technical memo

Project Name	3-006-F Watershed Management Plan Update	**Date**	9-16-2019 Revised on 11-13-2019
To / Contact info	CLFLWD Board of Managers		
Cc / Contact info	Mike Kinney, District Administrator		
From / Contact info	Meghan Funke, PhD, PE		
Regarding	Lake and Stream Water Quality Trends		

[This memo was revised on November 13, 2019 based on feedback received from the CLFLWD Board of Managers during the September 26, 2019 Regular Board meeting and the November 6, 2019 Board workshop. All revisions are underlined.]

In conjunction with the 2019 Watershed Management Plan (WMP) major amendment, EOR conducted an update of the 2017 comprehensive review of the District's historic water quality monitoring data with data collected by the District through 2018. The purpose of this review is to:

- Identify long-term trends in lake and stream water quality
- Determine progress towards District water quality goals
- Inform future monitoring
- Assess the need to update lake goals in the WMP

This memo summarizes the results and conclusions from the comprehensive review update for data collected by the District through 2018, with lakes and streams discussed separately.

There are four main types of stream and lake monitoring:

- Baseline monitoring: regularly scheduled monitoring of a water body (e.g., two or three times per month) to determine if water quality standards are being met and identify seasonal trends in water quality.
- Legacy or trend monitoring: baseline monitoring that occurs annually over a long period of time (at least 10 years) to determine statistical trends in water quality.
- Load/Effectiveness monitoring: targeted monitoring of a water body (e.g., following rain events) to determine whether a practice or combination of practices result in pollutant load reductions.
- Biological monitoring: monitoring of the composition of the biological community in a water body (e.g. Indices of Biological Integrity) to determine the overall environmental condition of a water body.

Stream Water Quality Data

The 2012 Comprehensive Monitoring Plan recommended that stream water quality monitoring include:

- Legacy site monitoring to determine long-term trends in pollutant loads
- Effectiveness monitoring of District projects

Parameters of interest for stream water quality include flow, phosphorus load, and phosphorus flow-weighted mean concentration. Total flow and phosphorus loads are most influenced by the amount and timing of precipitation, in addition to changes in land use and implementation of best management practices (BMPs). Flow weighted mean concentrations are determined as the total load divided by the total flow, which normalizes phosphorus loads to changes in flow. That is to say, during wet years, phosphorus loads may be higher due to overall higher watershed runoff and flows, even without any significant changes in land use or BMP implementation. In this way, flow weighted mean phosphorus concentrations are better indicators of watershed changes, such as land use changes or implementation of BMPs, than total phosphorus loads. Only data collected by the Washington Conservation District since 2004 are analyzed in this review to maintain consistency in laboratory and collection methods for purposes of long-term trend analyses.

Data Availability

The District has 6 legacy monitoring sites: 3 at lake outlets (Bone, Forest, and Comfort) and 3 at lake inlet tributaries (Bone, Little Comfort, and Comfort). Eight other sites have been monitored for several years but not continuously. Of these other eight sites, Bixby Park and County Line Ditch have the most years of monitoring data (4 and 6 years, respectively).

All phosphorus load, phosphorus flow-weighted mean concentration, annual flow, and runoff depth data available for all stream monitoring sites are summarized in Table 6 through Table 9 at the end of the memo, and illustrated for all sites in Attachment A.

Monthly gridded precipitation for the District is summarized in Figure 1. The average total annual rainfall between 1981 and 2010 was 31 inches per year. Wet rainfall years included 2007, 2010, and 2014-2016, and 2018. Below average rainfall years included 2006, 2008, 2009, and 2011.

