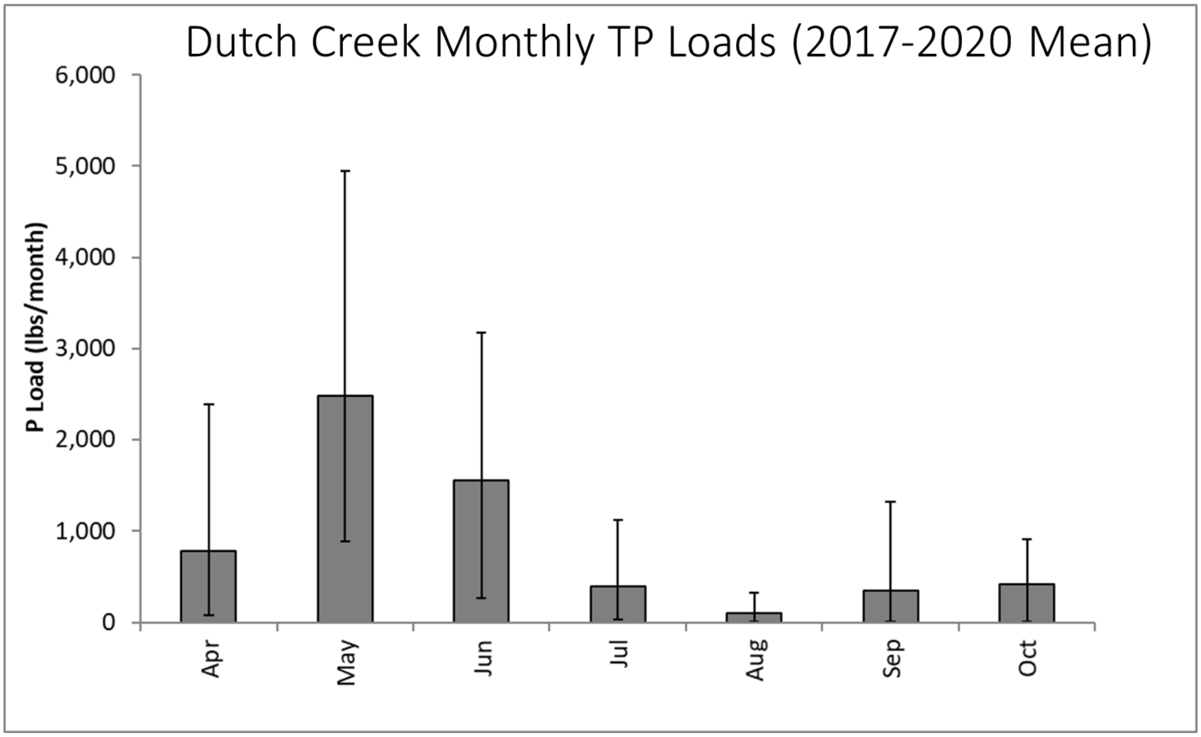


Figure 47. 2017-2020 monthly mean TP loads for Dutch Creek Station S003-000.

Note: error bars represent the maximum and minimum monthly loads from 2017 through 2020

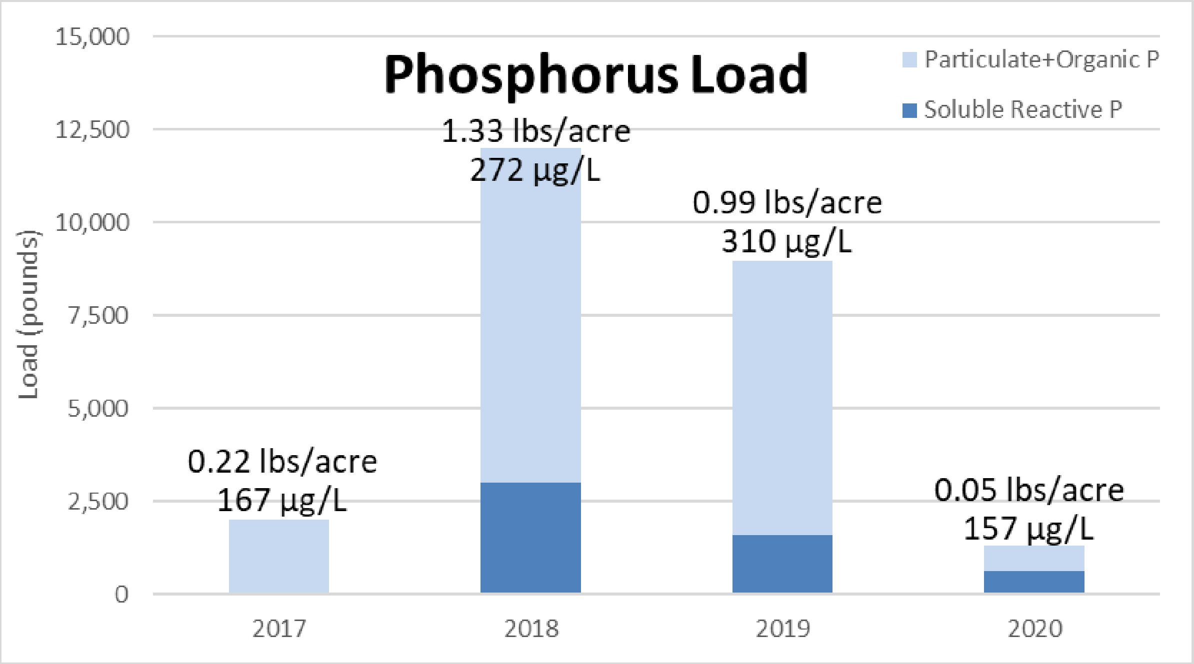


Figure 48. Monitoring season (April through October) monitored TP load at Dutch Creek Station S003-000 from 2017 through 2020.

Notes: flow weighted mean concentration and areal TP loading rate for each year included above each bar. TP loads are partitioned by soluble reactive phosphorus as measured by ortho-phosphorus (darker blue) and particulate and organic-bound phosphorus calculated as TP minus soluble reactive phosphorus (light blue)

Appendix B: Fairmont Chain of Lakes Water Quality Data Analyses

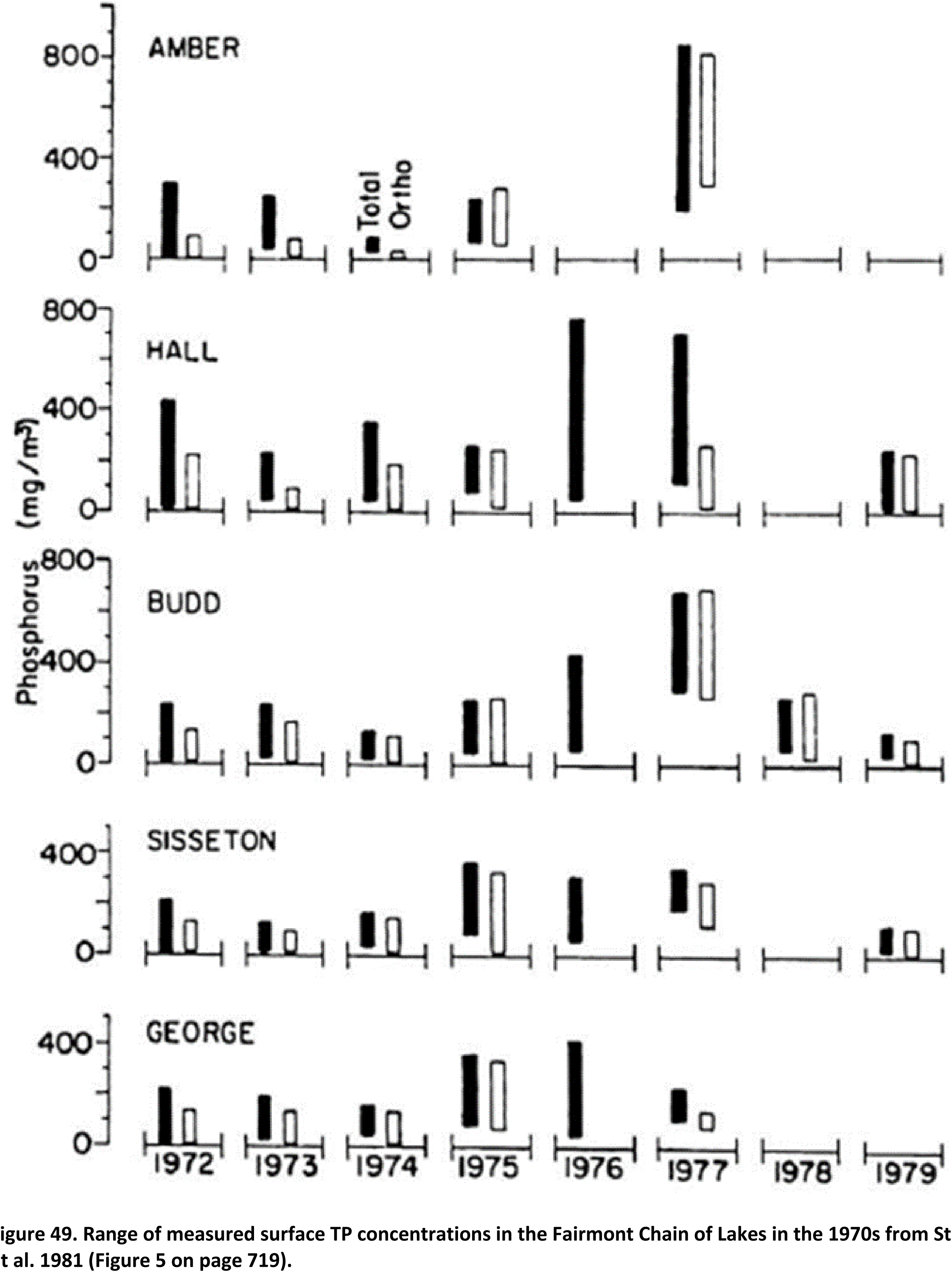
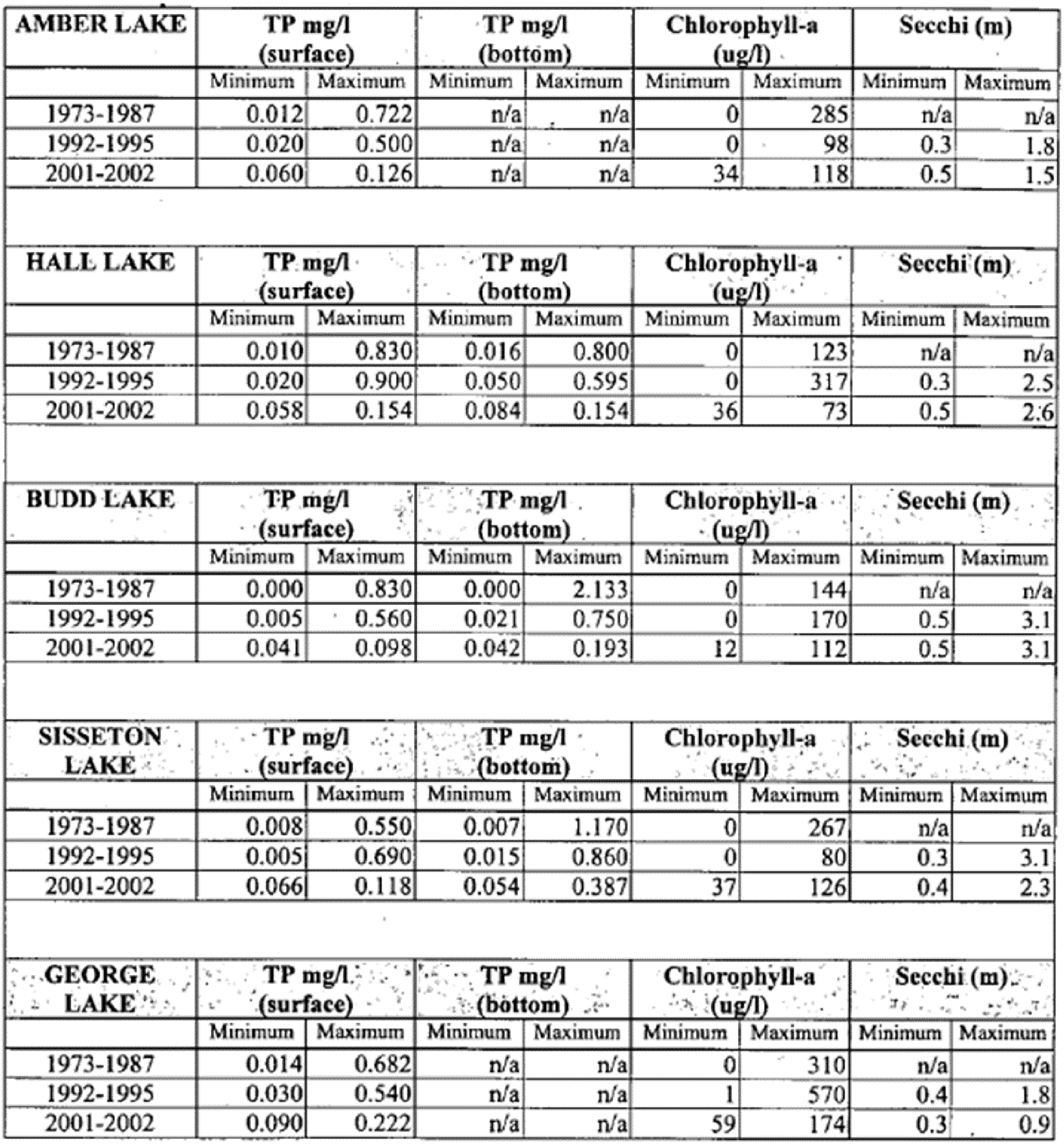


Figure 49. Range of measured surface TP concentrations in the Fairmont Chain of Lakes in the 1970s from Stefan et al. 1981 (Figure 5 on page 719).

Note: these data are not available in MPCA's EDA database

Table 34. Historic lake water quality data for the Fairmont Chain of Lakes presented in the 2002 Fairmont Chain of Lakes Monitoring Report (Table 8 on page 23; Martin County Environmental Services and MPCA 2003).
Note: 1973-1987 and 1992-1995 not available in MPCA's EDA database.



AMBER LAKE	TP mg/l (surface)		TP mg/l (bottom)		Chlorophyll-a (ug/l)		Secchi (m)	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
1973-1987	0.012	0.722	n/a	n/a	0	285	n/a	n/a
1992-1995	0.020	0.500	n/a	n/a	0	98	0.3	1.8
2001-2002	0.060	0.126	n/a	n/a	34	118	0.5	1.5

HALL LAKE	TP mg/l (surface)		TP mg/l (bottom)		Chlorophyll-a (ug/l)		Secchi (m)	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
1973-1987	0.010	0.830	0.016	0.800	0	123	n/a	n/a
1992-1995	0.020	0.900	0.050	0.595	0	317	0.3	2.5
2001-2002	0.058	0.154	0.084	0.154	36	73	0.5	2.6

BUDD LAKE	TP mg/l (surface)		TP mg/l (bottom)		Chlorophyll-a (ug/l)		Secchi (m)	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
1973-1987	0.000	0.830	0.000	2.133	0	144	n/a	n/a
1992-1995	0.005	0.560	0.021	0.750	0	170	0.5	3.1
2001-2002	0.041	0.098	0.042	0.193	12	112	0.5	3.1

SISSETON LAKE	TP mg/l (surface)		TP mg/l (bottom)		Chlorophyll-a (ug/l)		Secchi (m)	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
1973-1987	0.008	0.550	0.007	1.170	0	267	n/a	n/a
1992-1995	0.005	0.690	0.015	0.860	0	80	0.3	3.1
2001-2002	0.066	0.118	0.054	0.387	37	126	0.4	2.3

GEORGE LAKE	TP mg/l (surface)		TP mg/l (bottom)		Chlorophyll-a (ug/l)		Secchi (m)	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
1973-1987	0.014	0.682	n/a	n/a	0	310	n/a	n/a
1992-1995	0.030	0.540	n/a	n/a	1	570	0.4	1.8
2001-2002	0.090	0.222	n/a	n/a	59	174	0.3	0.9

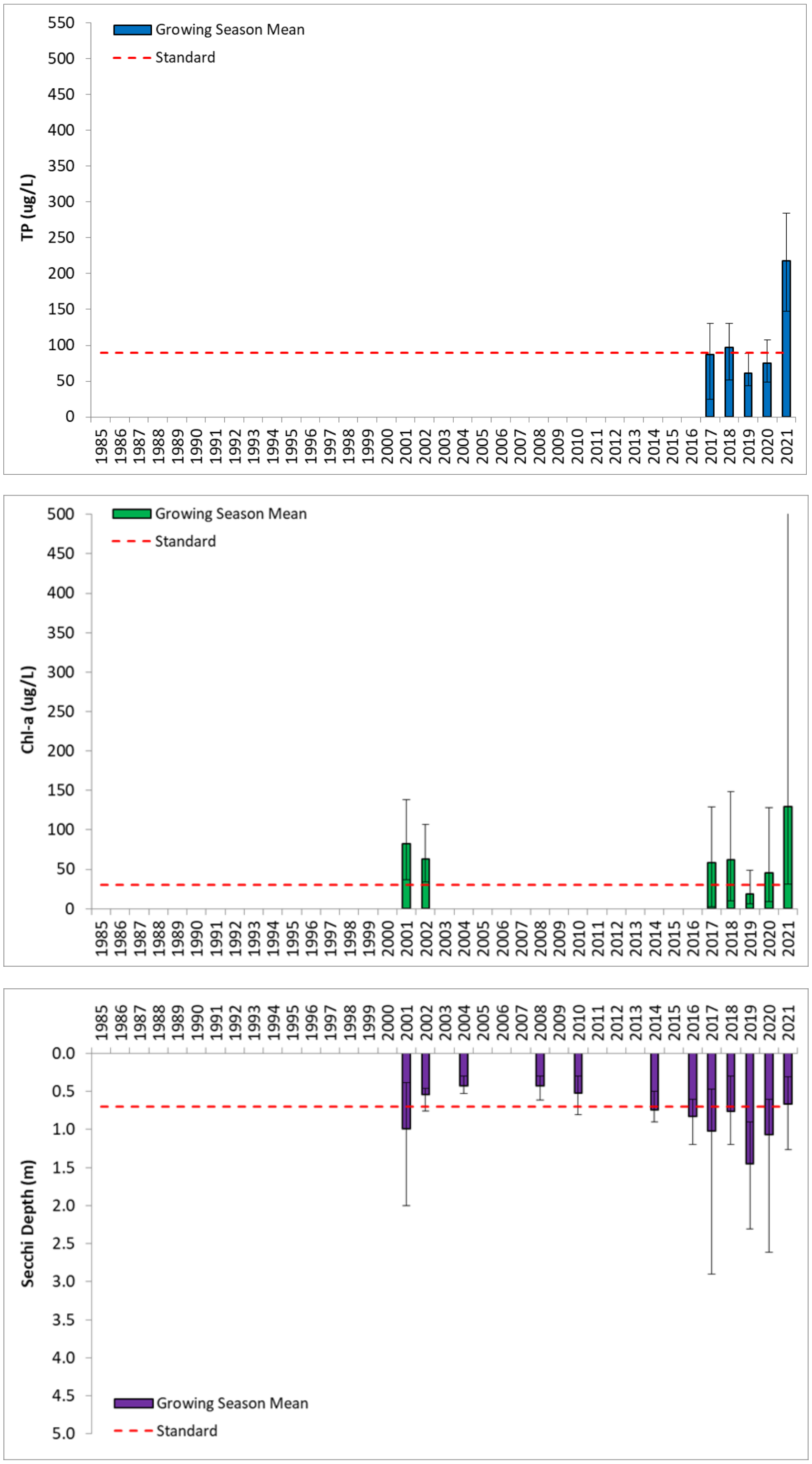


Figure 50. Amber Lake long-term mean growing season TP (top), chl-*a* (middle), and Secchi depth (bottom). Notes: Error bars represent maximum and minimum summer growing season concentrations. Dotted red line represents the WCBP shallow lake Secchi depth standard (0.7 m). Data includes discrete field samples (i.e., available in EDA), UMN Lake Browser data (remote sensing), and estimated TP values derived from regression relationships between TP and chl-*a*.

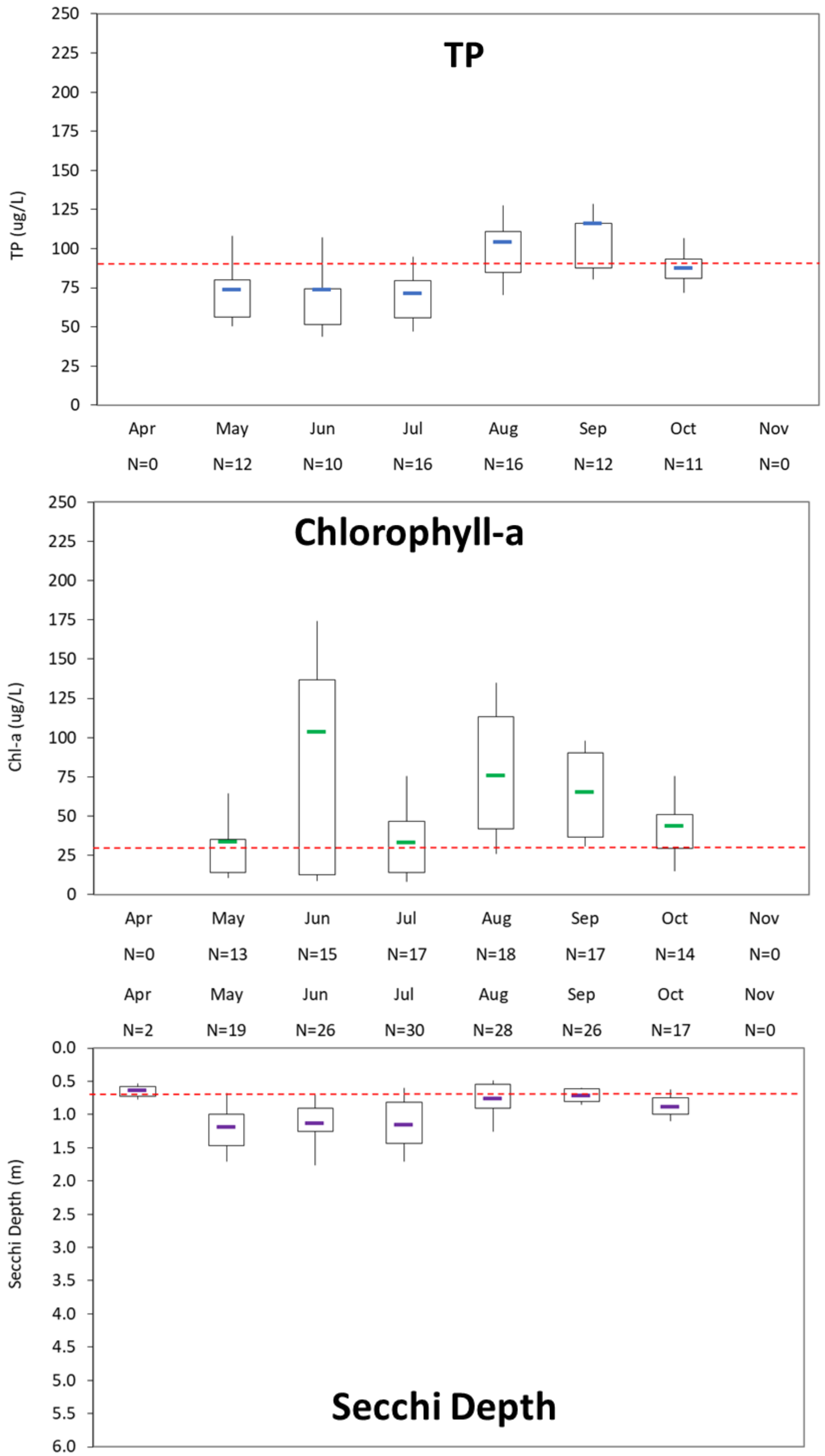


Figure 51. Box plots showing Amber Lake monthly surface TP (top), chl-*a* (middle), and Secchi depth (bottom) data from 2017 through 2021.