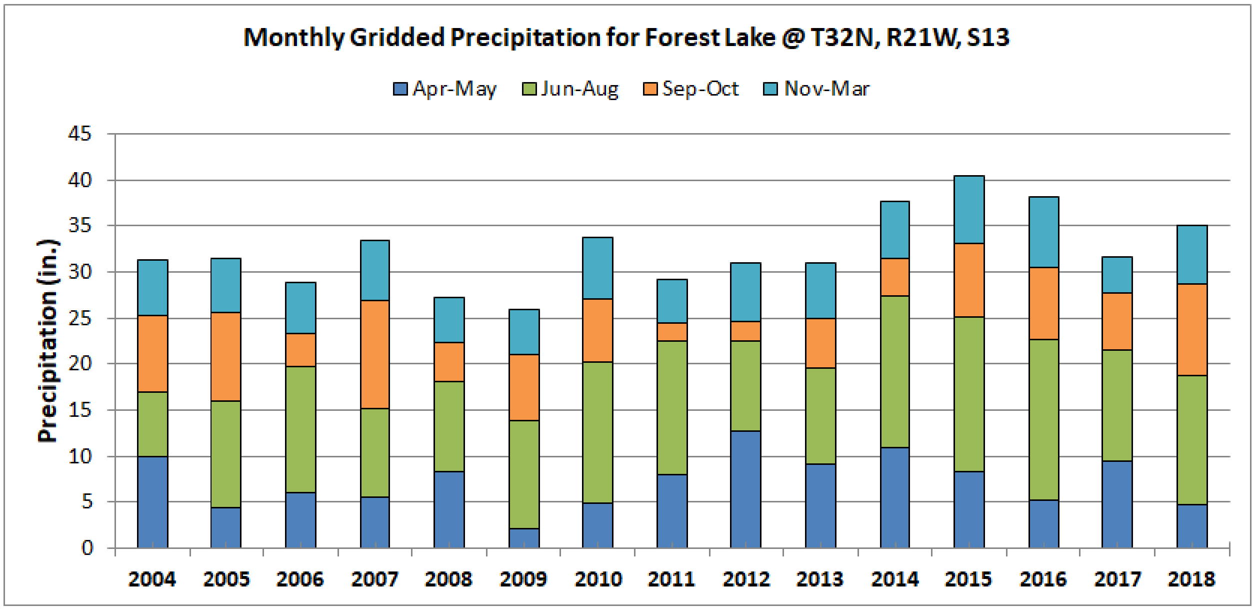

Figure 1. Monthly Gridded Precipitation for Forest Lake at Township 32N, Range 21W, Section 13

Trends in Stream Water Quality

Overall, stream flow and phosphorus loads are variable without any clear trends. Moreover, the year to year variability in stream flow and load is not always correlated to precipitation. This may be due in part to the numerous lakes and wetlands located in the landscape that can alter stream flows and loads through year-to-year variability in infiltration, evapotranspiration, and phosphorus sedimentation or release. These variables make it difficult to correlate changes in stream flow and load to land use changes or BMP implementation. For each monitoring station, the following information is summarized in Table 1 below:

- **Years of Data:** Number of years of data collected between 2004 and 2018, including the data range
- **TP FWMC:** The minimum and maximum annual total phosphorus (TP) flow-weighted mean concentration (FWMC) measurements. FWMC is calculated as the total annual load divided by the total annual flow. The TP FWMC indicates how much phosphorus is discharged relative to the flow. The FWMC tends to have a greater impact on lake water quality than the total phosphorus load. The state lake water quality standards for deep lakes in the North Central Hardwood Forests region of 40 µg/L can typically be met when watershed runoff TP FWMC are less than 100 µg/L. For example, if the TP load and flow both increase to a lake, resulting in a similar TP FWMC, the higher TP load will have less impact on lake water quality because the time the load spends in the lake decreases under higher flows (water flows in and out of the lake faster).
- **TP Load:** The minimum and maximum annual total phosphorus (TP) loads. Higher TP loads may represent more precipitation or more phosphorus load sources compared to lower TP loads.
- **Flow:** The minimum and maximum annual flow measurements. Higher stream flows may represent more precipitation or more runoff generated by precipitation due to greater imperviousness or drainage in a watershed.
- **Runoff Depth:** The depth of the total flow if it were evenly distributed across the monitoring site drainage area. Runoff depth normalizes stream flow to annual precipitation. Higher runoff depth may represent more runoff generated by precipitation due to greater imperviousness or drainage in a watershed.
- **TP FWMC Rating**: A rating of TP FWMC into Low, Moderate, or High concentration categories based on the criteria in the Rating Keys for Table 1 below.
- **Load Variability**: A rating of the variability of TP Load into Low, Moderate, or High variability categories based on the criteria in the Rating Keys for Table 1 below.
- **Observations:** General observations regarding TP FWMC concentrations and variability. Note that these observations are not based on statistical trend analyses.

Rating Keys for Table 1:

TP FWMC Rating Key:

Low: < 100 µg/L
(below background levels)

Moderate: 100-200 µg/L
(just above background levels)

High: > 200 µg/L
(potential hotspot where
projects could be targeted)

Load Variability Key:
Based on maximum ÷ minimum load

Low: 2 or less
(maximum is double the minimum at most)

Moderate: 2-10

High: greater than 10
(an order of magnitude difference)

Future Stream Monitoring Recommendations

1. There is potential to shift some monitoring program budget from stream legacy monitoring to a regular rotation of effectiveness monitoring within Lake Districts due to:
    - recent, successful use of targeted tributary monitoring within individual lake Districts for diagnostic study, implementation planning, and grant applications;
    - potential for new technologies (IORodeo phosphorus testing and DIY remote loggers) to expand the geographic scope of effectiveness monitoring;
    - the need to develop a consistent effectiveness monitoring program for completed projects within the District;
    - the use of in-lake monitoring is a direct and efficient way to assess progress towards the District lake-based goals; and
    - trends in stream loading confounded by weather variability and the influences of phosphorus sedimentation or recycling within lakes and wetlands in a depressional landscape.
2. The existing six stream legacy monitoring sites provide long-term flow records needed to calibrate H&H models used by the District for planning and BMP design.
3. If any changes in monitoring techniques are proposed, the old and new techniques should both be used over a period of 2-3 years to establish a statistical relationship between monitoring results produced from the old and new techniques. The statistical relationship is needed to maintain the continuity of long-term monitoring data records in the District.

Table 1. Stream water quality monitoring station data summary and observed trends

Location	Years of Data		Monitoring Data Range				TP FMWC Rating	TP Load Variability	Observations
	#	Range	TP FWMC (µg/L)	TP Load (lb/yr)	Annual Flow (ac-ft/yr)	Runoff Depth (in/yr)			
Bone Lake North Inlet	11	2005-2018	116 – 524	53 – 917	126 – 1,134	0.6 – 5.5	Moderate to High	High	Increasing TP FWMC in 2010-13, decreasing TP FMWC in 2013-17
Bone Lake South Inlet	2	2005-2006	161 – 232	229 – 231	363 – 528	5.7 – 8.3	Moderate	Low	<3 years of data
Bone Lake Outlet	9	2004-2018	25 – 82	49 – 652	539 – 4,356	1.2 – 9.5	Low	High	Consistently low TP FWMC
Sunrise R Trib @ Manning Tr	2	2008-2009	129 – 148	104 – 508	258 – 1,451	0.4 – 2.4	Moderate	Moderate	<3 years of data
Sunrise R Trib @ July Ave	2	2008-2009	85 – 89	151 – 431	623 – 1,858	0.9 – 2.8	Low	Moderate	<3 years of data
Little Comfort Lake Inlet	15	2004-2018	43 – 188	191 – 1,551	721 – 8,268	0.8 – 9.4	Low to Moderate	Moderate	TP FWMC < 100 ug/L and variable since 2010
FL44 Drainage	1	2015	79	85	395	6.0	Low	Low	<3 years of data
Shields Lake Outlet	2	2005-2006	244 – 299	332 – 420	408 – 634	5.9 – 9.2	High	Low	<3 years of data
Forest Lake Outlet	14	2004-2018	15 – 85	43 – 1,828	716 – 18,744	1.0 – 25.8	Low	High	Consistently low TP FWMC
Bixby Park	4	2009-2012	120 – 311	158 – 973	484 – 1,151	7.8 – 18.5	Moderate to High	Moderate	Higher TP FWMC in 2012 than 2009-11
County Line Ditch	6	2007-2012	19 – 116	85 – 1,792	1,634 – 8,642	2.0 – 10.6	Low to Moderate	High	Variable TP FWMC
Heims Lake Drainage	3	2012-2014	185 – 934	330 – 495	130 – 743	2.3 – 13.4	Moderate to High	Low	Consistently high TP FWMC
Greenway Avenue	5	2008-2018	79 – 389	1,505 – 6,370	5,315 – 11,103	5.9 – 12.3	Low to High	Moderate	Higher TP FWMC in 2012
256th Street	1	2018	69	1,978	10,616	n/a	Low		<3 years of data
Comfort Lake Inlet	15	2004-2018	47 – 185	547 – 2,880	2,469 – 11,939	2.2 – 10.4	Low to Moderate	Moderate	TP FWMC < 100 ug/L except 2006
Comfort Lake Outlet	14	2004-2018	18 – 80	134 – 2,129	1,401 – 19,894	0.7 – 9.7	Low	High	Consistently low TP FWMC