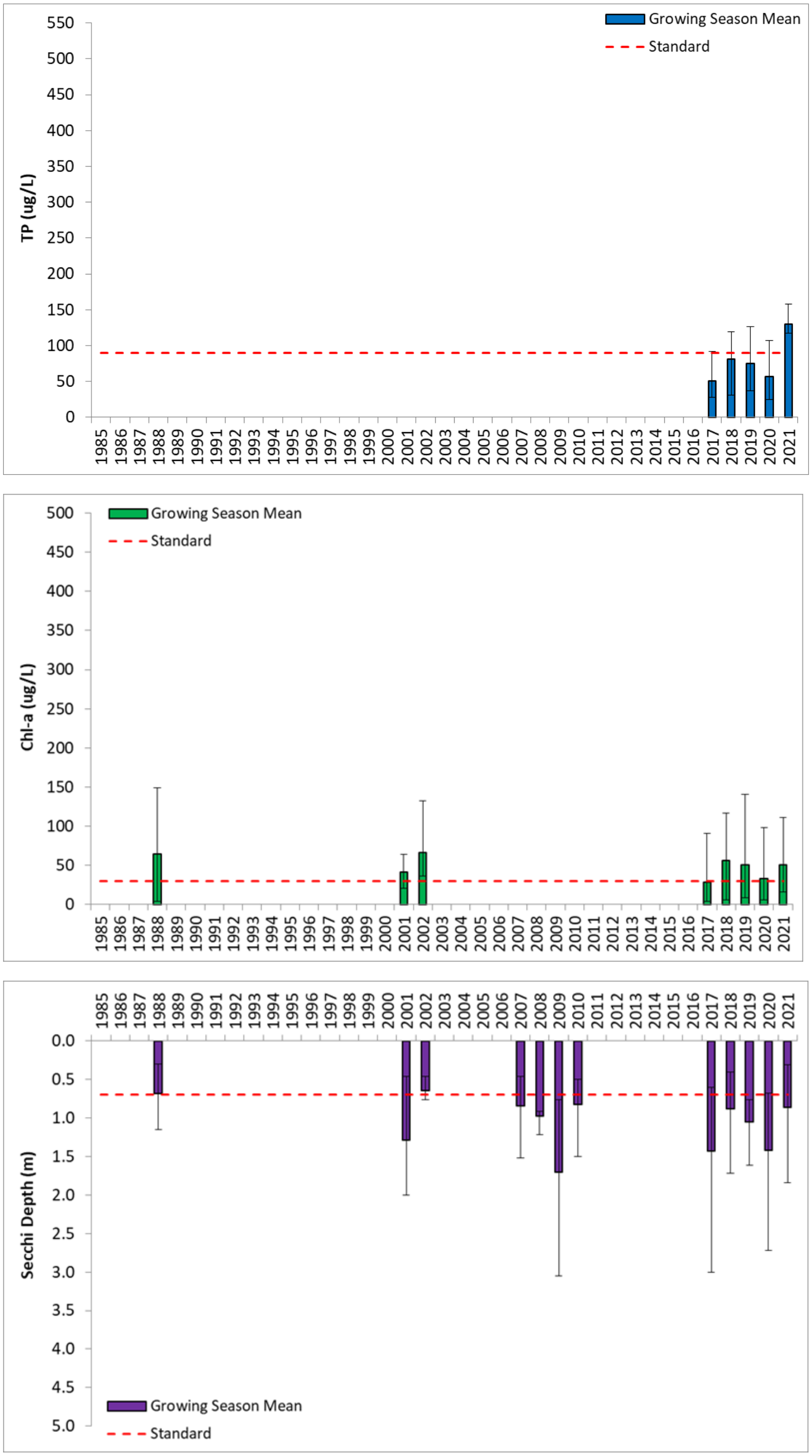


Figure 52. Hall Lake long-term mean growing season TP (top), chl-*a* (middle), and Secchi depth (bottom)

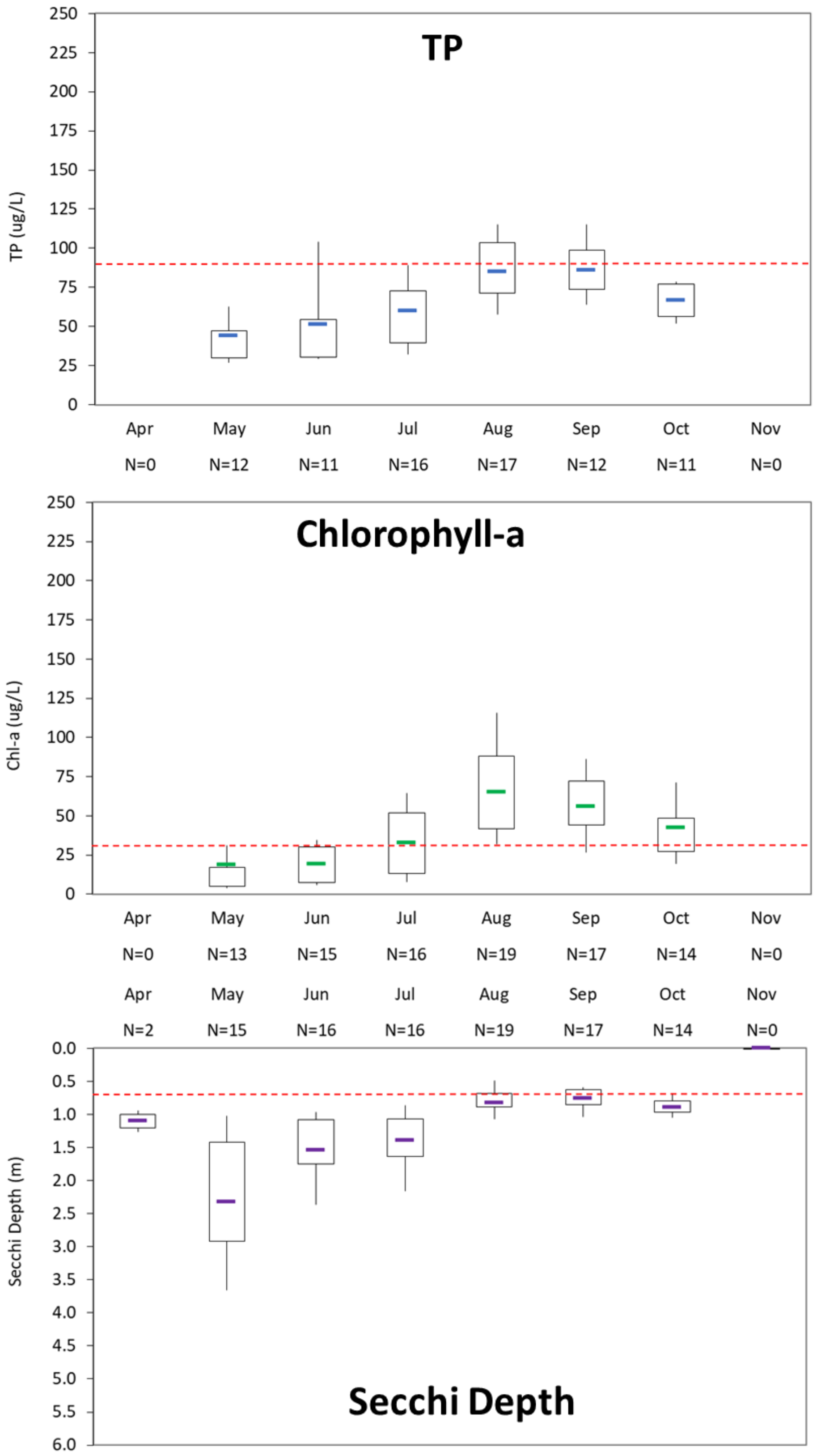


Figure 53. Box plots showing Hall Lake monthly surface TP (top), chl-*a* (middle), and Secchi depth (bottom) data from 2017 through 2021.

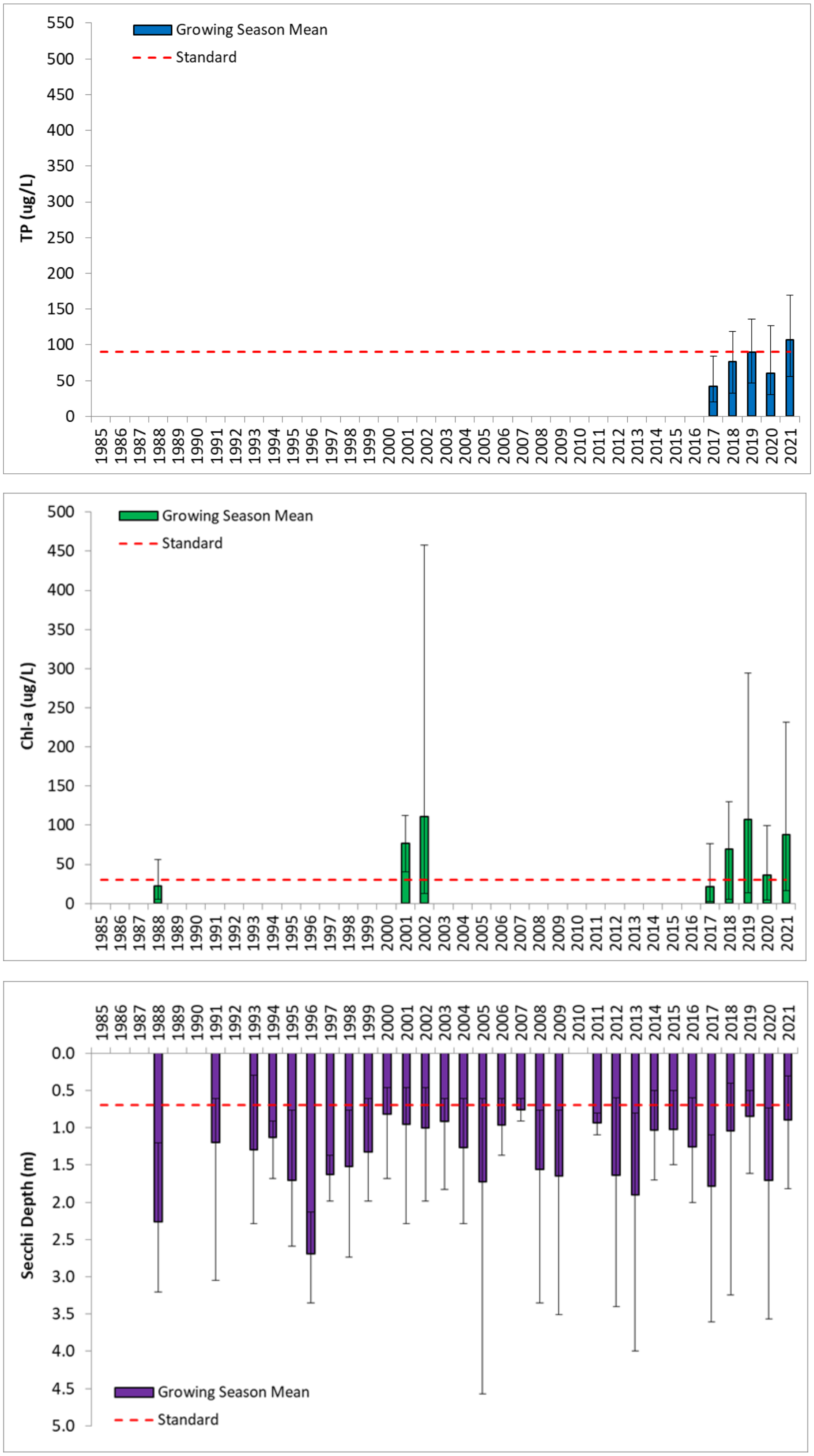


Figure 54. Budd Lake long-term mean growing season TP (top), chl-*a* (middle), and Secchi depth (bottom).

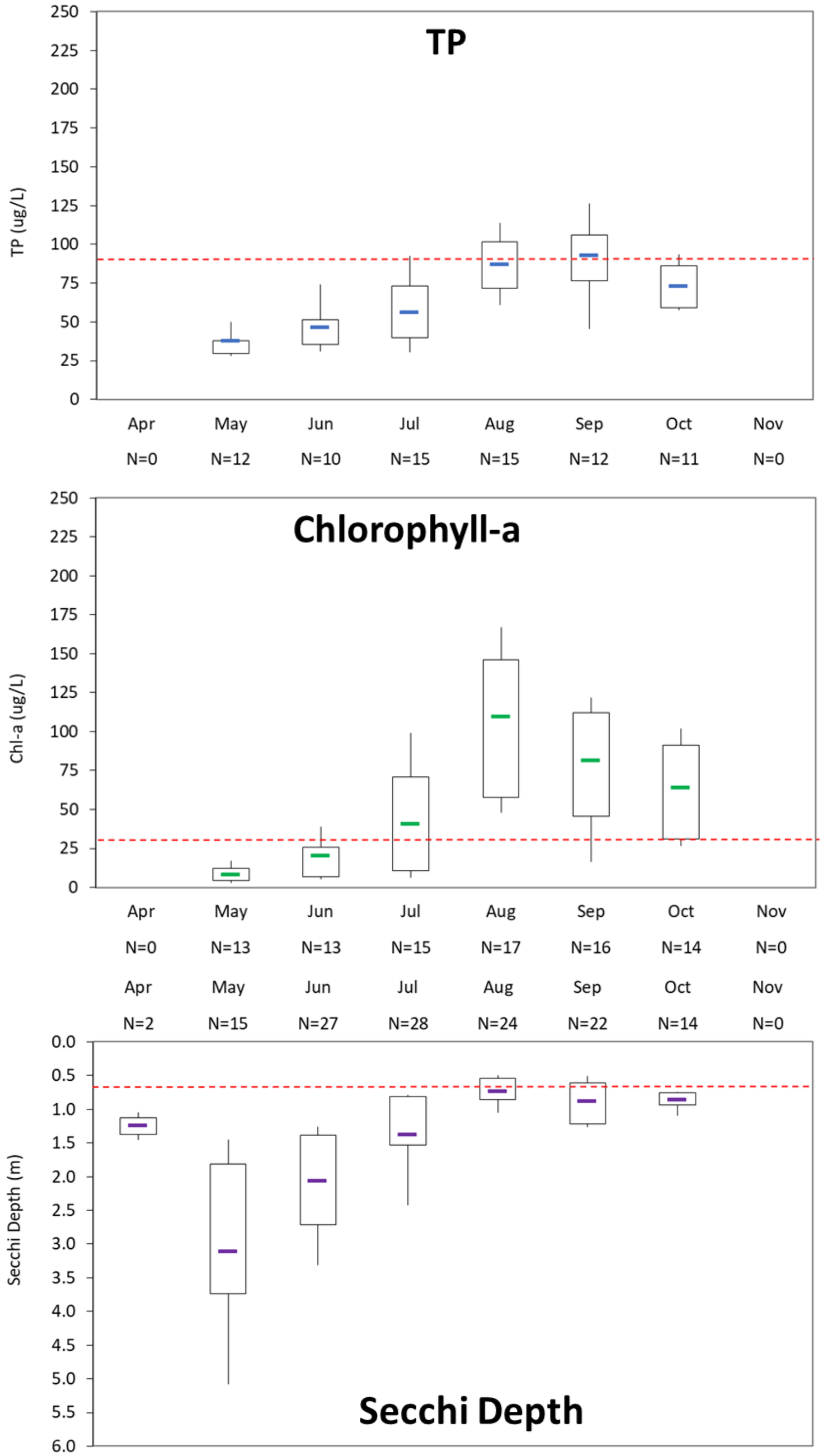


Figure 55. Box plots showing Budd Lake monthly surface TP (top), chl-*a* (middle), and Secchi depth (bottom) data from 2017 through 2021.

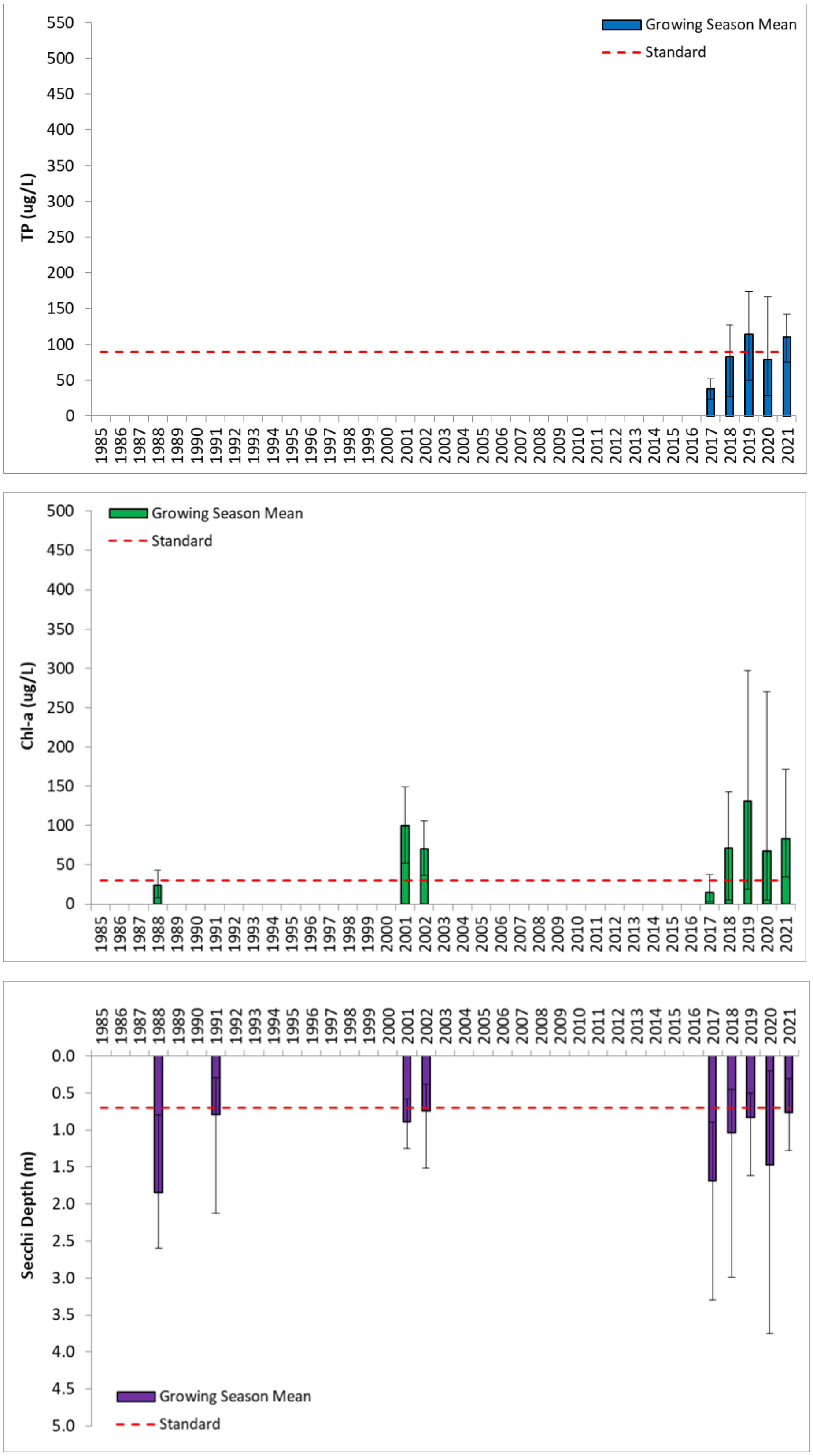


Figure 56. Sisseton Lake long-term mean growing season TP (top), chl-*a* (middle), and Secchi depth (bottom).

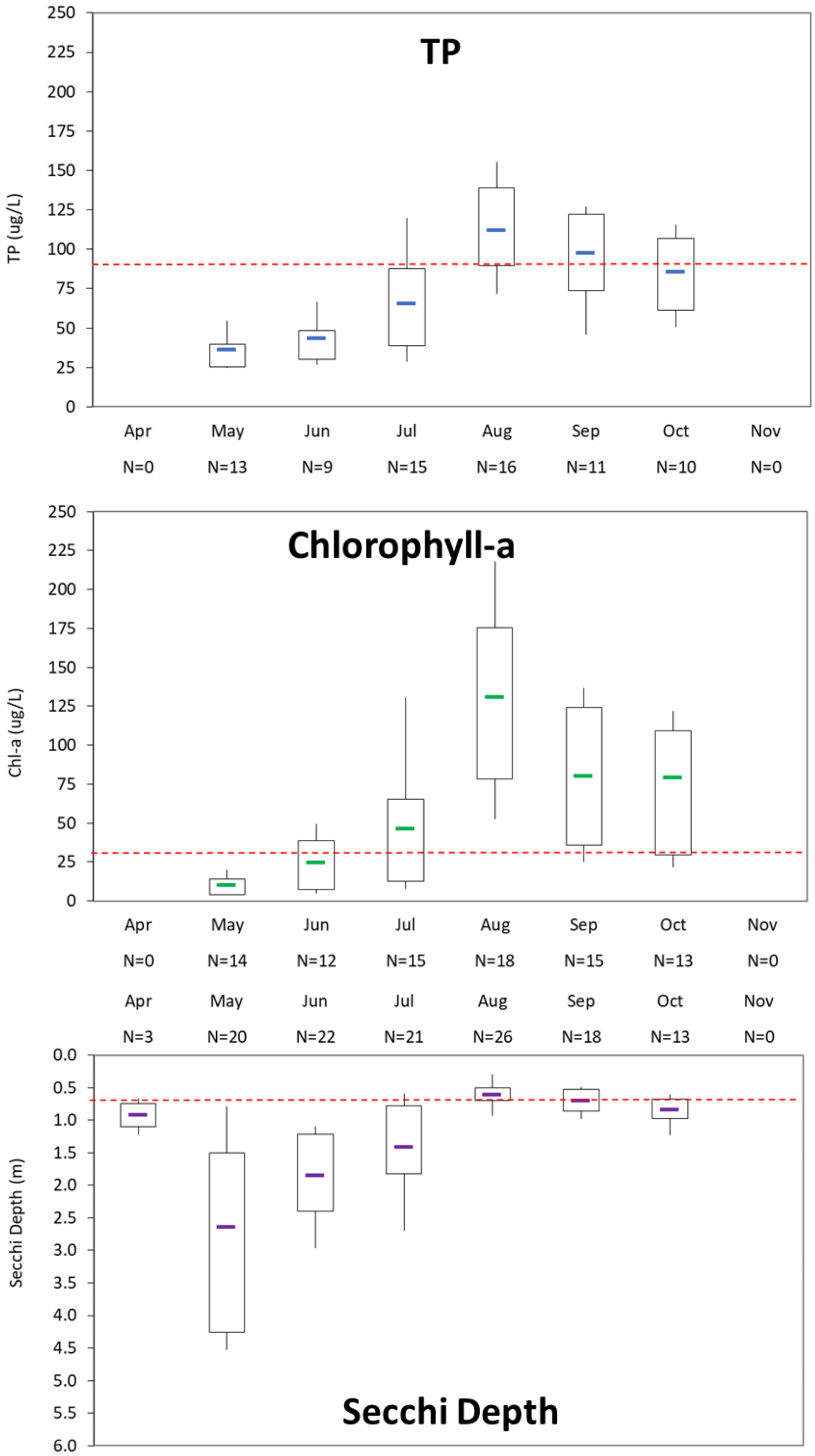


Figure 57. Box plots showing Sisseton Lake monthly surface TP (top), chl-*a* (middle), and Secchi depth (bottom) data from 2017 through 2021.