Lake Water Quality

Lake water quality monitoring data is collected by the District to measure progress towards achieving the District water quality goals and the State lake water quality standards. Ten lakes have District goals for phosphorus (Table 3) and Secchi transparency (Table 4), and 14 lakes have enough data within the last 10-years to be assessed against State lake water quality standards (Table 5). Note that District goals are based on 5-year summer averages while State water quality standards are based on 10-year summer averages.

Data Availability

Water quality data have been collected from District lakes for the last 32 years (since 1986). All summer average total phosphorus, chlorophyll-a, and Secchi depth data available for the lakes are summarized in Table 10 through Table 12 at the end of the memo, and growing season average annual phosphorus concentrations and Secchi depths are illustrated for the major lakes in Attachment B. Bone, Comfort, Forest (West Basin), Shields, and Keewhatin Lakes have the longest monitoring record, with more than 20 years of data. Forest (Middle Basin), Forest (East Basin), Moody, and Little Comfort Lakes have the next longest monitoring record, with 10-15 years of data. The rest of the lakes have 6 years of data or less.

Lake Water Quality Trends

Trends in lake water quality data are summarized for each lake as part of the annual CLFLWD Water Monitoring Report contracted by the Washington Conservation District. Lake water quality trends from Table 18 in the 2018 CLFLWD Water Monitoring Report are shown in Table 2 below. Trends are based on the Kendall's Tau statistical analysis which essentially reports how consistently a water quality parameter (such as TP or Secchi) increases or decreases over time. No trend means that it the parameter isn't consistently increasing or decreasing from year to year. The analysis does not measure how much the parameter is changing over time – this can be inferred from the long-term data record. Bone and Moody Lakes have improving (decreasing) phosphorus concentration trends; Bone and Comfort Lakes have improving (decreasing) chlorophyll-a trends; and Shields Lake has declining (increasing) chlorophyll-a trend and declining (decreasing) Secchi depth trend. Eleven lakes do not have enough monitoring data to determine long-term trends in water quality, and all three basins of Forest Lake have no trend in (unchanging) water quality.

Table 2. Lake Water Quality Trends (Table 18 from the 2018 CLFLWD Water Monitoring Report by WCD)

Since 2016, the trend analyses criteria for missing values was strengthened and reflected in the updated trend results reported in the table below from the 2018 CLFLWD Water Monitoring Report)

Lake	Acres	Secchi Disk Trend	Chlorophyll-a Trend	Total Phosphorus Trend
Birch	33	NA	NA	NA
Bone	221	No Trend	Improving	Improving
Comfort	218	No Trend	Improving	No Trend
Forest (West)	1,086	No Trend	NA	No Trend
Forest (Middle)	364	No Trend	NA	No Trend

Lake	Acres	Secchi Disk Trend	Chlorophyll-a Trend	Total Phosphorus Trend
Forest (East)	790	No Trend	No Trend	No Trend
Fourth	8	NA	NA	NA
Heims	90	NA	NA	NA
Keewahtin	75	NA	NA	NA
Lendt	42	NA	NA	NA
Little Comfort	36	NA	NA	NA
Moody	45	No Trend	No Trend	**Improving**
Nielsen	37	NA	NA	NA
Second	75	NA	NA	NA
School	47	NA	NA	NA
Sea	50	NA	NA	NA
Shields	30	**Declining**	**Declining**	No Trend
Third	42	NA	NA	NA