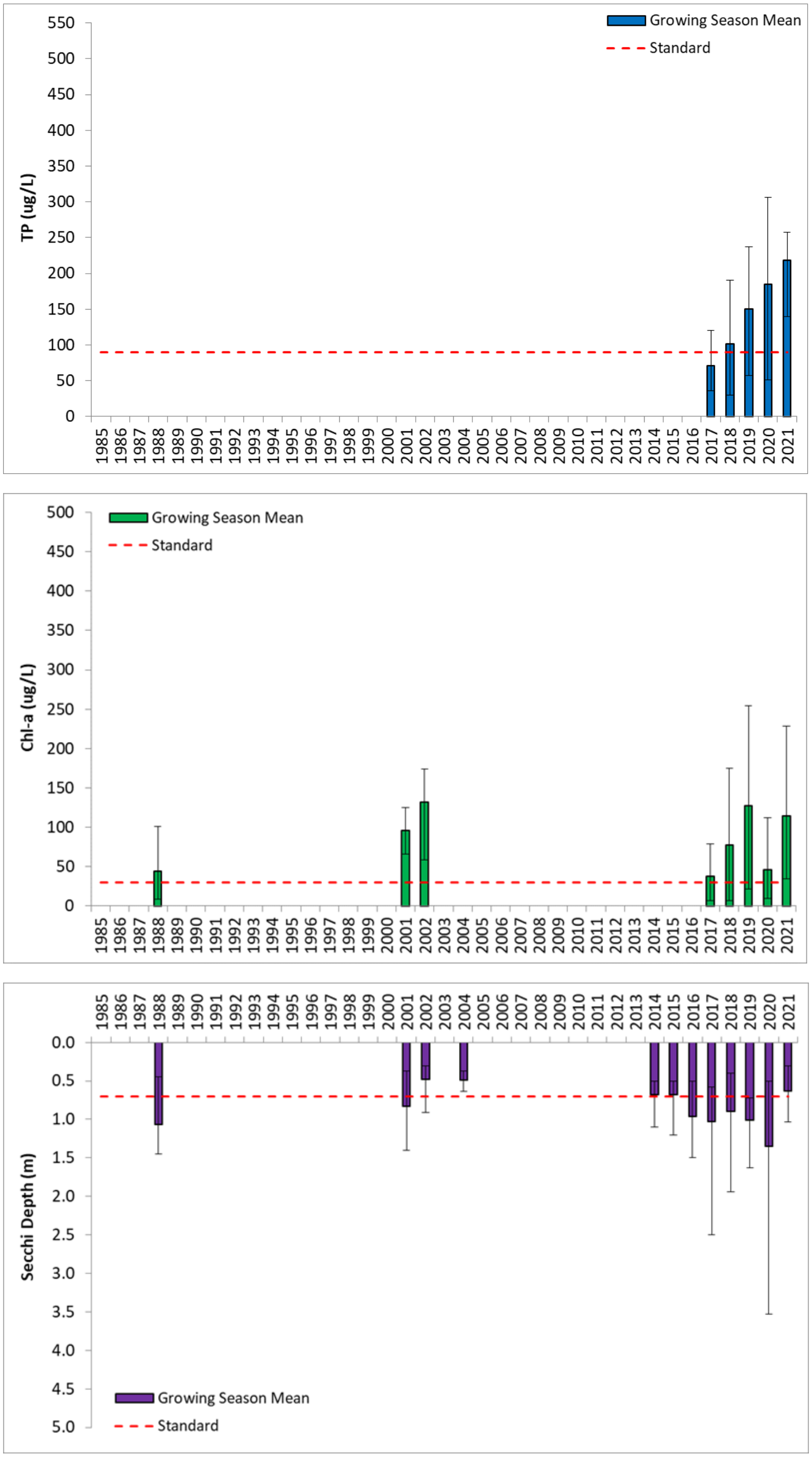


Figure 58. George Lake long-term mean growing season TP (top), chl-*a* (middle), and Secchi depth (bottom).

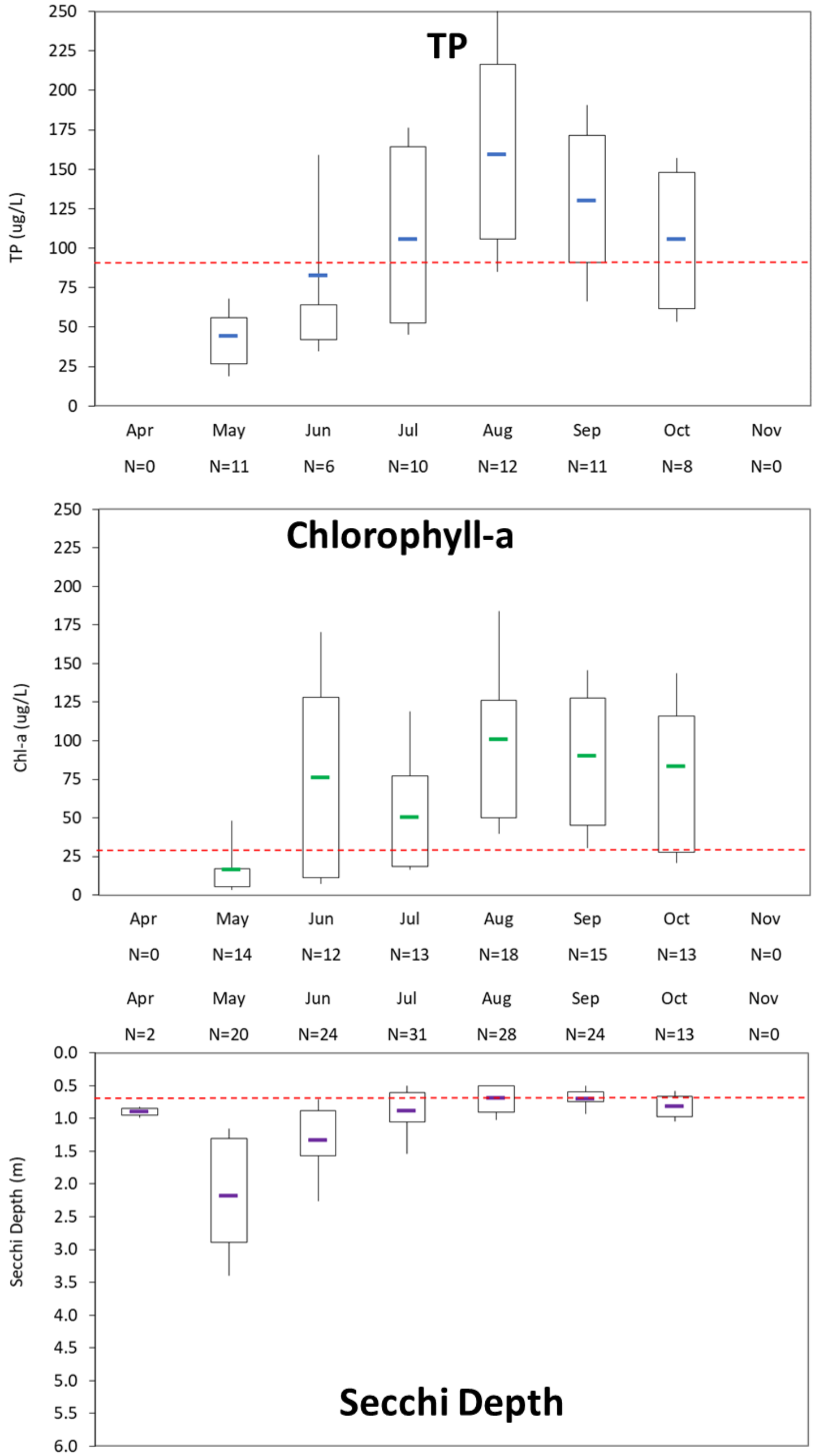


Figure 59. Box plots showing George Lake monthly surface TP (top), chl-*a* (middle), and Secchi depth (bottom) data from 2017 through 2021.

Recent Lake Water Quality Data (2017 through 2021)

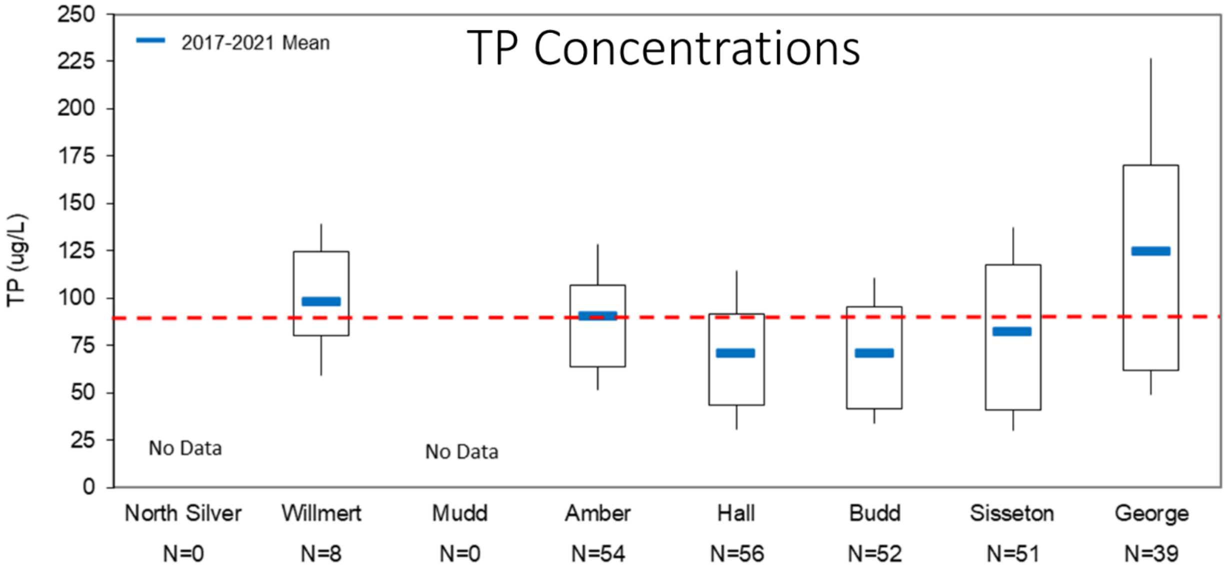


Figure 60. Box plots showing recent (2017 through 2021) growing season surface TP concentrations from upstream (left) to downstream (right) through the Fairmont Chain of Lakes.
Data sources: discrete field samples in MPCA's EDA database and estimated TP values derived from regression relationships between TP and chl-*a* applied to UMN Lake Browser (remote sensing) chl-*a* data.

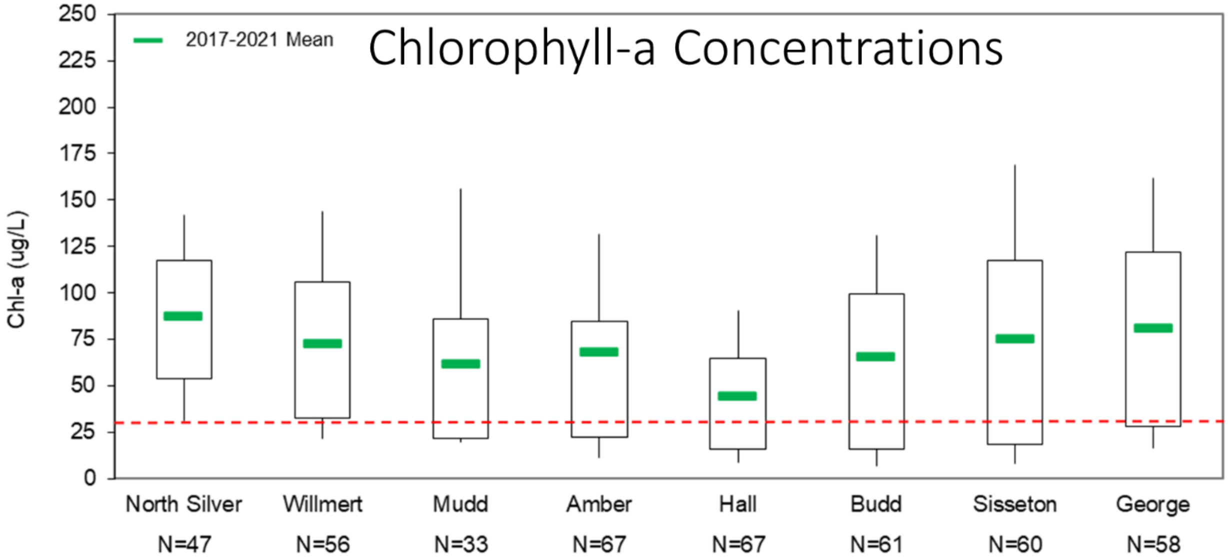


Figure 61. Box plots showing recent (2017 through 2021) growing season surface chl-*a* concentrations from upstream (left) to downstream (right) through the Fairmont Chain of Lakes.
Data sources: discrete field samples in MPCA's EDA database and UMN Lake Browser data (remote sensing)

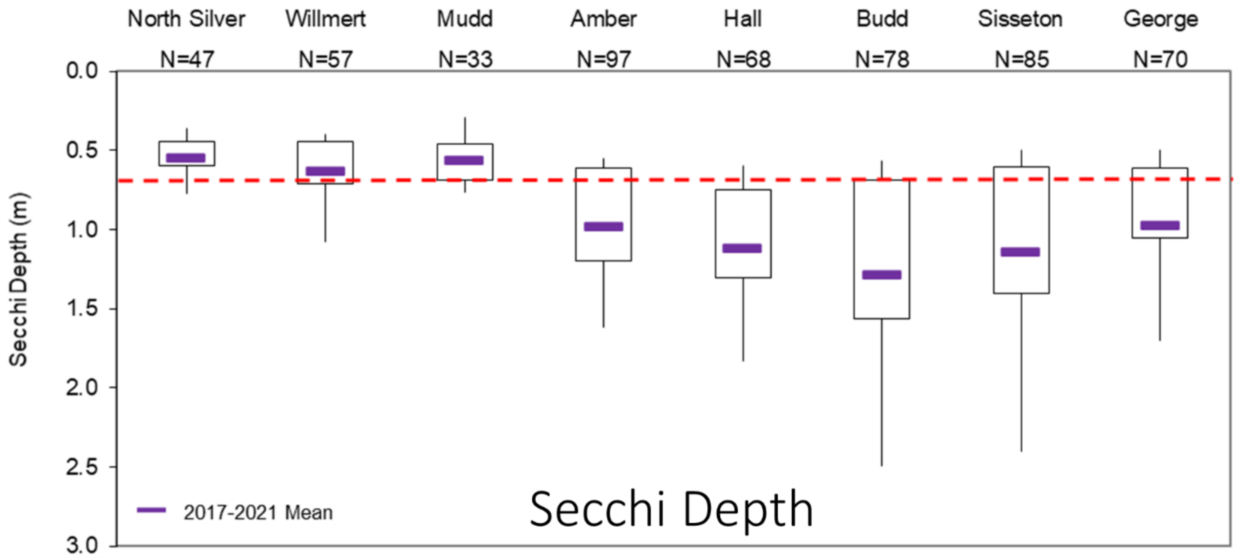


Figure 62. Box plots showing recent (2017 through 2021) growing season Secchi depth measurements from upstream (left) to downstream (right) through the Fairmont Chain of Lakes.
Data sources: discrete field samples in MPCA's EDA database and UMN Lake Browser data (remote sensing)

Table 35. Summary of available water quality data for North Silver, Willlmert, and Mud Lakes (2017-2021).
Data sources: discrete field samples in MPCA's EDA database and UMN Lake Browser data (remote sensing)

Parameter		**North Silver**	**Willmert**	**Mud**
TP	TP TSI (value)	--	70	--
	TP TSI (description)	--	hypereutrophic	--
	Mean Summer TP (µg/L)	--	93	--
	TP Standard (µg/L)			
Chl-a	Chl-a TSI (value)	74	72	71
	Chl-a TSI (description)	hypereutrophic	hypereutrophic	hypereutrophic
	Mean Summer Chl-a (µg/L)	87	70	62
	Chl-a Standard (µg/L)			
Secchi	Secchi TSI (value)	69	67	68
	Secchi TSI (description)	eutrophic	eutrophic	eutrophic
	Mean Summer Secchi (m)	0.5	0.6	0.6
	Secchi Standard (m)			

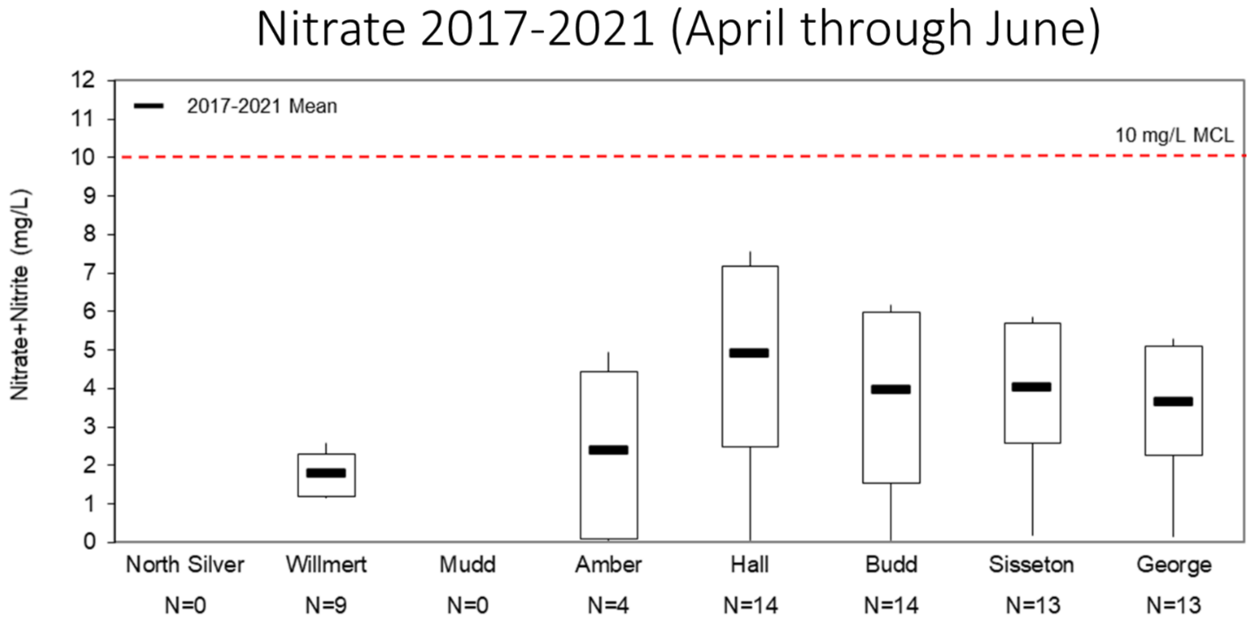


Figure 63. Box plots showing in-lake surface water nitrate concentrations (2017-2021, April through June samples only) from upstream (left) to downstream (right) throughout the Fairmont Chain of Lakes.

Note: the red dotted line represents the 10 mg/L drinking water maximum concentration limit

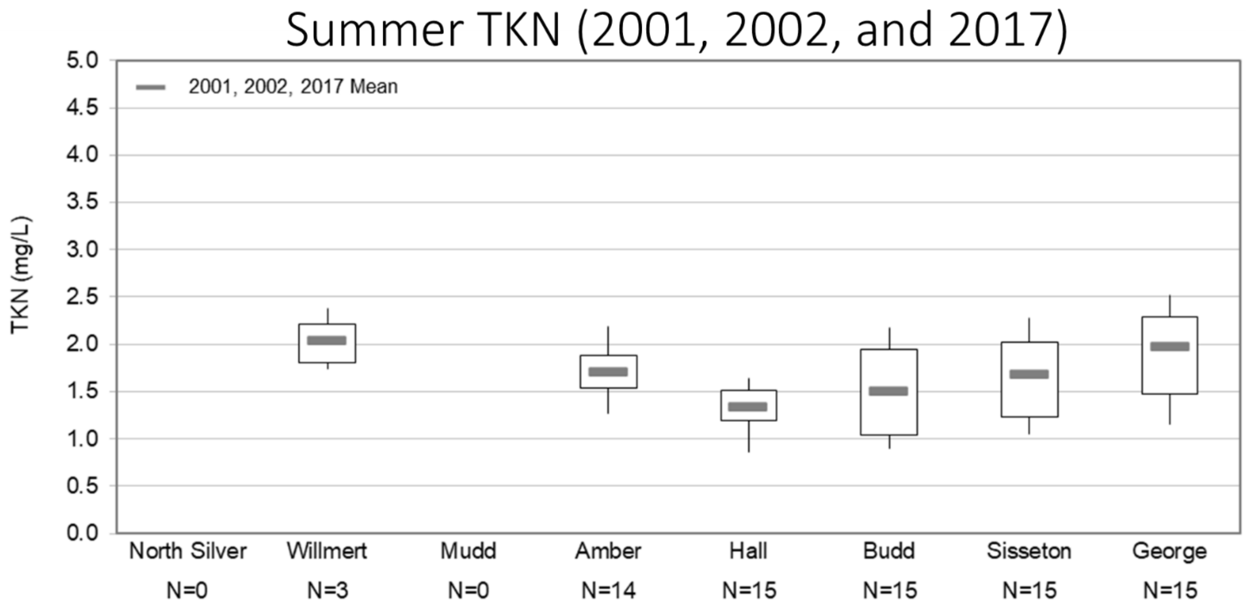


Figure 64. Box plots showing in-lake surface water TKN concentrations (summer months only in 2001, 2002, and 2017) from upstream (left) to downstream (right) throughout the Fairmont Chain of Lakes.