NA = not enough data available to determine a long-term trend in water quality

Progress towards District Goals

Progress of lakes towards achieving their respective District 2020, 2030, and 2040 goals are shown for phosphorus in Table 3 and for Secchi depth in Table 4. The lakes are listed in order of increasing in-lake phosphorus concentration, and therefore, in order of progress towards achieving their respective District goals, from closest to furthest. Keewhatin Lake currently meets its 2040 District goal; Bone, Comfort and Forest Lakes currently meet the 2020/2030 District goals from Table 1 of the 2012-2021 Watershed Management Plan.

Based on the fact that Bone, Comfort and Forest Lakes currently meet the 2030 District goals for TP, the Lake Associations requested slight reductions to the 2030 District goals (more stringent) during the 2017 Watershed Management Plan minor amendment (proposed as shown in Table 3 and Table 4). Note that the TP and Secchi District goals are based on scientifically based relationships between lake clarity responses to TP concentrations (Figure 2). For example, a growing season average in-lake phosphorus concentration of 20 µg TP/L is expected to result in water clarity of 10 feet (~3 meters), 30 µg TP/L with water clarity of 7 feet (~2.1 meters), 33 µg TP/L with water clarity of 6 feet (~1.8 meters), and 40 µg TP/L with water clarity of 5 feet (~1.5 meters).

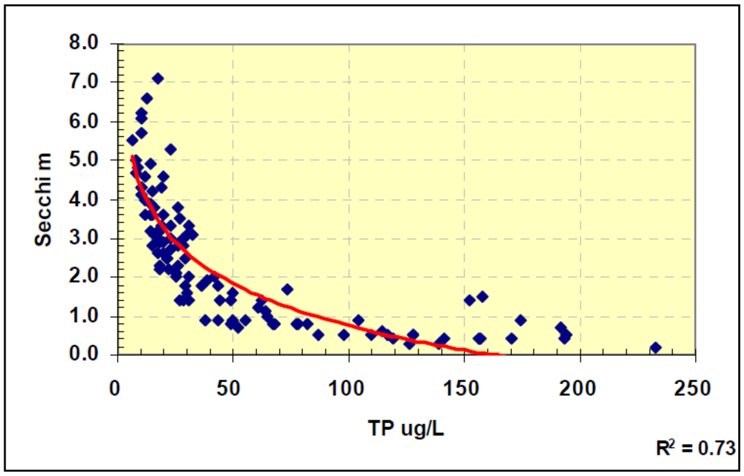

Figure 2. Summer-mean TP and Secchi relationships based on MN reference lake data (Figure 4a from Heiskary and Wilson. 2005. Minnesota Lake Water Quality Assessment Report: Developing Nutrient Criteria, Third Edition. Minnesota Pollution Control Agency, 176 pp.

Table 3. Progress towards District phosphorus goals

Lakes (in order of increasing TP)	10-Year Average In-Lake Phosphorus Concentration (µg/L)		5-Year Average In-Lake Phosphorus Concentration (µg/L)				
	2009-2018	Years of Data	Existing (2013-2018)	Years of Data	2020 District Goal	2030 District Goal	2040 District Goal
Keewahtin	**16**	9	**15**	4	**20 ✓**	**20 ✓**	**20 ✓**
Comfort	**33**	10	**34**	5	**40 ✓**	**33**	**30**
Forest	**34**	10	**36**	5	**37 ✓**	**33**	**30**
Forest East	**36**	8	**36**	5	**37 ✓**	**33**	**30**
Forest Middle	**36**	8	**35**	5	**37 ✓**	**33**	**30**
Forest West	**34**	10	**35**	5	**37 ✓**	**33**	**30**
Bone	**36**	10	**37**	5	**40 ✓**	**30**	**30**
Heims	**41**	3	**43**	2	**40**	**40**	**40**
School	**50**	3	**52**	2	**50**	**40**	**40**
Little Comfort	**52**	10	**61**	5	**40**	**40**	**30**
Birch	**97**	2	**97**	2	**60**	**60**	**60**
Moody	**108**	9	**103**	5	**60**	**40**	**40**
Shields	**224**	7	**243**	5	**100**	**60**	**60**

✓ = meets District Goal; ## = does not meet District Goal

Note that the Forest Lake and Bone Lake 2030 goals are proposed changes that will be considered during the next major plan amendment.