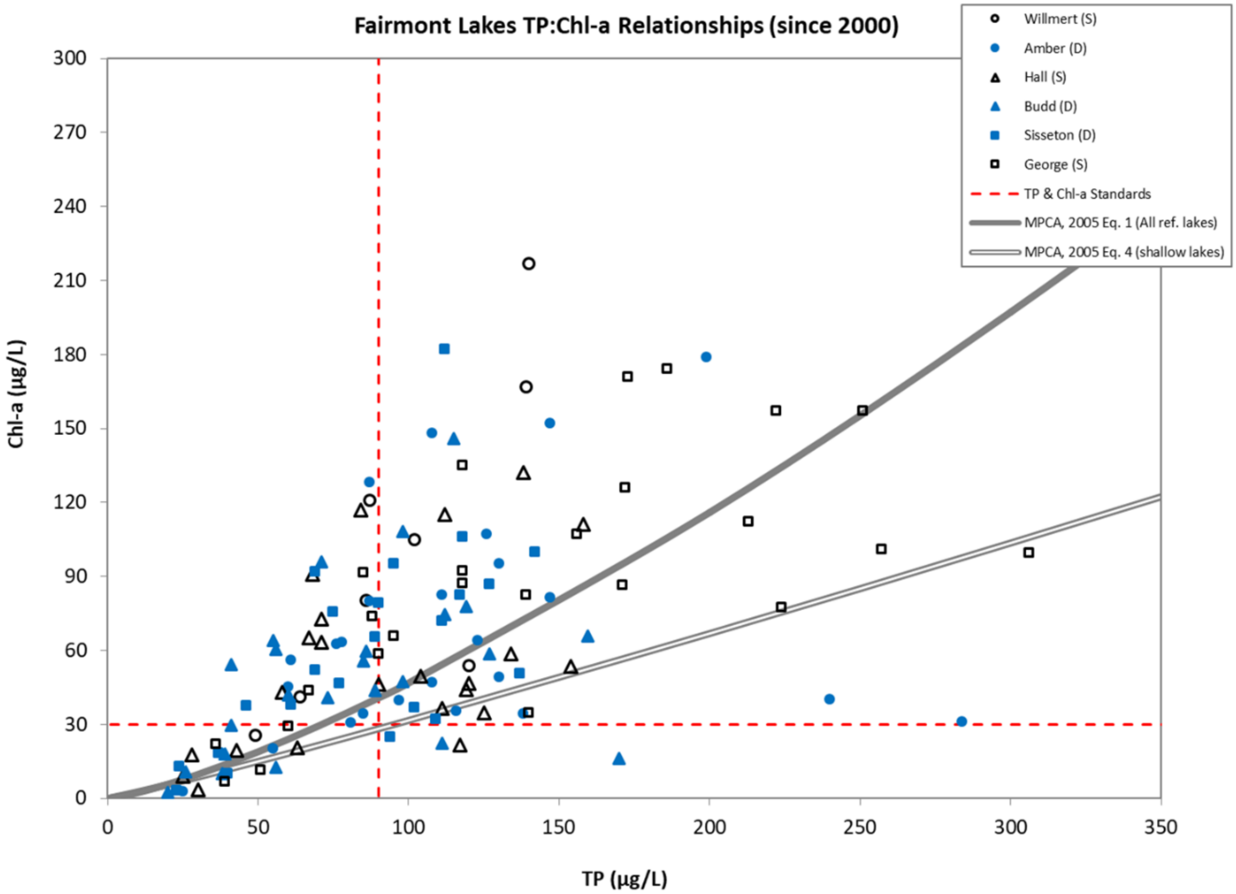
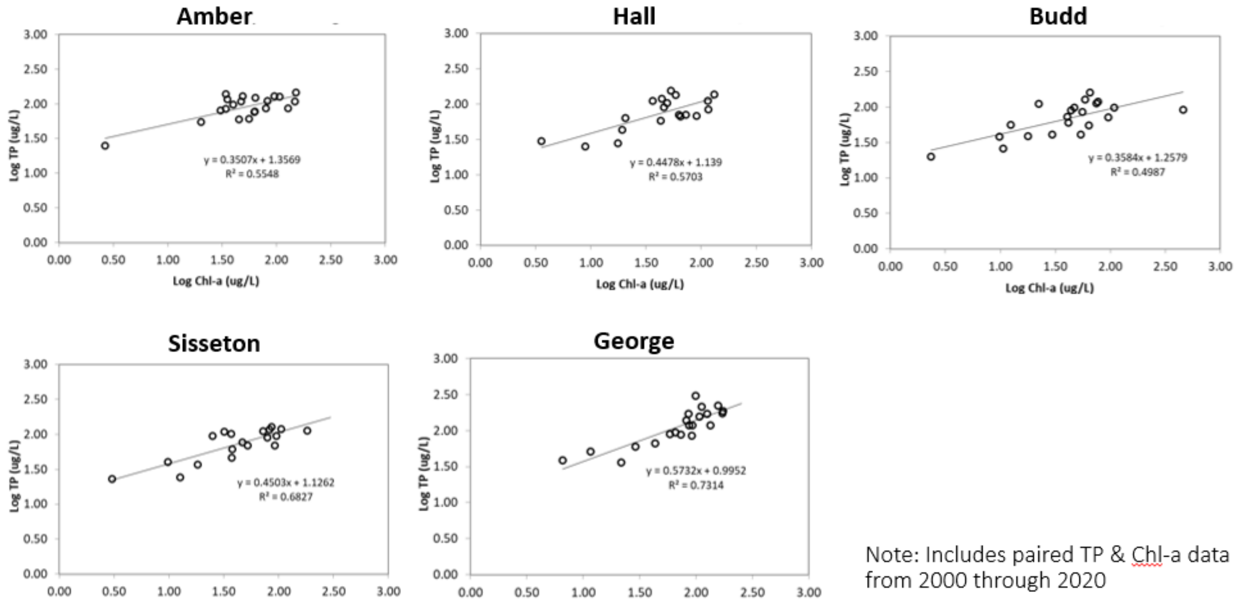


Figure 65. TP: chl-*a* relationships for discrete samples (2000 through 2021) throughout the Fairmont Chain of Lakes.

Notes: Red dotted line show the WCBP shallow lake TP (90 µg/L) and chl-*a* (30 µg/L). The solid and open gray lines represent the reference lake regression equations (MPCA 2005) used to develop the statewide lake and shallow lake standards, respectively.



Note: Includes paired TP & Chl-a data from 2000 through 2020

Figure 66. Individual TP:chl-*a* relationships for each lake in the Fairmont Chain of Lakes using discrete samples collected from 2000 through 2020.

Note: regression relationships were used to estimate TP concentrations for days in which remote sensing chl-*a* data is available in UMN Lake Browser, but field TP data is not available in MPCA's EDA database.

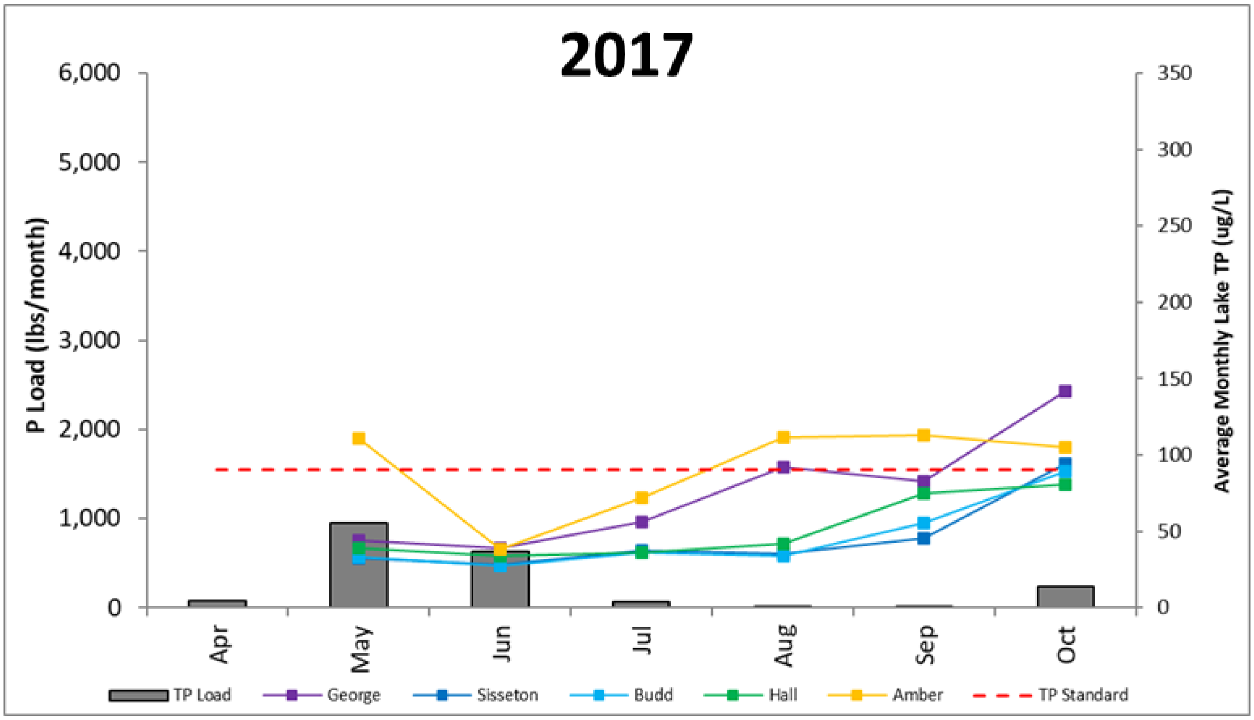


Figure 67. 2017 monthly monitored TP loads for Dutch Creek Station S003-000 (left axis, gray bars) and monthly mean in-lake surface TP concentrations (right axis) for the individual lakes in the Fairmont Chain of Lakes.

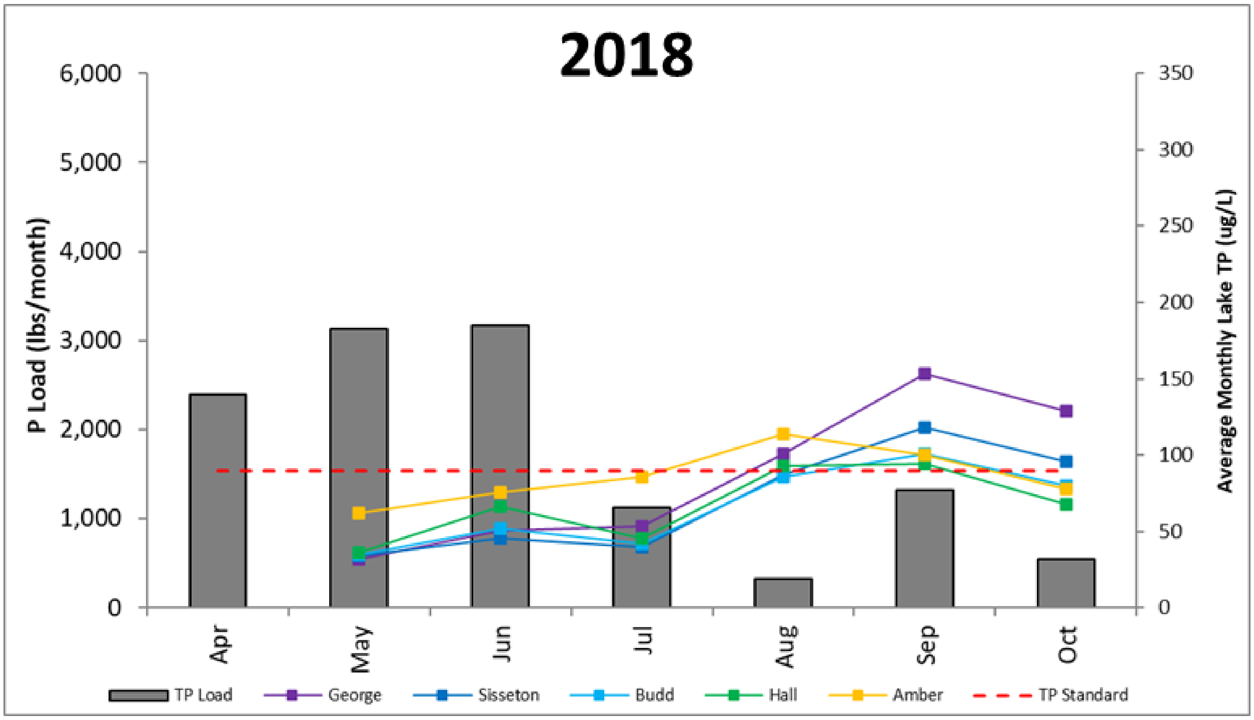


Figure 68. 2018 monthly monitored TP loads for Dutch Creek Station S003-000 (left axis, gray bars) and monthly mean in-lake surface TP concentrations (right axis) for the individual lakes in the Fairmont Chain of Lakes.

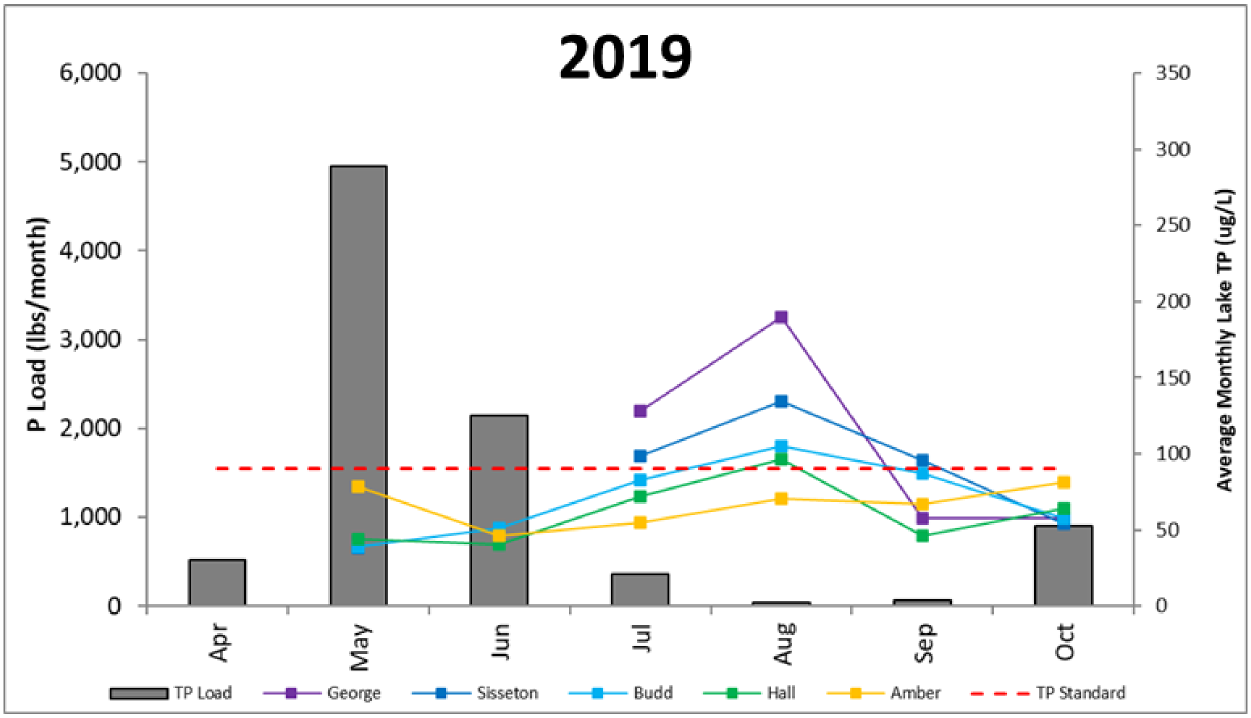


Figure 69. 2019 monthly monitored TP loads for Dutch Creek Station S003-000 (left axis, gray bars) and monthly mean in-lake surface TP concentrations (right axis) for the individual lakes in the Fairmont Chain of Lakes.

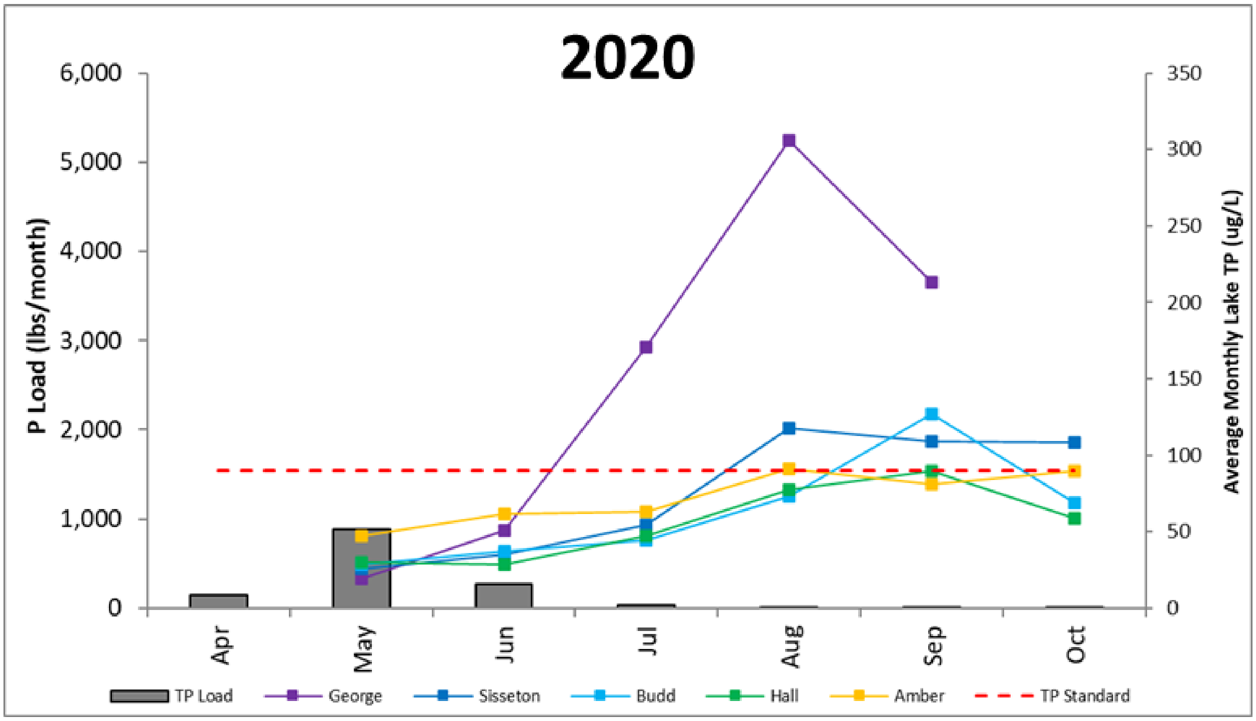


Figure 70. 2020 monthly monitored TP loads for Dutch Creek Station S003-000 (left axis, gray bars) and monthly mean in-lake surface TP concentrations (right axis) for the individual lakes in the Fairmont Chain of Lakes.

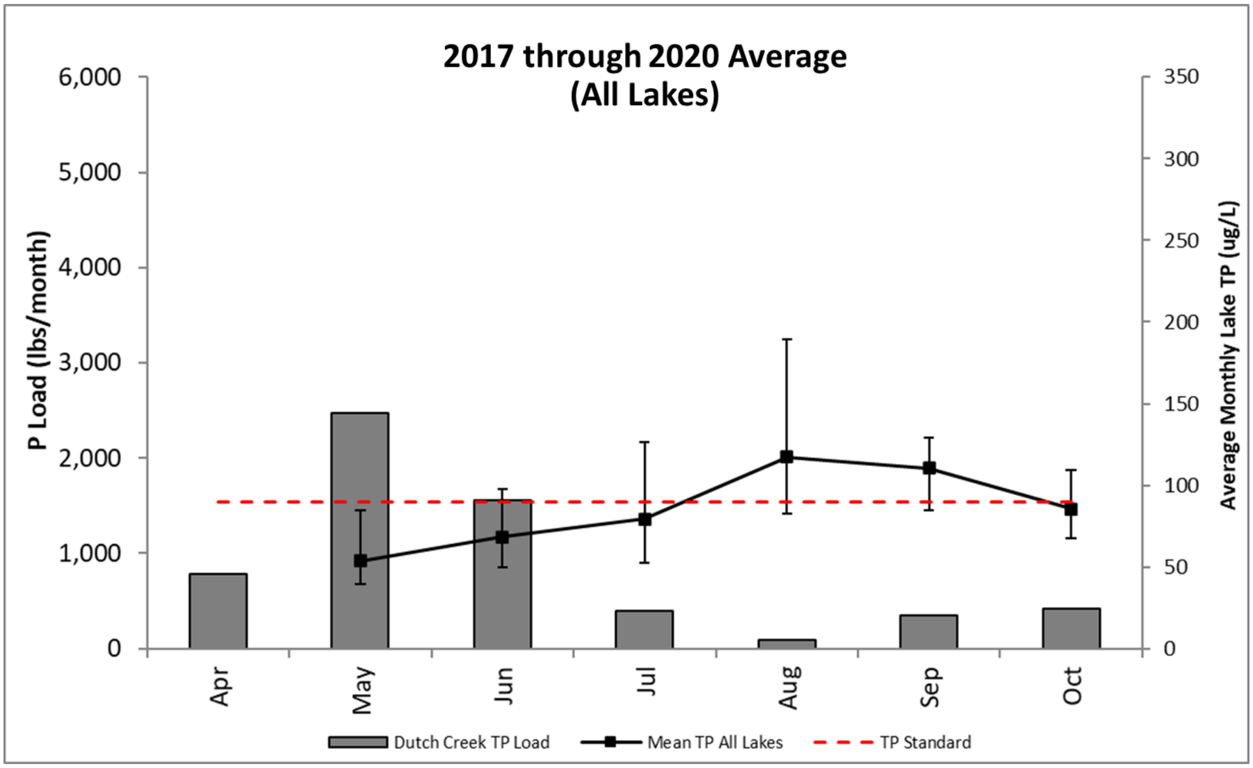


Figure 71. 2017-2020 monthly mean TP loads for Dutch Creek Station S003-000 (left axis, gray bars) and monthly mean in-lake surface TP concentrations for all lakes in the Fairmont Chain of Lakes (right axis).

Note: error bars represent the maximum and minimum monthly TP loads and maximum and minimum monthly lake surface TP concentrations from 2017 through 2020.

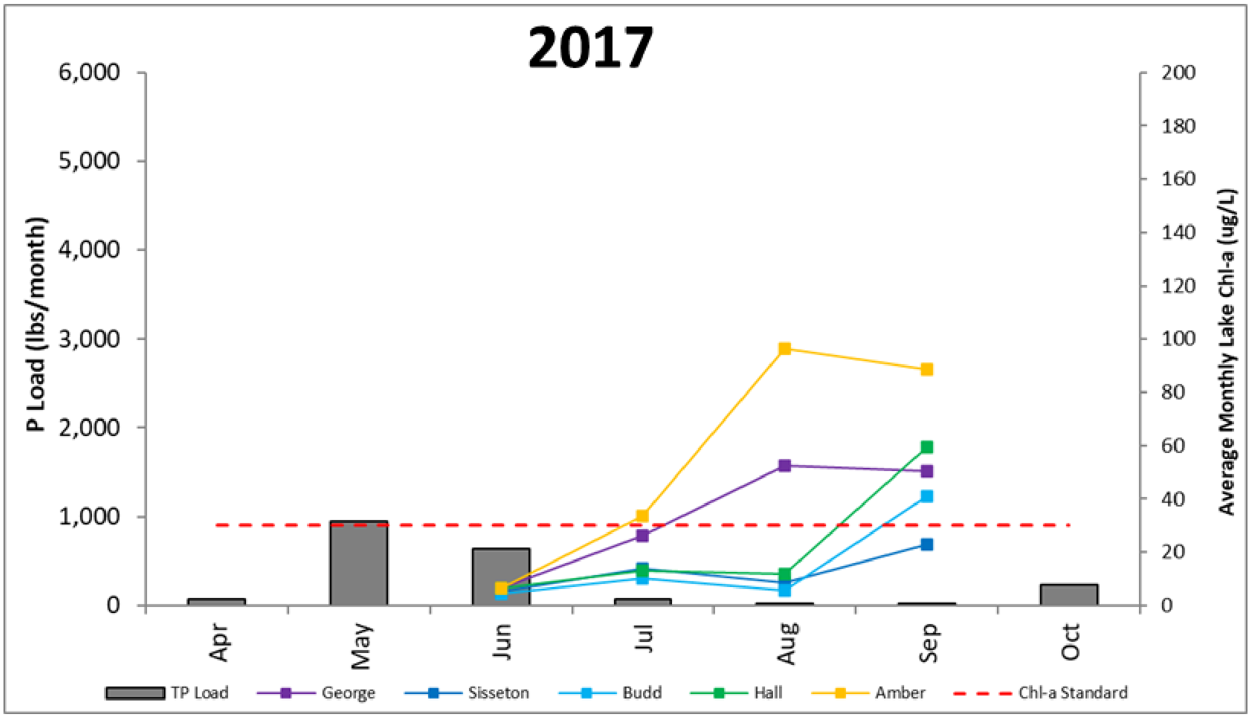


Figure 72. 2017 monthly monitored TP loads for Dutch Creek Station S003-000 (left axis, gray bars) and monthly mean in-lake surface chl-*a* concentrations (right axis) for the individual lakes in the Fairmont Chain of Lakes.

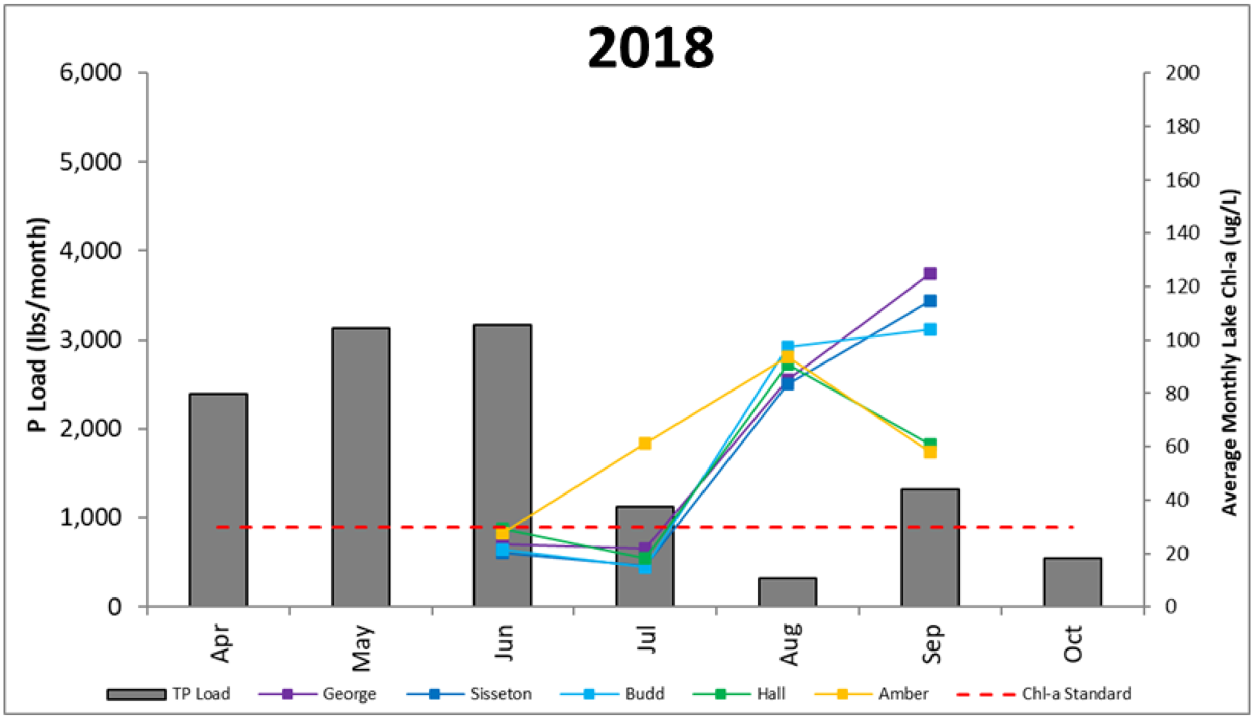


Figure 73. 2018 monthly monitored TP loads for Dutch Creek Station S003-000 (left axis, gray bars) and monthly mean in-lake surface chl-*a* concentrations (right axis) for the individual lakes in the Fairmont Chain of Lakes.

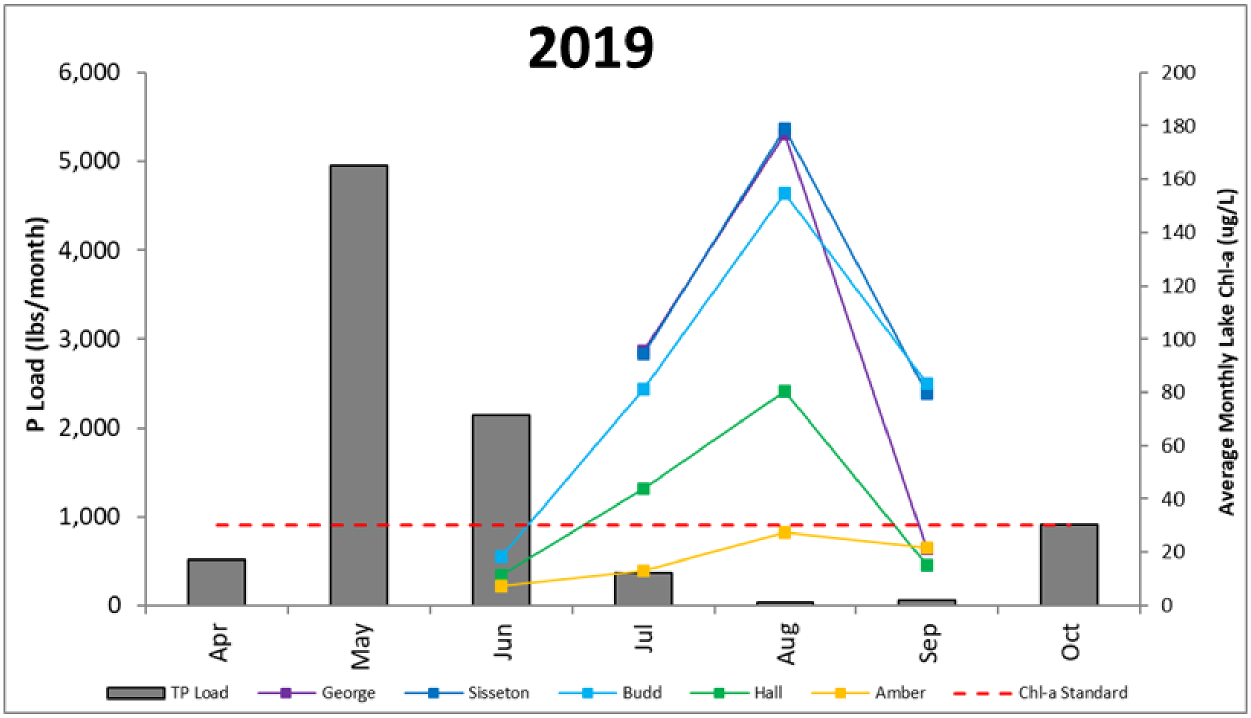


Figure 74. 2019 monthly monitored TP loads for Dutch Creek Station S003-000 (left axis, gray bars) and monthly mean in-lake surface chl-*a* concentrations (right axis) for the individual lakes in the Fairmont Chain of Lakes.

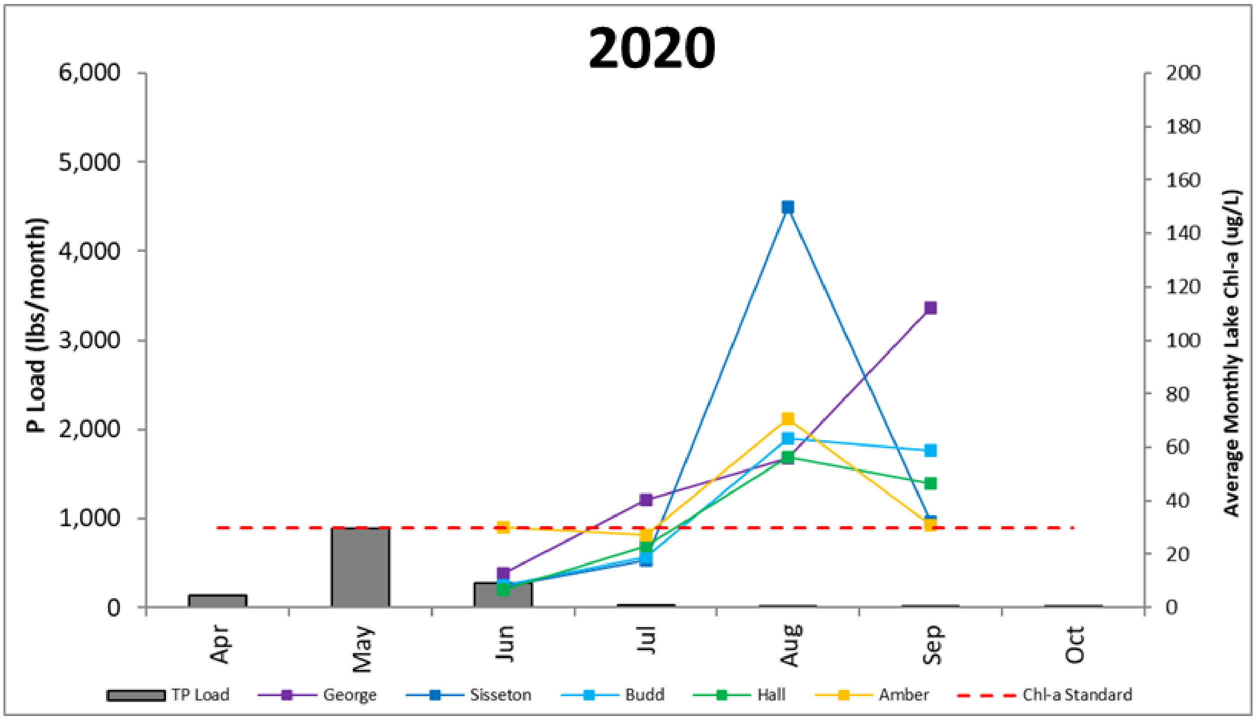


Figure 75. 2020 monthly monitored TP loads for Dutch Creek Station S003-000 (left axis, gray bars) and monthly mean in-lake surface chl-*a* concentrations (right axis) for the individual lakes in the Fairmont Chain of Lakes.

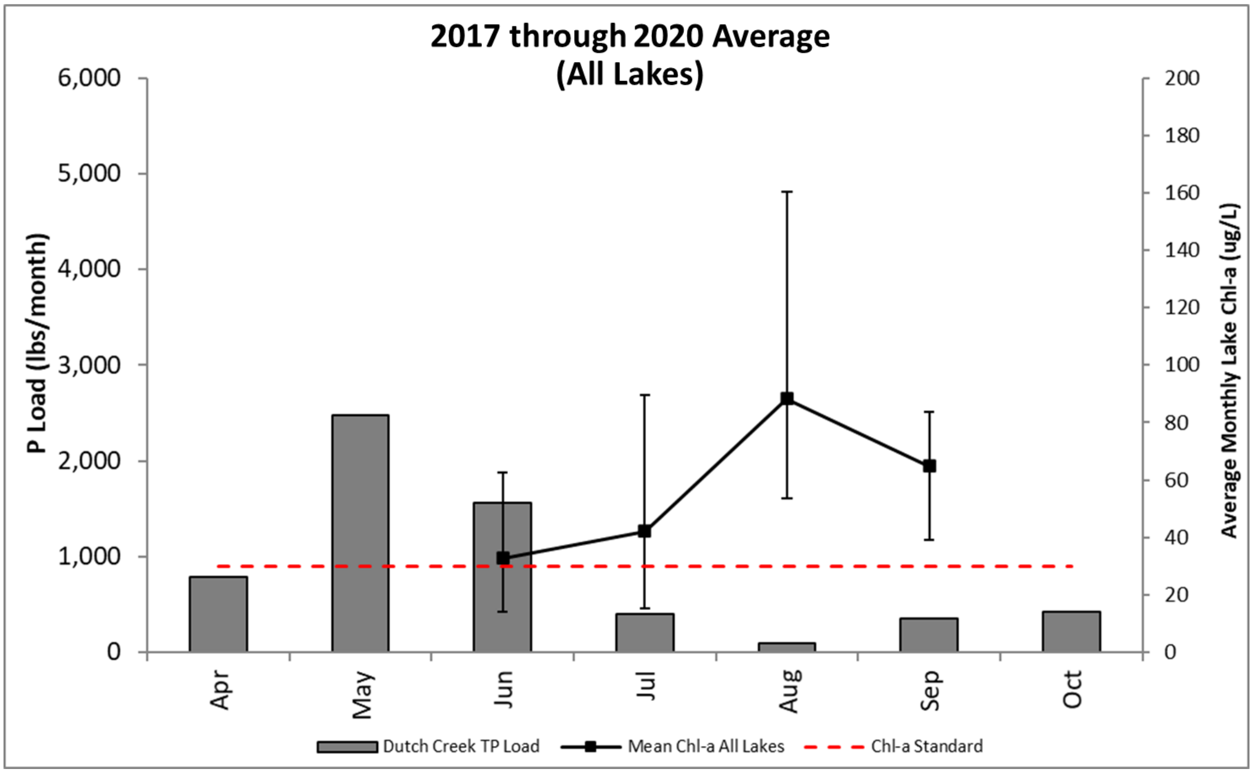


Figure 76. 2017-2020 monthly mean TP loads for Dutch Creek Station S003-000 (left axis, gray bars) and monthly mean in-lake surface chl-*a* concentrations for all lakes in the Fairmont Chain of Lakes (right axis).

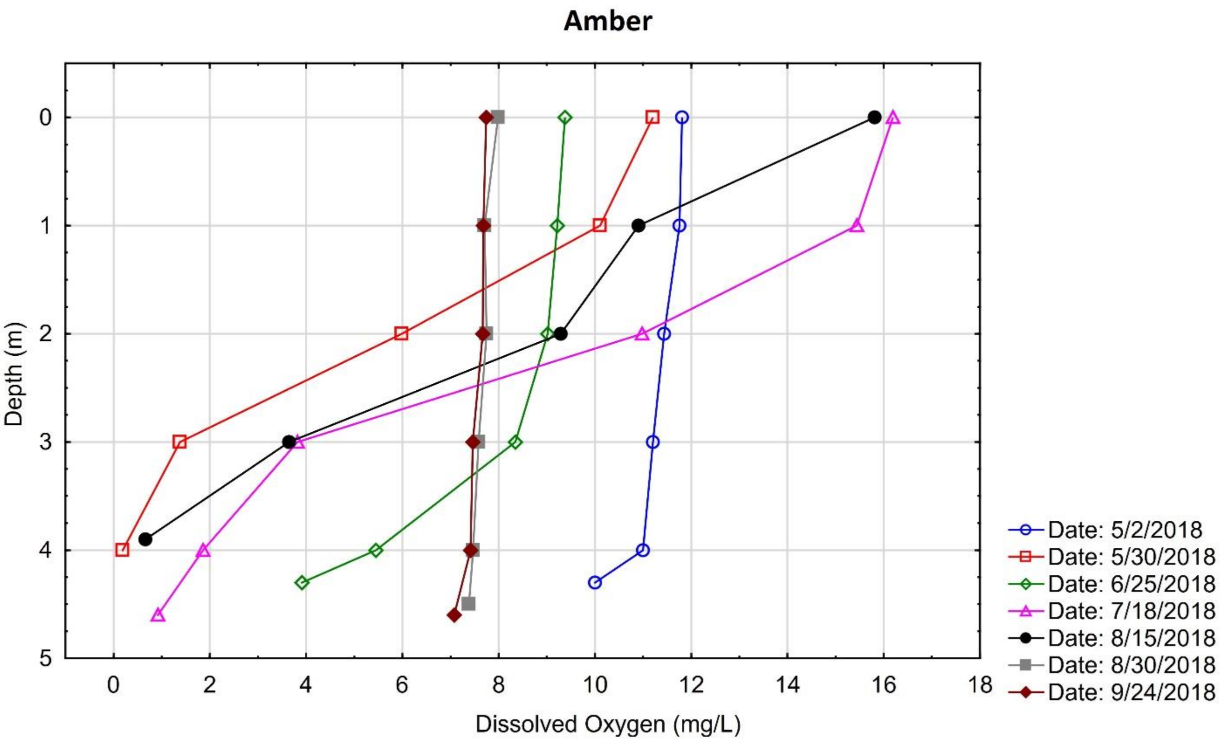


Figure 77. 2018 dissolved oxygen profiles for Amber Lake.

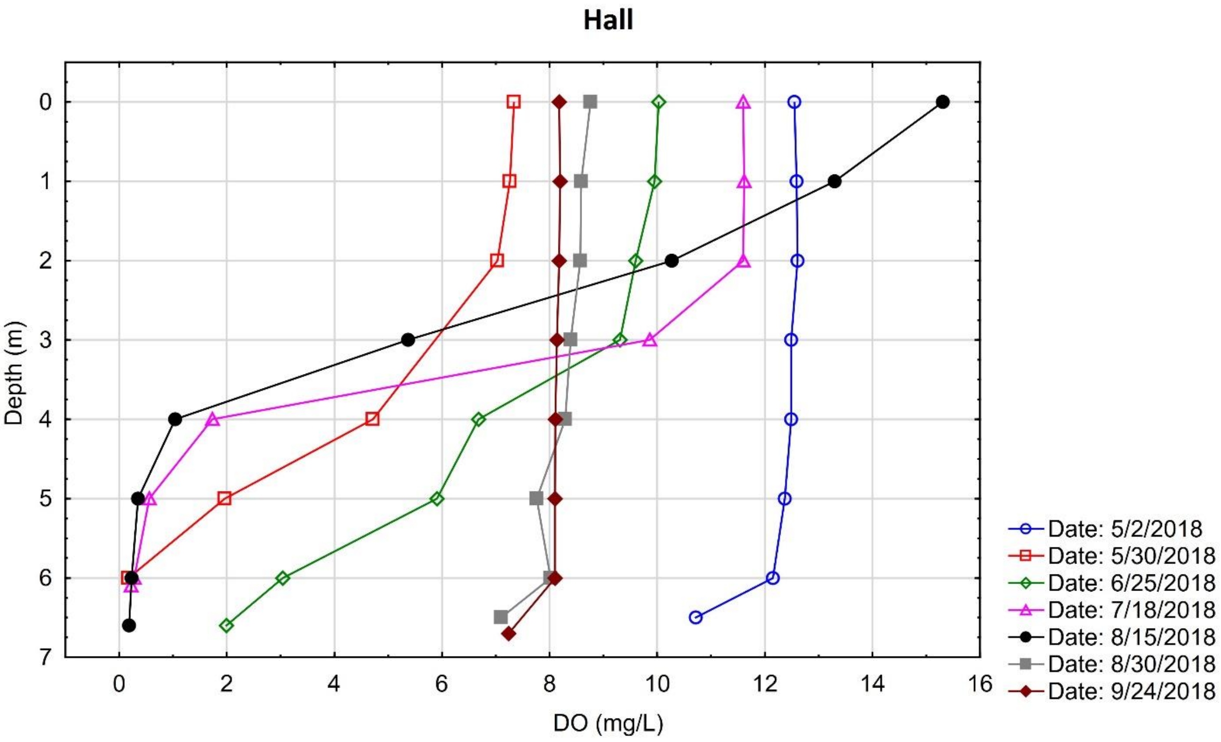


Figure 78. 2018 dissolved oxygen profiles for Hall Lake.

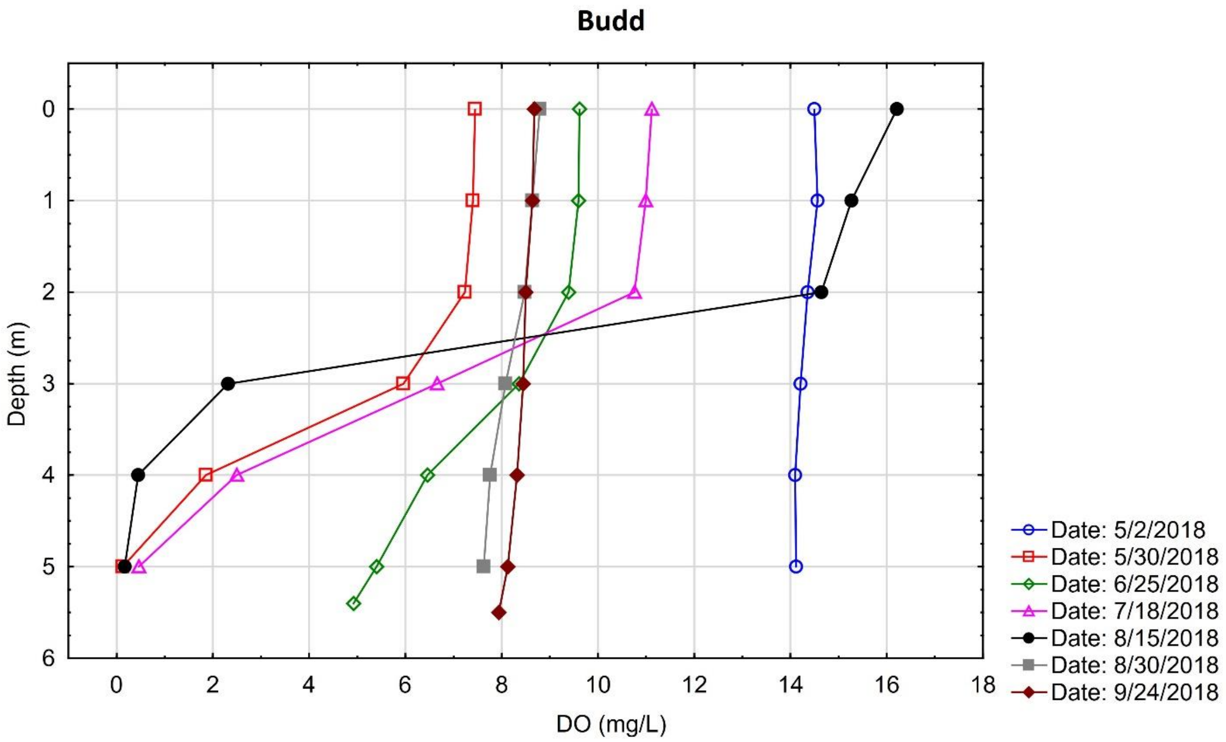


Figure 79. 2018 dissolved oxygen profiles for Budd Lake.

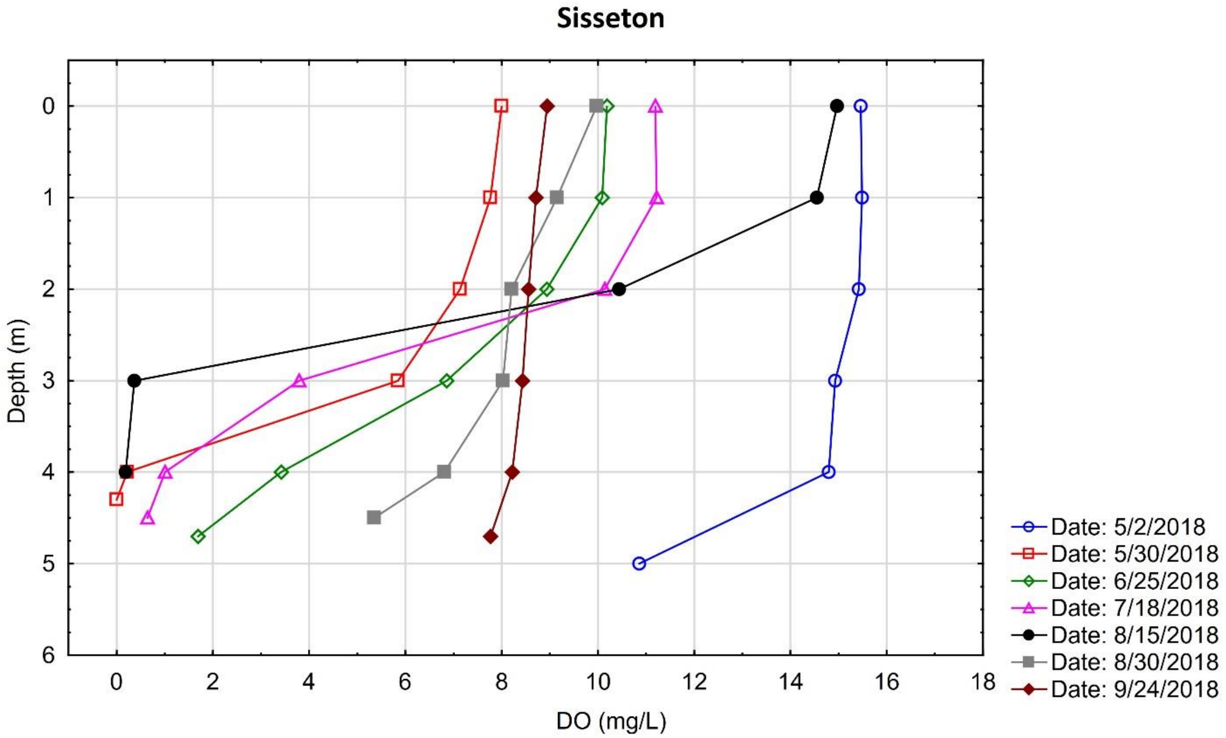


Figure 80. 2018 dissolved oxygen profiles for Sisseton Lake.