Table 4. Progress towards District Secchi Goals

Lakes (in order of increasing TP)	10-Year Average Secchi Depth (ft)		5-Year Average Secchi Depth (ft)				
	2009-2018	Years of Data	Existing (2013-2018)	Years of Data	2020 District Goal	2030 District Goal	2040 District Goal
Keewahtin	**15.0**	9	**14.9**	4	**10 ✓**	**10 ✓**	**10 ✓**
Comfort	**5.5**	10	**5.7**	5	**5 ✓**	**5 ✓**	**7**
Forest	**5.7**	10	**6.1**	5	**5 ✓**	**6 ✓**	**7**
Forest East	**6.4**	8	**6.7**	5	**5 ✓**	**6 ✓**	**7**
Forest Middle	**6.3**	8	**6.8**	5	**5 ✓**	**6 ✓**	**7**
Forest West	**4.9**	10	**4.8**	5	**5**	**6**	**7**
Bone	**4.7**	9	**4.9**	5	**4 ✓**	**7**	**7**
Heims	**2.2**	2	**2.8**	1			
School	**1.8**	3	**2.7**	2	**4**	**4.6**	**4.6**
Little Comfort	**5.0**	10	**4.3**	5	**5**	**5**	**7**
Birch	**4.2**	2	**4.2**	2	**3.3**	**3.3**	**3.3**
Moody	**2.5**	9	**2.2**	5	**3.3**	**4.6**	**4.6**
Shields	**3.0**	7	**2.4**	5	**4.26**	**4.26**	**4.26**

✓ = meets District Goal; ## = does not meet District Goal

Note that the Forest Lake and Bone Lake 2030 goals are proposed changes that will be considered during the next major plan amendment.

Progress towards State Standards

Table 5 illustrates the progress of lakes towards achieving their respective State water quality standards. The lakes are listed in order of increasing in-lake phosphorus concentration. Comfort (2002), Bone (2004), Little Comfort (2012), Moody (2008), School (2008), Shields (2006), and Second (2012) Lakes were listed as impaired for eutrophication due to excess nutrients by the State of Minnesota (the year the lake was added to the 303(d) list is included in parentheses after the lake name) and were included in a TMDL study.

All State water quality standards are based on growing season (June-September) averages. To be added to the impaired waters list, a lake must not meet the phosphorus standard AND not meet either the chlorophyll-a or Secchi depth standard based on at least 8 samples collected from at least 2 years within the most recent 10 year period. To be removed from the impaired waters list, a lake must meet the phosphorus standard AND the chlorophyll-a or Secchi depth standard based on at least 8 samples collected from at least 2 years within the most recent 10 year period. In addition, there must be an improving trend in TP or management activities in place to maintain improved chlorophyll-*a* or

Secchi observations. The local entity must provide information that details how the response conditions will be met over time for a lake to be de-listed.

Lakes that were historically impaired but currently meet the State water quality standards based on the most recent 10-year period (2009-2018) are Comfort, Bone and School Lakes. Second Lake met the State water quality standards based on the 2007-2016 ten-year period, but did not have data collected between 2009 and 2018. Fourth Lake was not previously identified as impaired, but does not meet the State water quality standards based on the most recent 10-year period (2009-2018). Little Comfort and School Lakes are close to meeting State water quality standards (that is to say, they achieve one of the three standards) and should be a focus for implementation efforts. Sea and Birch Lakes meet the State standards for Secchi depth and chlorophyll-a, but have high phosphorus concentrations.