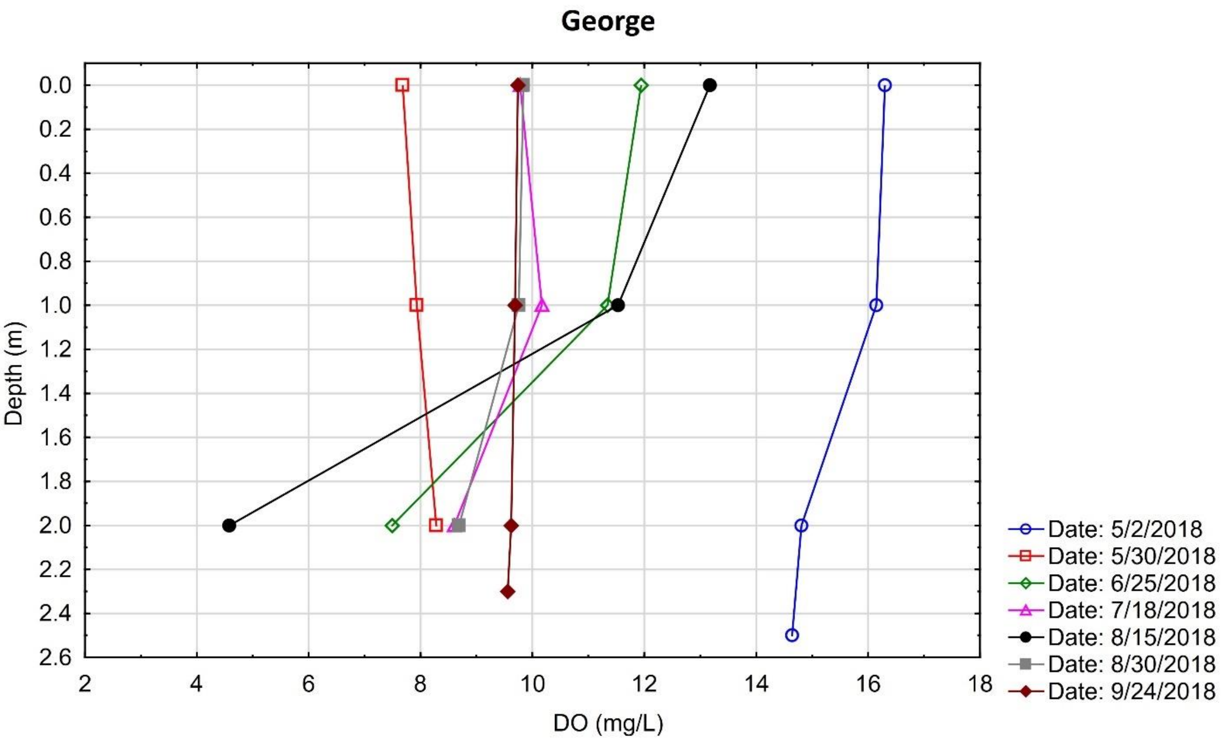
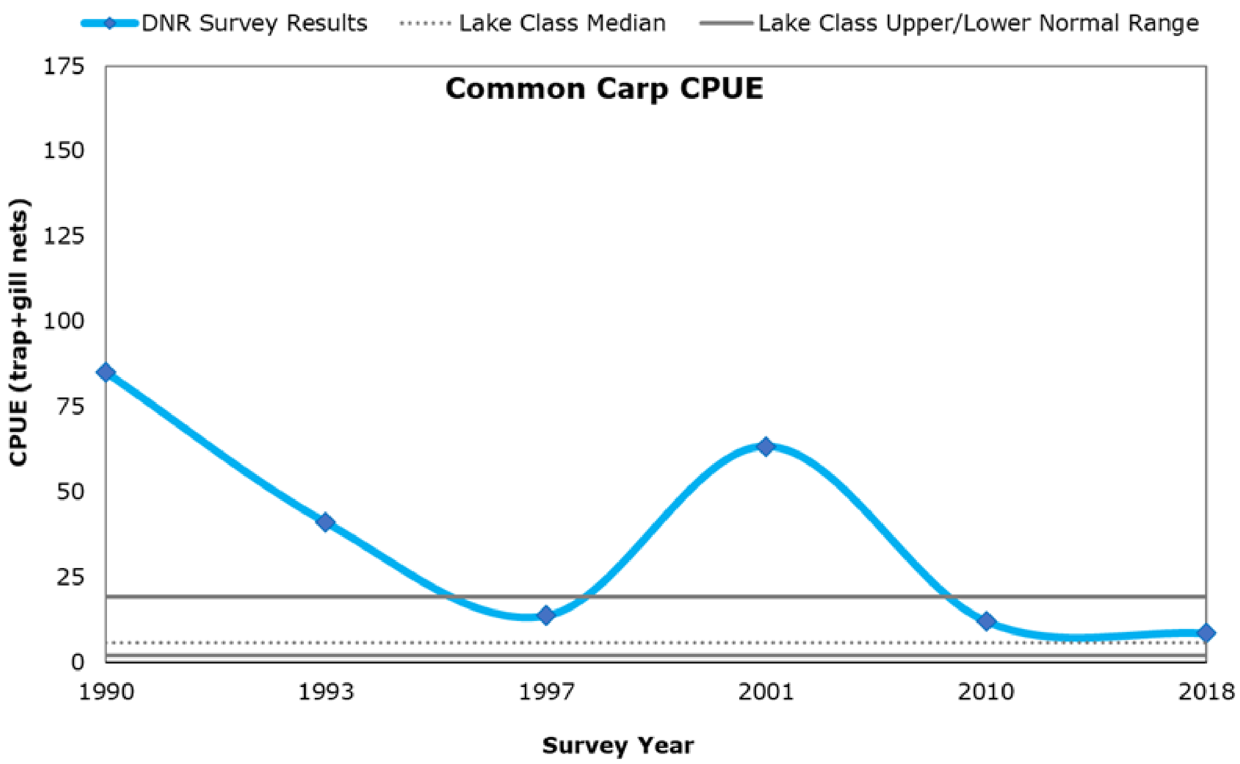


Figure 81. 2018 dissolved oxygen profiles for George Lake.

Appendix C: Common carp data analyses



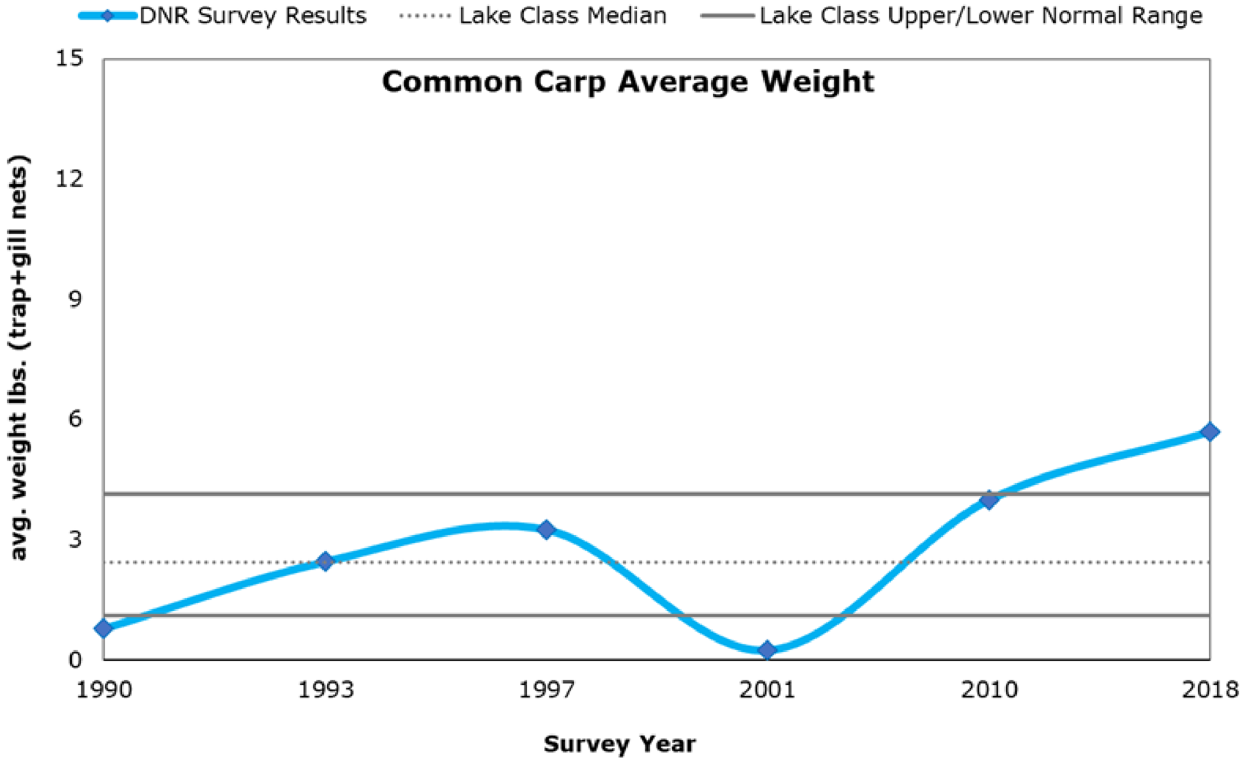


Figure 82. Willmert Lake DNR trap/gill net survey common carp catch per unit effort numbers (top) and average weights from 1990 through 2018.

Notes: The solid gray lines represent the upper and lower normal ranges for lakes of the same lake class. The dotted gray lines represent median lake class values.

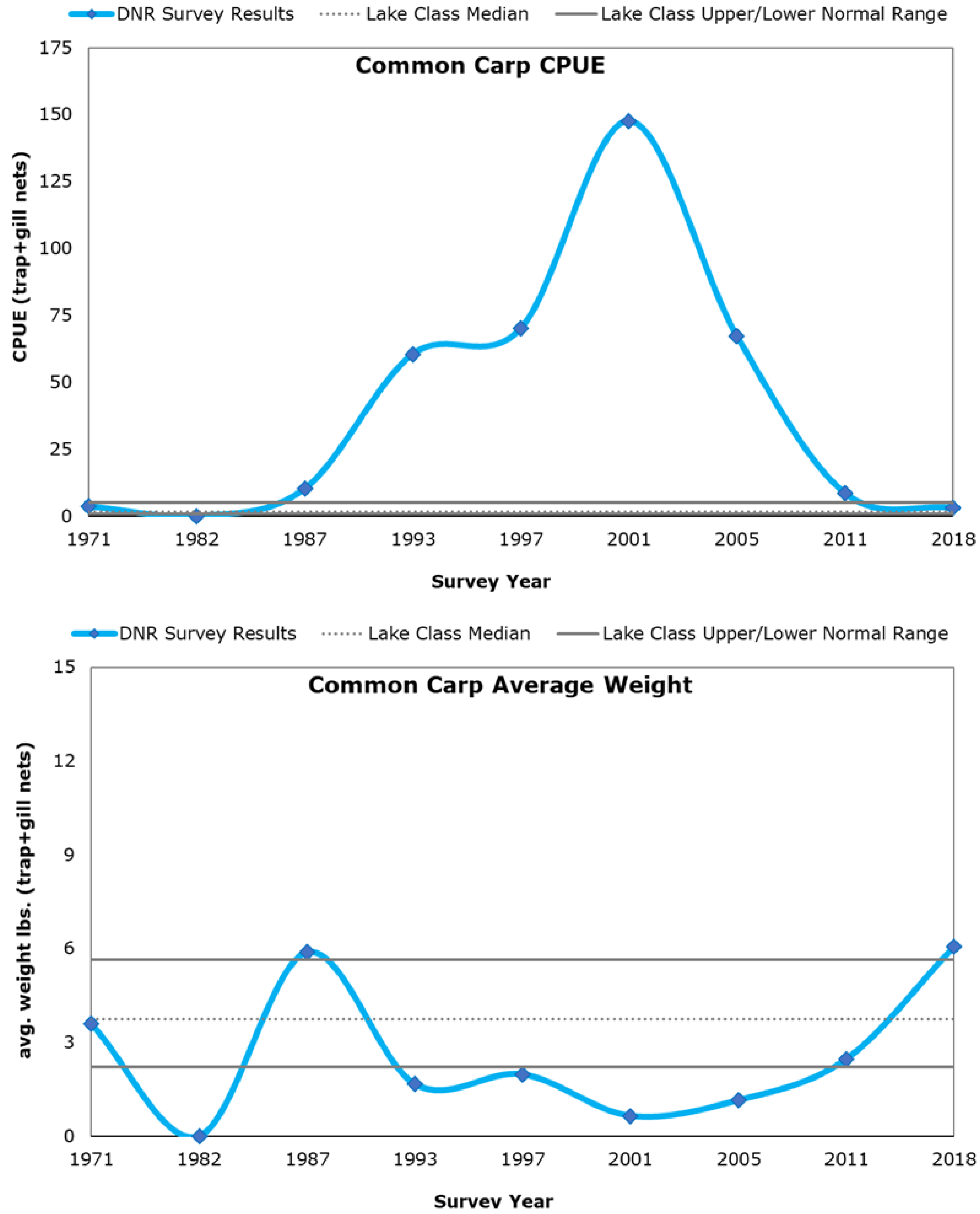
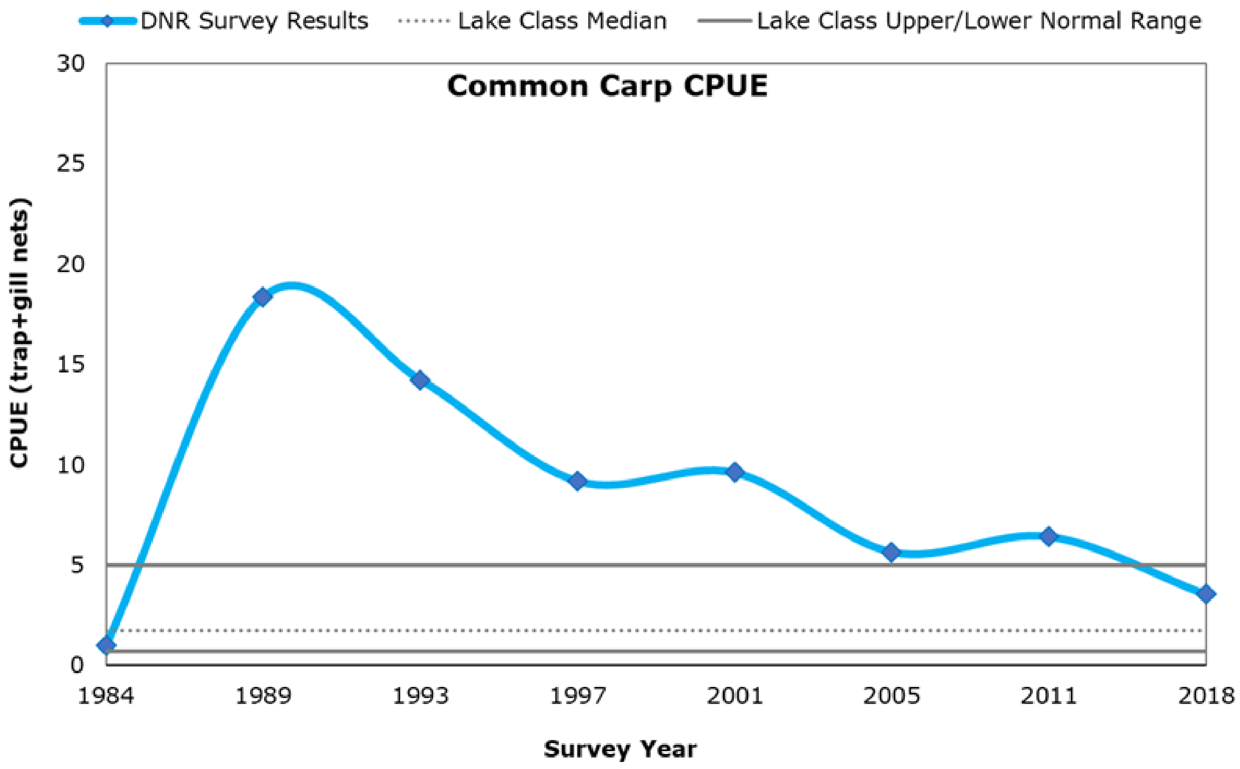


Figure 83. Amber Lake DNR trap/gill net survey common carp catch per unit effort numbers (top) and average weights from 1971 through 2018.

Notes: The solid gray lines represent the upper and lower normal ranges for lakes of the same lake class. The dotted gray lines represent median lake class values.



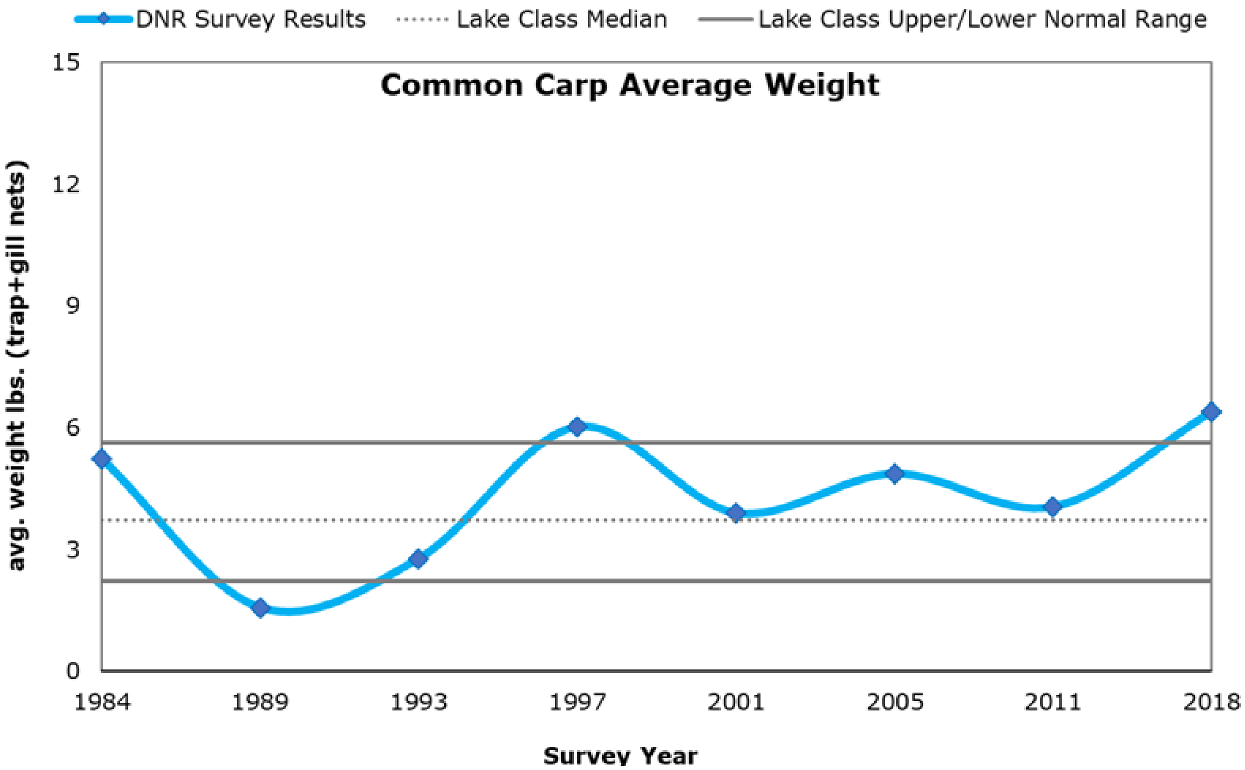
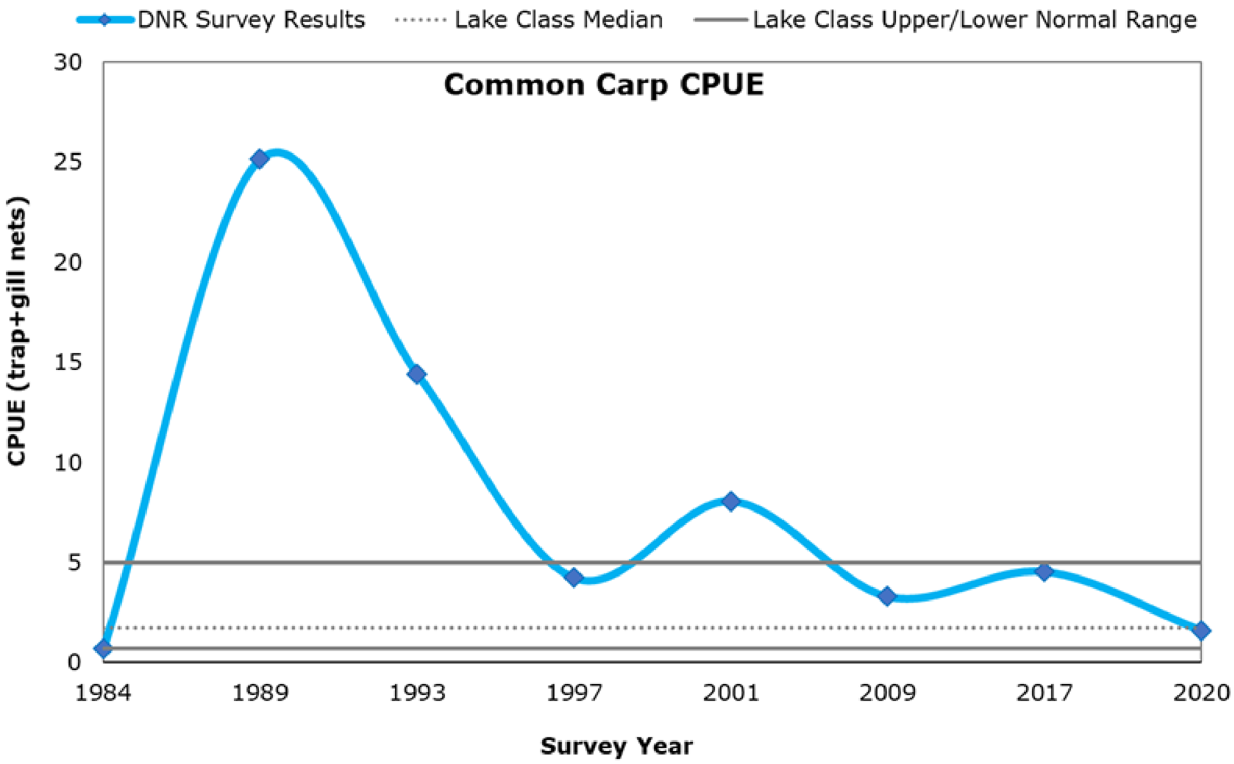


Figure 84. Hall Lake DNR trap/gill net survey common carp catch per unit effort numbers (top) and average weights from 1984 through 2018.

Notes: The solid gray lines represent the upper and lower normal ranges for lakes of the same lake class. The dotted gray lines represent median lake class values.



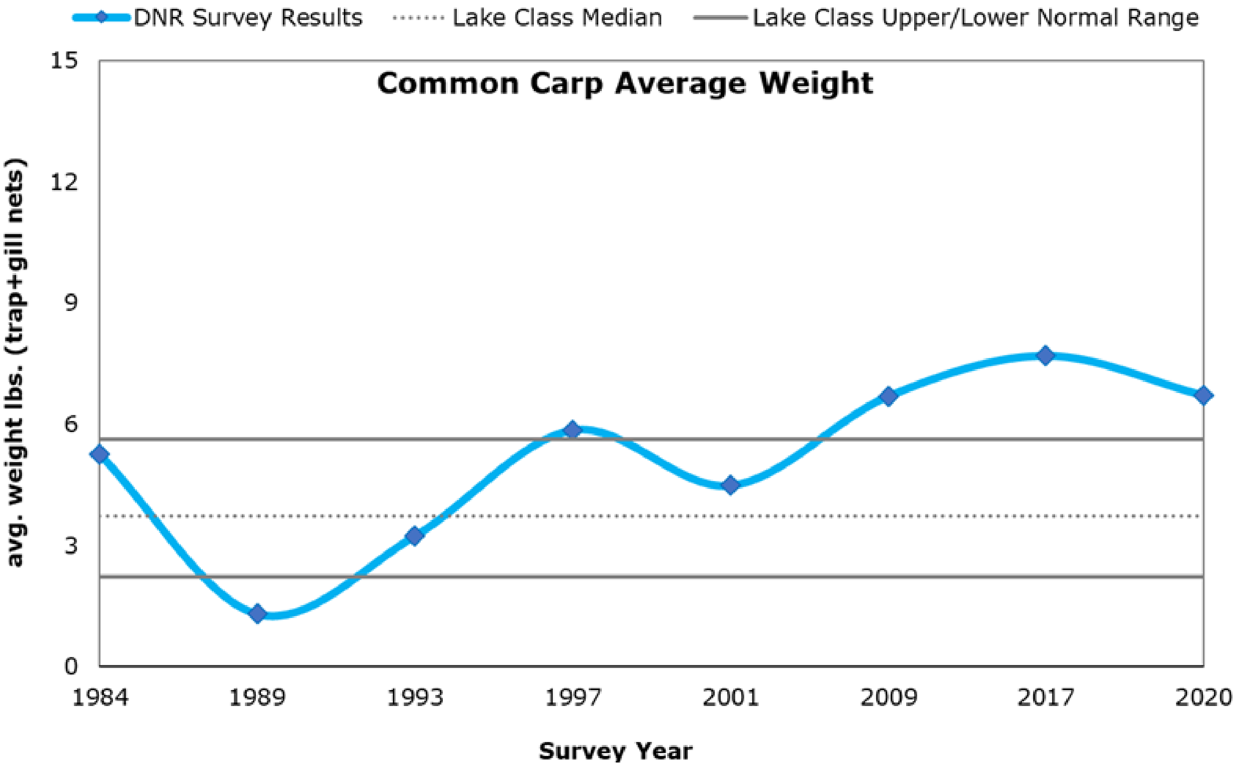


Figure 85. Budd Lake DNR trap/gill net survey common carp catch per unit effort numbers (top) and average weights from 1984 through 2018.