Table 5. Progress towards State Water Quality Standards

Lakes (in order of increasing TP)	Total Phosphorus (µg/L)			Chlorophyll-a (µg/L)			Secchi Depth (ft)		
	2009-18 Average	Years of Data	Standard	2009-18 Average	Years of Data	Standard	2009-18 Average	Years of Data	Standard
GENERAL LAKES									
Keewahtin	**16**	*9*	**40 ✓**	**3**	9	**14 ✓**	**15.0**	9	**4.6 ✓**
Comfort *	**33**	*10*	**40 ✓**	**16**	10	**14**	**5.5**	10	**4.6 ✓**
Forest	**34**	*10*	**40 ✓**	**16**	10	**14**	**5.7**	10	**4.6 ✓**
Bone *	**36**	*10*	**40 ✓**	**16**	10	**14**	**4.7**	9	**4.6 ✓**
Little Comfort *	**53**	*10*	**40**	**19**	10	**14**	**5.0**	10	**4.6 ✓**
Moody *	**108**	*9*	**40**	**61**	9	**14**	**2.5**	9	**4.6**
SHALLOW LAKES									
Lendt	**15**	*2*	**60 ✓**		0		**4.9**	2	**3.3 ✓**
Third	**24**	*3*	**60 ✓**		0		**3.8**	1	**3.3 ✓**
Heims	**41**	*3*	**60 ✓**		0		**2.2**	2	**3.3**
School *	**50**	*3*	**60 ✓**	**41**	2	**20**	**1.8**	3	**3.3**
Second **		*0*			0			0	
Sea	**74**	*3*	**60**	**9**	2	**20 ✓**	**3.7**	3	**3.3 ✓**
Fourth	**95**	*2*	**60**		0		**2.0**	2	**3.3**
Birch	**97**	*2*	**60**	**18**	2	**20 ✓**	**4.2**	2	**3.3 ✓**
Shields *	**224**	*7*	**60**	**50**	7	**20**	**3.0**	7	**3.3**

N = number of years data has been collected with the 2009-2018 time period.

* = Impaired, included in the 2010 Six Lakes TMDL Study

** = Impaired, included in the 2014 Sunrise River Watershed TMDL Study but no data collected within the last 10-years

Lake names in bold have District Goals; ## ✓ = meets Standard; ## = does not meet Standard

Future Lake Monitoring and Goal Recommendations

1. Bottom water column phosphorus concentration data should be collected from lakes with completed/planned alum treatments (currently Moody and Shields Lakes) to determine the magnitude of internal loading and long-term effectiveness of the alum treatment. Large seasonal increases in bottom water phosphorus concentration indicate internal loading and loss of alum treatment effectiveness. Bottom water column phosphorus concentration data should also be collected from lakes that have been identified in past studies as having potential for future internal loading issues (currently Bone, Little Comfort, and Forest Lake East).
2. At least two years of water quality data should be collected every 10 years in Comfort, Bone, Little Comfort, Moody, School, Shields, and Second Lakes to support future de-listing as impaired due to eutrophication and excess nutrients. It is recommended that water quality samples are collected at least twice per month for the summer growing season (June-September).
3. Because the District goals are based on 5-year average concentrations, there is a need to annually collect monitoring data from lakes with District goals. Note that Heims Lake currently has a District goal, but was recommended to be removed from the goal table during the 2017 Watershed Management Plan minor amendment. Very little monitoring data has been collected from Heims Lake over the past 30 years, and the 2016 Heims Lake Diagnostic Study identified current high water quality and low potential for increasing phosphorus loads to the lake in the future.
4. Proposed Lake Goal Revisions:
    a. Bone Lake: The current 5-year average in-lake phosphorus concentration in Bone Lake of 37 μg/L and the level of implementation planned over the next 10 years in the Bone Lake watershed support a proposed reduction in the 2030 District TP goal from 40 to 30 μg/L.
    b. Comfort Lake: The current 5-year average in-lake phosphorus concentration of Comfort Lake of 34 μg/L and the level of implementation planned over the next 10 years in the Comfort Lake watershed support a proposed reduction in the 2030 District TP goal from 40 to 33 μg/L.
    c. Forest Lake: The current 5-year average in-lake phosphorus concentration of the Forest Lake basins of 35-36 ug/L and the level of implementation planned over the next 10 years in the Comfort Lake watershed support a proposed reduction in the 2030 District TP goal from 37 to 33 μg/L.
    d. District Secchi goals are currently based on the TP goals according to the TP and Secchi relationship established in Figure 2. There was discussion during the November 6 workshop regarding the potential for establishing lake specific relationships between in-lake phosphorus and water clarity to account for variable responses of lake water clarity to TP levels, as evidenced by the mismatch in lakes