Notes: The solid gray lines represent the upper and lower normal ranges for lakes of the same lake class. The dotted gray lines represent median lake class values.

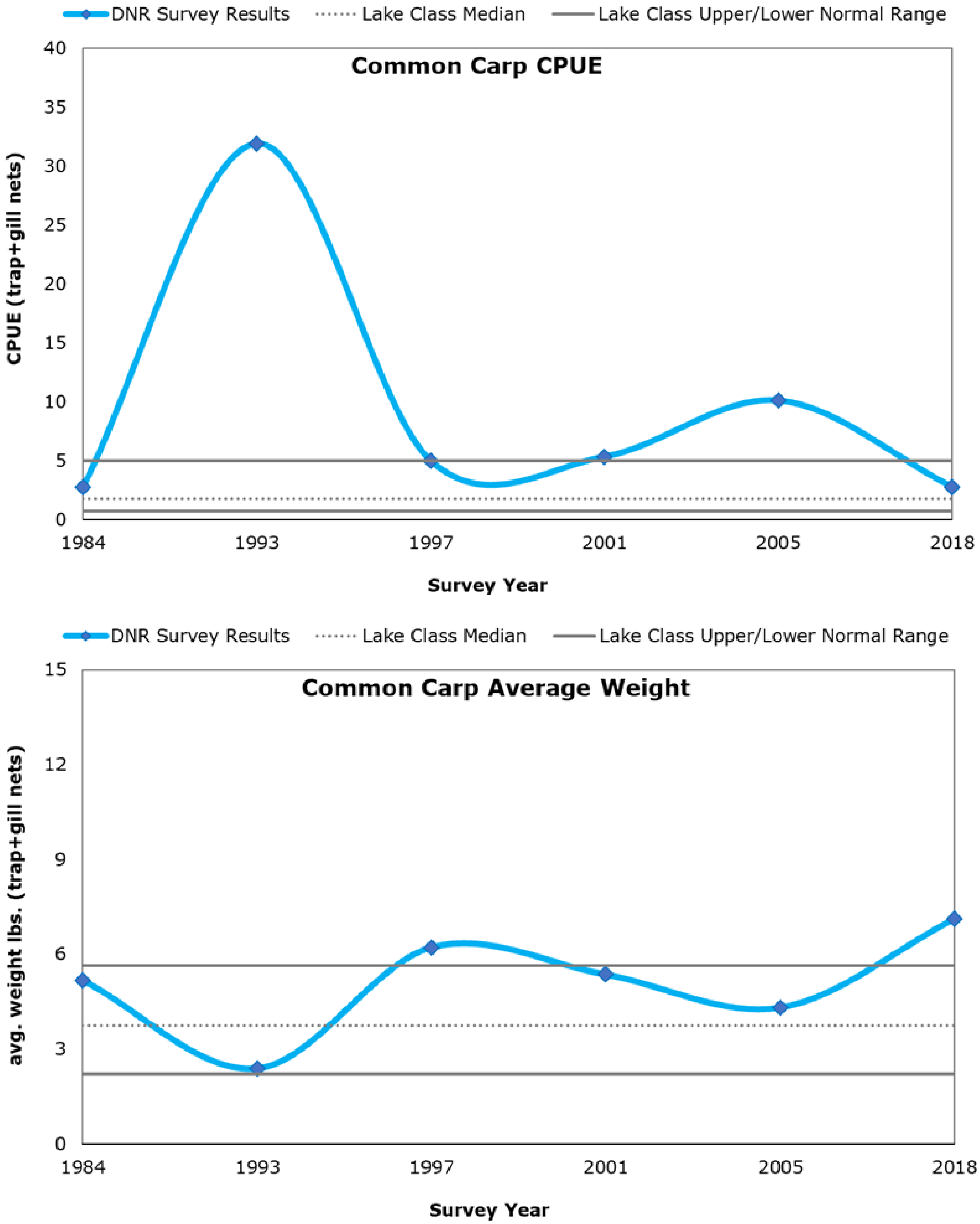
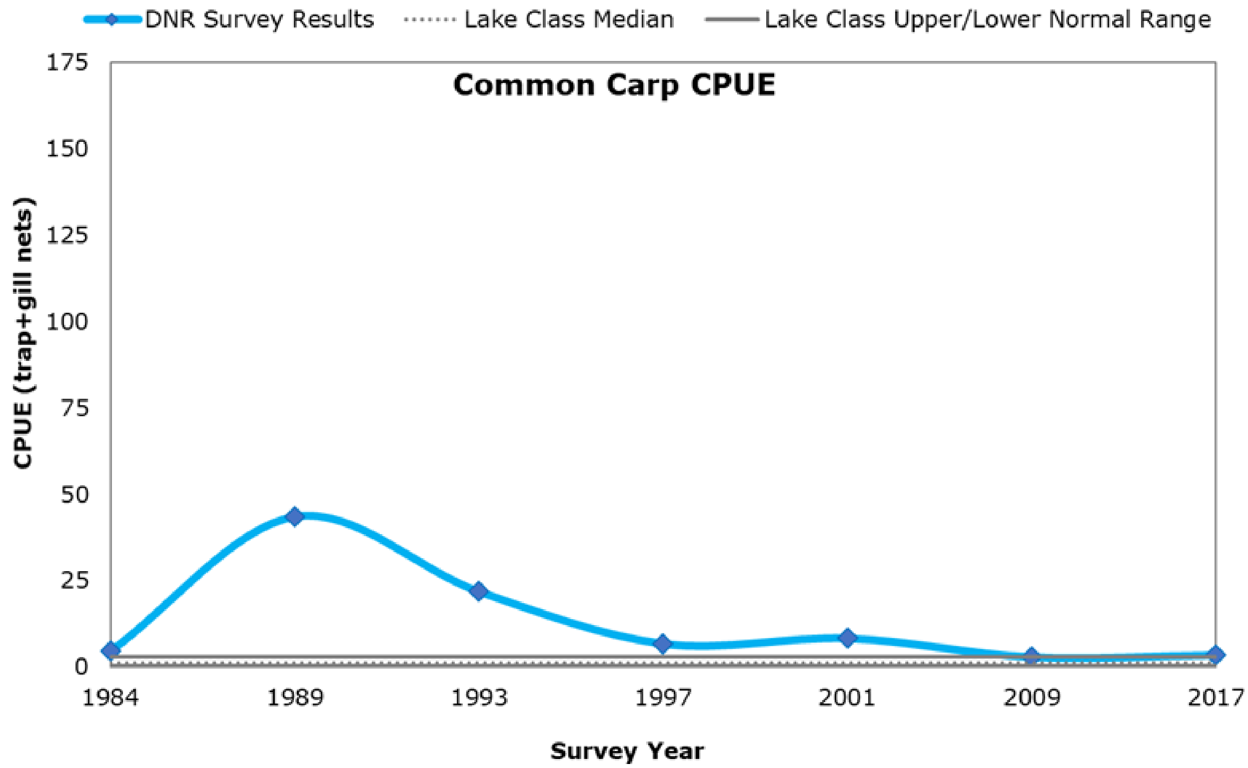


Figure 86. Sisseton Lake DNR trap/gill net survey common carp catch per unit effort numbers (top) and average weights from 1984 through 2018.

Notes: The solid gray lines represent the upper and lower normal ranges for lakes of the same lake class. The dotted gray lines represent median lake class values.



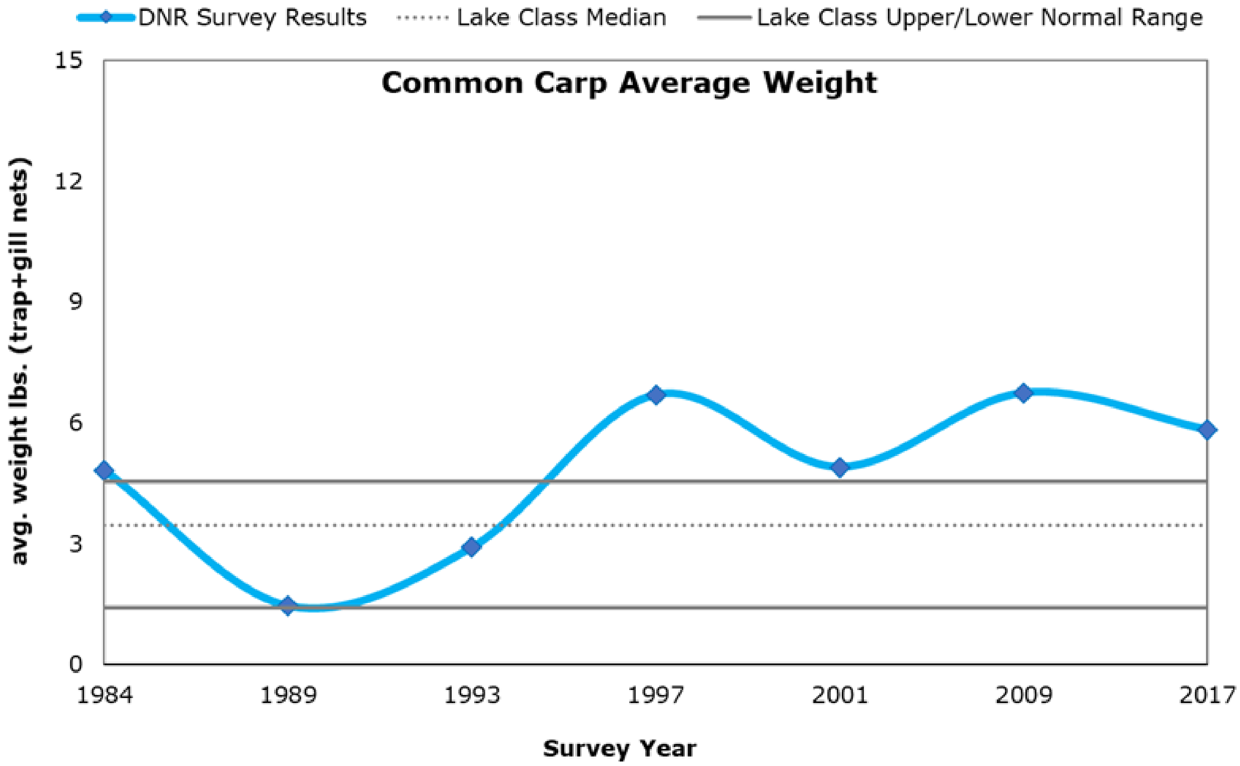


Figure 87. George Lake DNR trap/gill net survey common carp catch per unit effort numbers (top) and average weights from 1984 through 2018.

Notes: The solid gray lines represent the upper and lower normal ranges for lakes of the same lake class. The dotted gray lines represent median lake class values.

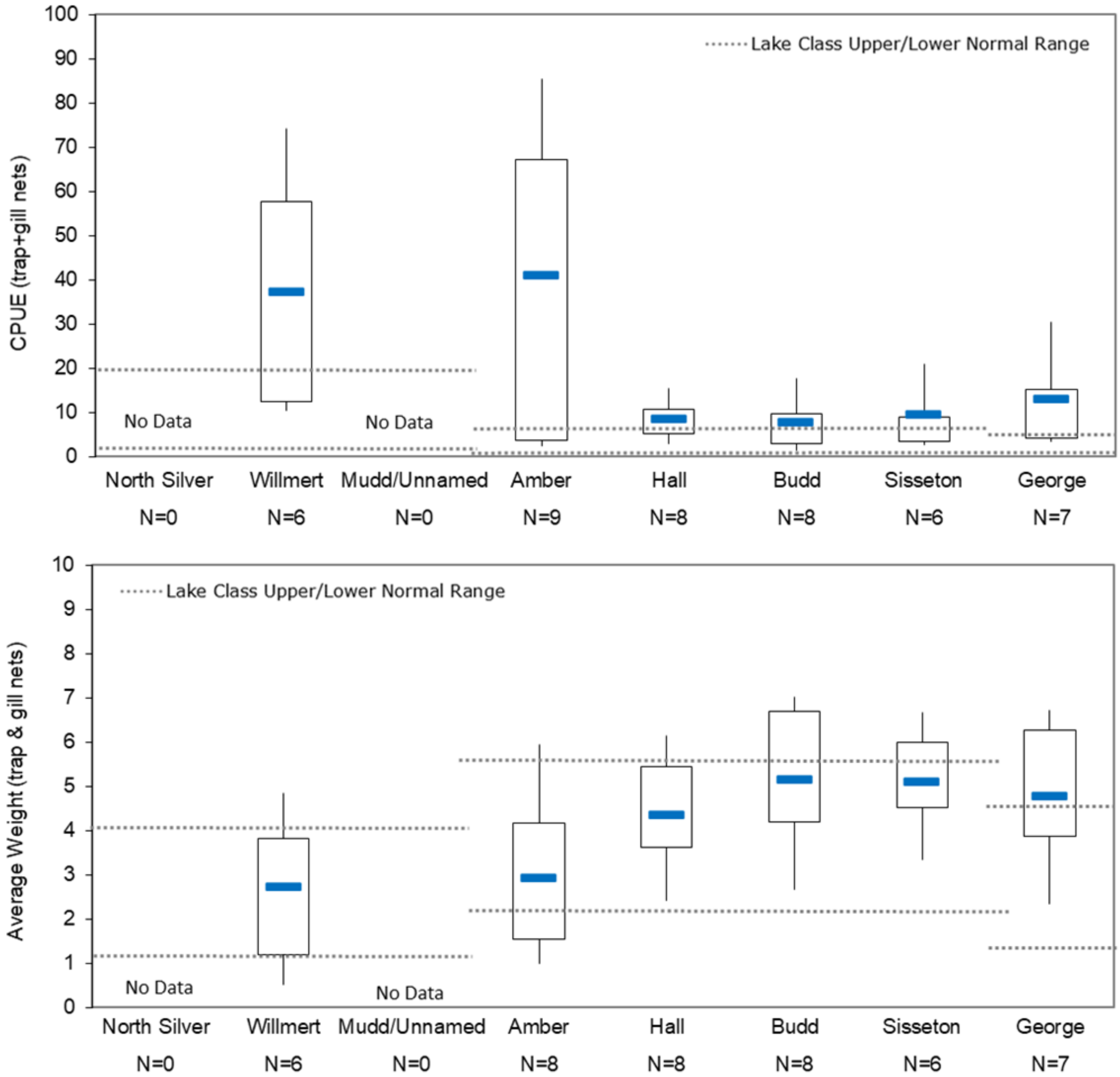


Figure 88. Box plots showing DNR trap/gill net survey common carp catch per unit effort numbers (top) and weights from upstream (left) to downstream (right) for each lake in the Fairmont Chain of Lakes from 1971 through 2018.

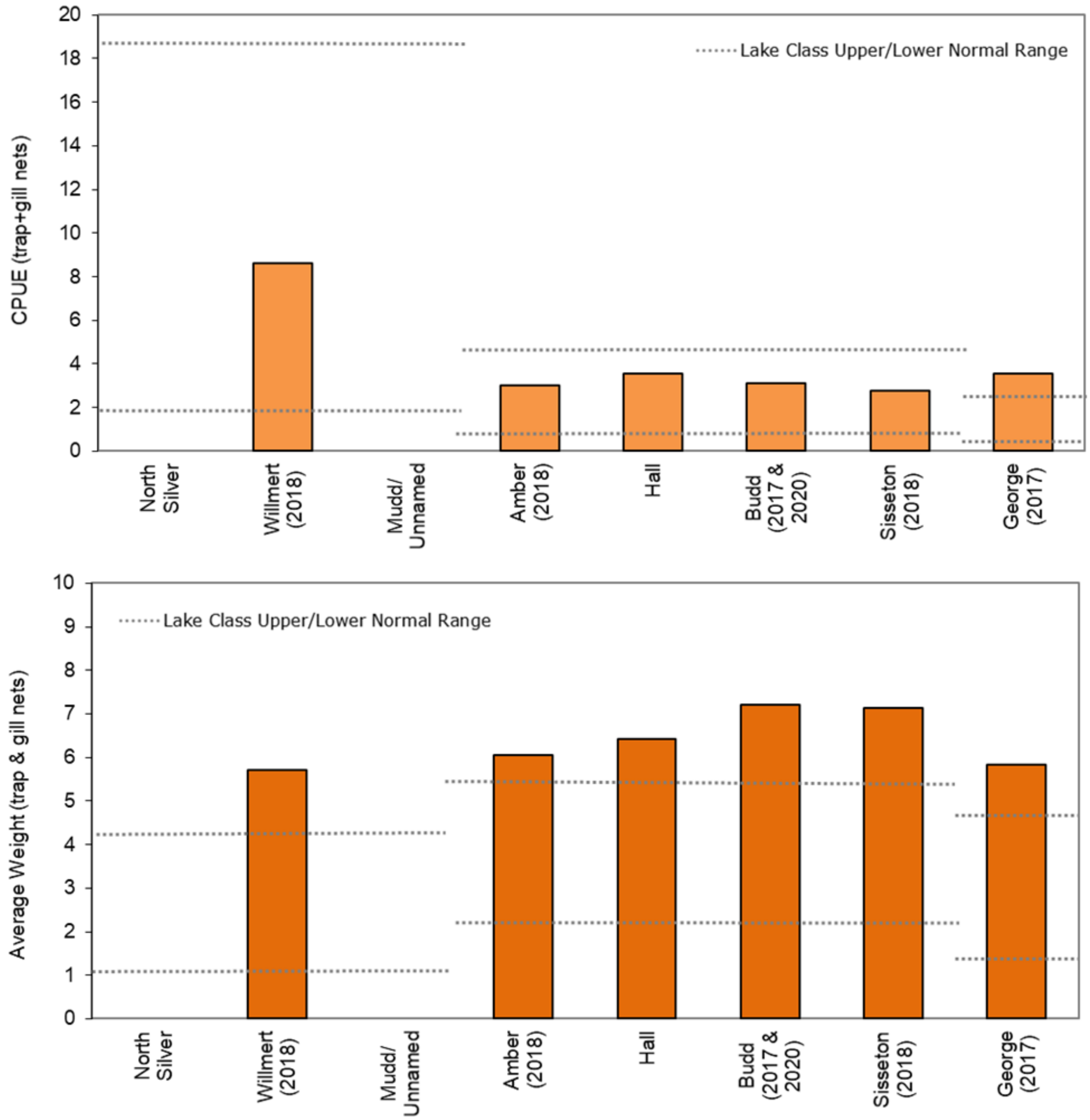


Figure 89. DNR trap/gill net survey common carp catch per unit effort numbers (top) and average weights (bottom) for each lake in the Fairmont Chain of Lakes from the most recent survey (2017, 2018, and/or 2020).

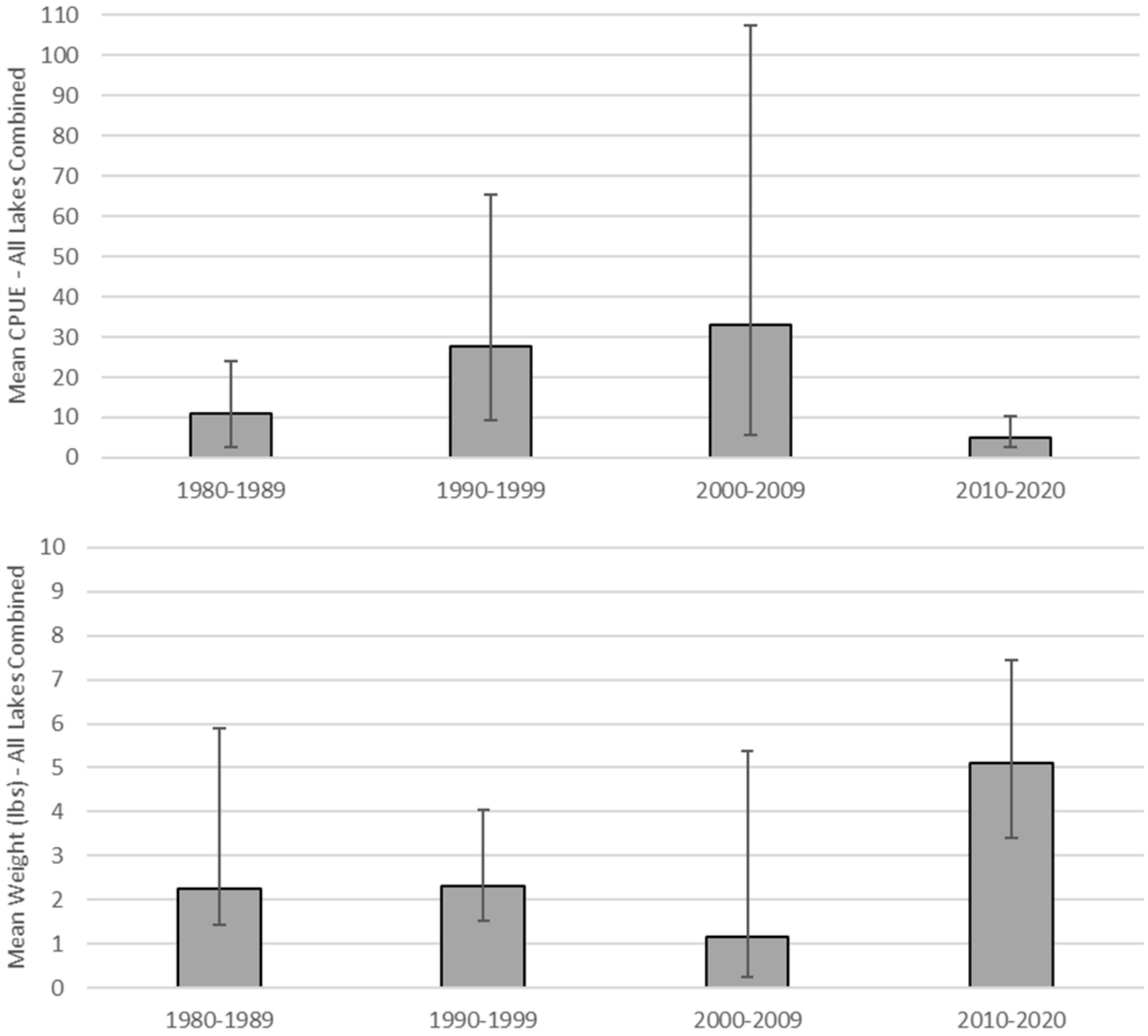


Figure 90. DNR trap/gill net survey common carp catch per unit effort (top) and average weight (bottom) by decade for all lakes (combined) in the Fairmont Chain of Lakes.

Note: gray bars represent the mean value for all lakes and error bars represent the maximum and minimum individual lake values.

Appendix D: BATHTUB lake modeling documentation

A spreadsheet version of the lake model BATHTUB (Walker 1987) was used to model lake phosphorus concentration in each priority lake. See Section 4.1 of this report for more information on the lake modeling. The first table in this appendix presents results of the modeling scenarios used to identify appropriate in-lake and watershed TP targets for the priority lakes (see Section 4.2 of this report for more details). Also included in this appendix are tables showing the BATHTUB model inputs and select outputs for each priority lake.

Table 36. Fairmont Chain of Lakes BATHTUB model scenarios to identify potential TP targets.

Scenario	Scenario conditions	Amber	Hall	Budd	Sisseton	George
Current Conditions (2017–2021)	In-lake TP	107 µg/L	79 µg/L	75 µg/L	85 µg/L	145 µg/L
	Watershed TP	245 µg/L	247 µg/L	298 µg/L	236 µg/L	280 µg/L
	Watershed TP load	4,280 lb/yr	7,154 lb/yr	298 lb/yr	938 lb/yr	184 lb/yr
Scenario 1 (in-lake target = 90 µg/L)	In-lake TP target	Amber and George meet 90 µg/L				
	Watershed TP target	189 µg/L	247 µg/L	298 µg/L	236 µg/L	280 µg/L
	Watershed TP load at target	3,304 lb/yr	7,154 lb/yr	298 lb/yr	938 lb/yr	184 lb/yr
	Watershed TP reduction	23%	0%	0%	0%	0%
	Modeled in-lake TP	90 µg/L	76 µg/L	73 µg/L	83 µg/L	83 µg/L
Scenario 2 (in-lake target = 75 µg/L)	In-lake TP target	All priority lakes meet 75 µg/L				
	Watershed TP target	143 µg/L	247 µg/L	298 µg/L	130 µg/L	28 µg/L
	Watershed TP load at target	2,495 lb/yr	7,154 lb/yr	298 lb/yr	518 lb/yr	18 lb/yr
	Watershed TP reduction	42%	0%	0%	45%	90%
	Modeled in-lake TP	75 µg/L	74 µg/L	72 µg/L	75 µg/L	75 µg/L
Scenario 3 (in-lake target = 65 µg/L)	In-lake TP target	All priority lakes meet 65 µg/L				
	Watershed TP target	114 µg/L	204 µg/L	298 µg/L	88 µg/L	18 µg/L
	Watershed TP load at target	1,983 lb/yr	5,897 lb/yr	298 lb/yr	350 lb/yr	12 lb/yr
	Watershed TP reduction	54%	18%	0%	63%	93%
	Modeled in-lake TP	65 µg/L	65 µg/L	64 µg/L	65 µg/L	65 µg/L
Scenario 4 (in-lake target = 50 µg/L)	In-lake TP target	All priority lakes meet 50 µg/L				
	Watershed TP target	72 µg/L	139 µg/L	241 µg/L	52 µg/L	3 µg/L
	Watershed TP load at target	1,261 lb/yr	4,012 lb/yr	241 lb/yr	208 lb/yr	2 lb/yr

Scenario	Scenario conditions	Amber	Hall	Budd	Sisseton	George
	Watershed TP reduction	71%	44%	19%	78%	99%
	Modeled in-lake TP	50 µg/L	50 µg/L	50 µg/L	50 µg/L	50 µg/L
Scenario 5 (in-lake target = 40 µg/L)	In-lake TP target	All priority lakes meet 40 µg/L				
	Watershed TP target	47 µg/L	100 µg/L	153 µg/L	38 µg/L	0 µg/L
	Watershed TP load at target	812 lb/yr	2,895 lb/yr	153 lb/yr	151 lb/yr	0 lb/yr
	Watershed TP reduction	81%	60%	49%	84%	100%
	Modeled in-lake TP	40 µg/L	40 µg/L	40 µg/L	40 µg/L	40 µg/L

Scenario	Scenario conditions	Amber	Hall	Budd	Sisseton	George
Scenario 6 (Watershed target = 200 µg/L)	In-lake TP target	95 µg/L	70 µg/L	70 µg/L	80 µg/L	95 µg/L
	Watershed TP target	200 µg/L	200 µg/L	200 µg/L	200 µg/L	200 µg/L
	Watershed TP load at target	3,490 lb/yr	5,784 lb/yr	200 lb/yr	795 lb/yr	132 lb/yr
	Watershed TP reduction	18%	19%	33%	15%	28%
	Modeled in-lake TP	93 µg/L	69 µg/L	66 µg/L	78 µg/L	95 µg/L
Scenario 7 (Watershed target = 175 µg/L)	In-lake TP target	90 µg/L	65 µg/L	65 µg/L	75 µg/L	90 µg/L
	Watershed TP target	175 µg/L	175 µg/L	175 µg/L	175 µg/L	175 µg/L
	Watershed TP load at target	3,054 lb/yr	5,061 lb/yr	174 lb/yr	696 lb/yr	115 lb/yr
	Watershed TP reduction	29%	29%	41%	26%	37%
	Modeled in-lake TP	86 µg/L	64 µg/L	62 µg/L	72 µg/L	90 µg/L
Scenario 8 (Watershed target = 150 µg/L)	In-lake TP target	80 µg/L	60 µg/L	60 µg/L	70 µg/L	85 µg/L
	Watershed TP target	150 µg/L	150 µg/L	150 µg/L	150 µg/L	150 µg/L
	Watershed TP load at target	2,617 lb/yr	4,338 lb/yr	150 lb/yr	596 lb/yr	99 lb/yr
	Watershed TP reduction	39%	39%	50%	36%	46%
	Modeled in-lake TP	77 µg/L	57 µg/L	57 µg/L	66 µg/L	85 µg/L
Scenario 9 (Watershed target = 125 µg/L)	In-lake TP target	70 µg/L	55 µg/L	55 µg/L	60 µg/L	
	Watershed TP target	125 µg/L	125 µg/L	125 µg/L	125 µg/L	125 µg/L
	Watershed TP load at target	2,181 lb/yr	3,615 lb/yr	125 lb/yr	497 lb/yr	82 lb/yr
	Watershed TP reduction	49%	49%	58%	47%	55%

Scenario	Scenario conditions	Amber	Hall	Budd	Sisseton	George
	Modeled in-lake TP	69 µg/L	51 µg/L	52 µg/L	59 µg/L	75 µg/L
Scenario 10 (Watershed target = 100 µg/L)	In-lake TP target	60 µg/L	45 µg/L	45 µg/L	50 µg/L	65 µg/L
	Watershed TP target	100 µg/L	100 µg/L	100 µg/L	100 µg/L	100 µg/L
	Watershed TP load at target	1,745 lb/yr	2,892 lb/yr	100 lb/yr	398 lb/yr	66 lb/yr
	Watershed TP reduction	59%	60%	66%	58%	64%
	Modeled in-lake TP	60 µg/L	44 µg/L	43 µg/L	49 µg/L	64 µg/L
Scenario 11 (Optimal watershed target = 183 µg/L)	In-lake TP target	90 µg/L	65 µg/L	65 µg/L	75 µg/L	90 µg/L
	Watershed TP target	183 µg/L	183 µg/L	183 µg/L	183 µg/L	183 µg/L
	Watershed TP load at target	3,193 lb/yr	5,298 lb/yr	183 lb/yr	728 lb/yr	120 lb/yr
	Watershed TP reduction	25%	26%	39%	22%	35%
	Modeled in-lake TP	88 µg/L	65 µg/L	62 µg/L	72 µg/L	90 µg/L

Table 37. Amber Lake BATHTUB model inputs and documentation.

Global variables		
Averaging period (yrs)	0.67	
Precipitation (in/yr)	27.6	
Evaporation (in/yr)	27.6	
Atmospheric TP Load (kg/km^2-yr)	41.7	
Model options		
P balance	CB-Lakes	
P calibration	decay rates	
Model coefficients		
TP	1.05	
TP availability factor	1	
Segment		
Area (ac)	182	
Mean depth (ft)	12.1	
Mean depth of mixed layer (ft)	12.1	
Observed TP (µg/L)	107	
Target TP (µg/L)	90	
TP internal load release rate (mg/m2-d)	0.0	0.0
TP internal load time of release (d)	122	122
Hydraulic residence time (yr)	0.2	
Overflow rate (m/yr)	14.8	
Watershed		
Watershed area (ac)	11,926	
Watershed:lake area	65.5	

Segment mass balance: Baseline	**Flow (hm3/yr)**	**% Flow**	**TP load (lb/yr)**	**% TP load**	**TP concentration (µg/L)**
Precipitation	0.52	5%	67.74	1%	59
Watershed Runoff (Includes upstream lake(s))	10.87	95%	4,889	99%	204
Point	–	–	–	–	–
Internal or Unidentified	–	–	–	–	–
TOTAL IN	11.39	100%	4,957	100%	197
Evaporation	0.52	5%	0	0%	0
Sedimentation/retention			2,382	48%	
Outflow	10.87	95%	2,575	52%	107
TOTAL OUT	11.39	100%	4,957	100%	197
Segment mass balance: Target	**Flow (hm3/yr)**	**% Flow**	**TP load (lb/yr)**	**% TP load**	**TP concentration (µg/L)**
Precipitation	0.52	5%	67.74	2%	59
Watershed Runoff (Includes upstream lake(s))	10.87	95%	3,780	98%	158
Point	–	–	–	–	–
Internal or Unidentified	–	–	–	–	–
TOTAL IN	11.39	100%	3,848	100%	153
Evaporation	0.52	5%	0	0%	0
Sedimentation/retention			1,738	45%	
Outflow	10.87	95%	2,110	55%	88
TOTAL OUT	11.39	100%	3,848	100%	153

Load Reductions	**TP load reduction (lb/yr)**	**% TP reduction**
Precipitation	0	0%
Watershed Runoff (Includes upstream lake(s))	1,109	23%
Point	–	–
Internal or Unidentified	–	–
TOTAL	1,109	22%

Table 38. Hall Lake BATHTUB model inputs and documentation.

Global variables		
Averaging period (yrs)	0.67	
Precipitation (in/yr)	27.6	
Evaporation (in/yr)	27.6	
Atmospheric TP Load (kg/km^2-yr)	41.7	
Model options		
P balance	CB-Lakes	
P calibration	decay rates	
Model coefficients		
TP	1.76	
TP availability factor	1	
Segment		
Area (ac)	548	
Mean depth (ft)	7.8	
Mean depth of mixed layer (ft)	7.8	
Observed TP (µg/L)	78.8	
Target TP (µg/L)	65.0	
TP internal load release rate (mg/m2-d)	0.0	0.0
TP internal load time of release (d)	122	122
Hydraulic residence time (yr)	0.2	
Overflow rate (m/yr)	10.8	
Watershed		
Watershed area (ac)	25,787	
Watershed:lake area	47.1	

Segment mass balance: <u>Baseline</u>	**Flow (hm3/yr)**	**% Flow**	**TP load (lb/yr)**	**% TP load**	**TP concentration (µg/L)**
Precipitation	1.56	6%	203.9	2%	59
Watershed Runoff (Includes upstream lake(s))	24.0	94%	9,734	98%	184
Point	0.01	<1%	1.04	<1%	45
Internal or Unidentified	–	–	–	–	–
TOTAL IN	25.57	100%	9,939	100%	176
Evaporation	1.56	6%	0	0%	0
Sedimentation/retention			5,767	58%	
Outflow	24.01	94%	4,172	42%	79
TOTAL OUT	25.57	100%	9,939	100%	79
Segment mass balance: <u>Target</u>	**Flow (hm3/yr)**	**% Flow**	**TP load (lb/yr)**	**% TP load**	**TP concentration (µg/L)**
Precipitation	1.56	6%	203.9	3%	59
Watershed Runoff (Includes upstream lake(s))	24.0	94%	7,459	97%	141
Point	0.00	<1%	0	0%	0
Internal or Unidentified	–	–	–	–	–
TOTAL IN	25.56	100%	7,663	100%	136
Evaporation	1.56	6%	0	0%	0
Sedimentation/retention			4,223	55%	
Outflow	24.00	94%	3,440	45%	65
TOTAL OUT	25.57	100%	7,663	100%	136

Load Reductions	**TP load reduction (lb/yr)**	**% TP reduction**
Precipitation	0	0%
Watershed Runoff (Includes upstream lake(s))	2,275	23%
Point	1	100%
Internal or Unidentified	–	–
TOTAL	2,276	23%

Table 39. Budd Lake BATHTUB model inputs and documentation.

Global variables		
Averaging period (yrs)	0.67	
Precipitation (in/yr)	27.6	
Evaporation (in/yr)	27.6	
Atmospheric TP Load (kg/km^2-yr)	41.7	
Model options		
P balance	CB-Lakes	
P calibration	decay rates	
Model coefficients		
TP	0.28	
TP availability factor	1	
Segment		
Area (ac)	228	
Mean depth (ft)	12.8	
Mean depth of mixed layer (ft)	12.8	
Observed TP (µg/L)	75.1	
Target TP (µg/L)	61.8	
TP internal load release rate (mg/m2-d)	0.0	0.0
TP internal load time of release (d)	122	122
Hydraulic residence time (yr)	0.1	
Overflow rate (m/yr)	26.5	
Watershed		
Watershed area (ac)	26,538	
Watershed:lake area	116	

Segment mass balance: Baseline	**Flow (hm3/yr)**	**% Flow**	**TP load (lb/yr)**	**% TP load**	**TP concentration (µg/L)**
Precipitation	0.65	3%	84.79	2%	59
Watershed Runoff (Includes upstream lake(s))	24.46	97%	4,468	98%	83
Point	–	–	–	–	–
Internal or Unidentified	–	–	–	–	–
TOTAL IN	25.11	100%	4,553	100%	82
Evaporation	0.65	3%	0	0%	0
Sedimentation/retention			503.1	11%	
Outflow	24.46	97%	4,050	89%	75
TOTAL OUT	25.11	100%	4,553	100%	75
Segment mass balance: Target	**Flow (hm3/yr)**	**% Flow**	**TP load (lb/yr)**	**% TP load**	**TP concentration (µg/L)**
Precipitation	0.65	3%	84.70	2%	59
Watershed Runoff (Includes upstream lake(s))	24.46	97%	3,623	98%	67
Point	–	–	–	–	–
Internal or Unidentified	–	–	–	–	–
TOTAL IN	25.11	100%	3,708	100%	67
Evaporation	0.65	3%	0	0%	0
Sedimentation/retention			376.7	10%	
Outflow	24.46	97%	3,331	90%	62
TOTAL OUT	25.11	100%	3,708	100%	67

Load Reductions	**TP load reduction (lb/yr)**	**% TP reduction**
Precipitation	0	0%
Watershed Runoff (Includes upstream lake(s))	845	19%
Point	–	–
Internal or Unidentified	–	–
TOTAL	845	19%

Table 40. Sisseton Lake BATHTUB model inputs and documentation.

Global variables		
Averaging period (yrs)	0.67	
Precipitation (in/yr)	27.6	
Evaporation (in/yr)	27.6	
Atmospheric TP Load (kg/km^2-yr)	41.7	
Model options		
P balance	CB-Lakes	
P calibration	decay rates	
Model coefficients		
TP	0.10	
TP availability factor	1	
Segment		
Area (ac)	138	
Mean depth (ft)	9.5	
Mean depth of mixed layer (ft)	9.5	
Observed TP (µg/L)	84.8	
Target TP (µg/L)	72.2	
TP internal load release rate (mg/m2-d)	0.0	0.0
TP internal load time of release (d)	122	122
Hydraulic residence time (yr)	0.1	
Overflow rate (m/yr)	47.0	
Watershed		
Watershed area (ac)	28,510	
Watershed:lake area	207	

Segment mass balance: <u>Baseline</u>	**Flow (hm3/yr)**	**% Flow**	**TP load (lb/yr)**	**% TP load**	**TP concentration (µg/L)**
Precipitation	0.39	1%	51.42	1%	59
Watershed Runoff (Includes upstream lake(s))	26.27	99%	4,993	99%	86
Point	–	–	–	–	–
Internal or Unidentified	–	–	–	–	–
TOTAL IN	26.66	100%	5,044	100%	86
Evaporation	0.39	1%	0	0%	0
Sedimentation/retention			131.3	3%	
Outflow	26.27	99%	4,913	97%	85
TOTAL OUT	26.66	100%	5,044	100%	85
Segment mass balance: <u>Target</u>	**Flow (hm3/yr)**	**% Flow**	**TP load (lb/yr)**	**% TP load**	**TP concentration (µg/L)**
Precipitation	0.39	1%	51.42	1%	59
Watershed Runoff (Includes upstream lake(s))	26.27	99%	4,235	99%	73
Point	–	–	–	–	–
Internal or Unidentified	–	–	–	–	–
TOTAL IN	26.66	100%	4,287	100%	73
Evaporation	0.39	1%	0	0%	0
Sedimentation/retention			103.8	2%	
Outflow	26.27	99%	4,183	98%	72
TOTAL OUT	26.66	100%	4,287	100%	72

Load Reductions	**TP load reduction (lb/yr)**	**% TP reduction**
Precipitation	0	0%
Watershed Runoff (Includes upstream lake(s))	785	15%
Point	–	–
Internal or Unidentified	–	–
TOTAL	785	15%

Table 41. George Lake BATHTUB model inputs and documentation.

Global variables		
Averaging period (yrs)	0.67	
Precipitation (in/yr)	27.6	
Evaporation (in/yr)	27.6	
Atmospheric TP Load (kg/km^2-yr)	41.7	
Model options		
P balance	CB-Lakes	
P calibration	decay rates	
Model coefficients		
TP	0.0	
TP availability factor	1	
Segment		
Area (ac)	83	
Mean depth (ft)	5.6	
Mean depth of mixed layer (ft)	5.6	
Observed TP (µg/L)	145.3	
Target TP (µg/L)	90.0	
TP internal load release rate (mg/m2-d)	37.4	8.58
TP internal load time of release (d)	122	122
Hydraulic residence time (yr)	0.02	
Overflow rate (m/yr)	78.9	
Watershed		
Watershed area (ac)	28,938	
Watershed:lake area	349	

Segment mass balance: Baseline	**Flow (hm3/yr)**	**% Flow**	**TP load (lb/yr)**	**% TP load**	**TP concentration (µg/L)**
Precipitation	0.24	1%	30.94	<1%	59
Watershed Runoff (Includes upstream lake(s))	26.57	99%	5,097	60%	87
Point	–	–	–	–	–
Internal or Unidentified			3,381	40%	
TOTAL IN	26.81	100%	8,509	100%	144
Evaporation	0.24	1%	0	0%	0
Sedimentation/retention			0	0%	
Outflow	26.57	99%	8,509	100%	145
TOTAL OUT	26.81	100%	8,509	100%	145
Segment mass balance: Target	**Flow (hm3/yr)**	**% Flow**	**TP load (lb/yr)**	**% TP load**	**TP concentration (µg/L)**
Precipitation	0.24	1%	30.94	<1%	59
Watershed Runoff (Includes upstream lake(s))	26.57	99%	4,464	85%	76
Point	–	–	–	–	–
Internal or Unidentified			776	15%	
TOTAL IN	26.81	100%	5,271	100%	89
Evaporation	0.24	1%	0	0%	
Sedimentation/retention			0	0%	
Outflow	26.57	99%	5,271	100%	
TOTAL OUT	26.81	100%	5,271	100%	90

Load Reductions	**TP load reduction (lb/yr)**	**% TP reduction**
Precipitation	0	0%
Watershed Runoff (Includes upstream lake(s))	633	12%
Point	–	–
Internal or Unidentified	2,605	77%
TOTAL	3,238	38%

Table 42. Fox Lake BATHTUB model inputs and documentation.

Global variables		
Averaging period (yrs)	1	
Precipitation (in/yr)	32.3	
Evaporation (in/yr)	32.3	
Atmospheric TP Load (kg/km^2-yr)	41.7	
Model options		
P balance	2nd order, Available P	
P calibration	decay rates	
Model coefficients		
TP	1.08	
TP availability factor	1.00	
Segment	**Baseline**	**TMDL**
Area (ac)	949	
Mean depth (ft)	10.2	
Mean depth of mixed layer (ft)	0.0	
Observed TP (µg/L)	78	
Target TP (µg/L)	65	
TP internal load release rate (mg/m2-d)	0.0	0.0
TP internal load time of release (d)	122	122
Hydraulic residence time (yr)	4.4	
Overflow rate (m/yr)	0.7	
Watershed		
Watershed area (ac)	12.4	
Watershed:lake area	3.2	

Segment mass balance: Baseline	**Flow (hm3/yr)**	**% Flow**	**TP load (lb/yr)**	**% TP load**	**TP concentration (µg/L)**
Precipitation	3.15	54%	353.0	18%	51
SSTS	0.02	0%	110.9	6%	2642
Watershed Runoff total	2.70	46%	1483.9	76%	249
Point	0.00	0%	0.0	0%	
Internal or Unidentified	--	--	0.0	0%	
TOTAL IN	5.87	100%	1947.9	100%	150
Evaporation	3.15	54%	0.0	0%	0
Sedimentation/retention			1479.7	76%	
Outflow	2.72	46%	468.1	24%	78
TOTAL OUT	5.87	100%	1947.9	100%	
Segment mass balance: Target	**Flow (hm3/yr)**	**% Flow**	**TP load (lb/yr)**	**% TP load**	**TP concentration (µg/L)**
Precipitation	3.15	54%	353.0	25%	51
SSTS	0.02	0%	104.9	7%	2498
Watershed Runoff total	2.70	46%	959.8	68%	161
Point	0.00	0%	0.0	0%	
Internal or Unidentified			0.0	0%	
TOTAL IN	5.87	100%	1417.7	100%	110
Evaporation	3.15	54%	0.0	0%	0
Sedimentation/retention			1027.6	72%	
Outflow	2.72	46%	390.1	28%	65

TOTAL OUT	5.87	100%	1417.7	100%	

<u>Load Reductions</u>	**TP load reduction (lb/yr)**	**% TP reduction**
Precipitation	0.00	0%
SSTS	6.03	5%
Watershed Runoff total	524.13	35%
Point	0.00	
Internal or Unidentified	0.00	
TOTAL	530.16	27%

Table 43. Big Twin Lake BATHTUB model inputs and documentation.

Global variables		
Averaging period (yrs)	1	
Precipitation (in/yr)	32.3	
Evaporation (in/yr)	32.3	
Atmospheric TP Load (kg/km^2-yr)	41.7	
Model options		
P balance	CB-Lakes	
P calibration	decay rates	
Model coefficients		
TP	0.88	
TP availability factor	1	
Segment	**Baseline**	**TMDL**
Area (ac)	461	
Mean depth (ft)	6.9	
Mean depth of mixed layer (ft)	0.0	
Observed TP (µg/L)	54	
Target TP (µg/L)	65	
TP internal load release rate (mg/m2-d)	0.0	0.0
TP internal load time of release (d)	122	122
Hydraulic residence time (yr)	7.0	
Overflow rate (m/yr)	0.3	
Watershed		
Watershed area (ac)	2.8	
Watershed:lake area	1.48	

Segment mass balance: <u>Baseline</u>	**Flow (hm3/yr)**	**% Flow**	**TP load (lb/yr)**	**% TP load**	**TP concentration (µg/L)**
Precipitation	1.53	73%	171.4	35%	51
SSTS	0.00	0%	21.7	4%	2642
Watershed Runoff total	0.56	27%	294.9	60%	240
Point	0.00	0%	0.0	0%	
Internal or Unidentified			0.0	0%	
TOTAL IN	2.09	100%	488.0	100%	106
Evaporation	1.53	73%	0.0	0%	0
Sedimentation/retention			421.2	86%	
Outflow	0.56	27%	66.8	14%	54
TOTAL OUT	2.09	100%	488.0	100%	
Segment mass balance: <u>Target</u>	**Flow (hm3/yr)**	**% Flow**	**TP load (lb/yr)**	**% TP load**	**TP concentration (µg/L)**
Precipitation	1.53	73%	171.4	48%	51
SSTS	0.00	0%	20.5	6%	2498
Watershed Runoff total	0.56	27%	165.7	46%	135
Point	0.00	0%	0.0	0%	
Internal or Unidentified			0.0	0%	
TOTAL IN	2.09	100%	357.6	100%	78
Evaporation	1.53	73%	0.0	0%	0
Sedimentation/retention			302.3	85%	
Outflow	0.56	27%	55.3	15%	45
TOTAL OUT	2.09	100%	357.6	100%	

Load Reductions	**TP load reduction (lb/yr)**	**% TP reduction**
Precipitation	0.0	0%
SSTS	1.2	5%
Watershed Runoff total	129.2	44%
Point	0.0	
Internal or Unidentified	0.0	
TOTAL	130.4	27%