meeting District TP goals versus Secchi goals (see Table 3 and Table 4). The relationship between lake TP and Secchi is based on size of algae found in the lake because larger cells scatter light less than smaller cells for the same overall mass of algae. This is to say, lakes with larger bodied algae (such as filamentous algae) will have better (deeper) water clarity than lakes with smaller bodied algae (such as blue green algae) when both lakes have the same overall mass of algae. Because the composition of algae is variable in a lake, it is recommended that the state-wide established TP and Secchi relationships illustrated in Figure 2 remain the basis for District lake goals.

e. With District lake TP goals being met ahead of schedule and with the high levels of implementation planned over the next 10-years, the District could consider setting non-TP lake goals during the 2020 Watershed Management Plan Update, such as:
    i. Suspended sediment and wave action disturbance of lake sediments
    ii. In-lake biology (fish and aquatic plants)
    iii. Shoreline condition

Table 6. Total Annual Flow by Stream Monitoring Site, 2004-2018 (in ac-ft)

Type		Station	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	⌘	**Bone Lake North Inlet**		323	221				126	1,051	279	372	1,134	948	1,091	698	457
		Bone Lake South Inlet		528	363												
💧	⌘	**Bone Lake Outlet**	1,522	600	539							1,858	2,491	2,764	4,356	1,730	769
		Sunrise R Trib @ Manning Tr					1,451	258									
		Sunrise R Trib @ July Avenue					1,858	623									
	⌘	**Little Comfort Lake Inlet**	3,955	3,421	3,029	3,977	8,268	2,324	2,370	3,403	1,175	1,379	3,047	2,662	3,022	3,215	721
		FL44 Subwatershed Drainage												395			
💧		**Shields Lake Otlet**		634	408												
💧	⌘	**Forest Lake Outlet**	5,351	4,310	2,120	2,960	3,656	716	3,063	18,744	3,561	7,157		7,693	5,891	7,699	10,764
		Bixby Park						507	484	705	1,151						
		County Line Ditch				3,860	3,841	1,634	4,183	8,642	3,632						
		Heims Lake Drainage									130	221	743				
		Greenway Avenue					5,315			10,157	6,027	7,498					11,103
		256th Street															10,616
	⌘	**Comfort Lake Inlet**	9,694	6,527	3,762	5,671	6,527	2,469	5,026	11,709	8,095	8,154	9,725	11,241	11,082	11,939	11,036
💧	⌘	**Comfort Lake Outlet**	15,473	4,634	4,208		5,841	1,401	5,514	19,894	7,656	9,779	19,683	11,765	11,007	12,613	15,450

💧 = Lake outlet monitoring site

⌘ = Legacy monitoring site

Table 7. Total Annual Flow by Stream Monitoring Site, 2004-2018 (as inches of runoff depth over the drainage area)

Type		Station	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	⌘	**Bone Lake North Inlet**		1.6	1.1				0.6	5.1	1.4	1.8	5.5	4.6	5.3	3.4	2.2
		Bone Lake South Inlet		8.3	5.7												
💧	⌘	**Bone Lake Outlet**	3.3	1.3	1.2							4.1	5.4	6.0	9.5	3.8	1.7
		Sunrise R Trib @ Manning Tr					2.4	0.4									
		Sunrise R Trib @ July Avenue					2.8	0.9									
	⌘	**Little Comfort Lake Inlet**	4.5	3.9	3.5	4.5	9.4	2.7	2.7	3.9	1.3	1.6	3.5	3.0	3.4	3.7	0.8
		FL44 Subwatershed Drainage												6.0			
💧		**Shields Lake Outlet**		9.2	5.9												
💧	⌘	**Forest Lake Outlet**	7.4	5.9	2.9	4.1	5.0	1.0	4.2	25.8	4.9	9.9		10.6	8.1	10.6	14.8
		Bixby Park						8.1	7.8	11.3	18.5						
		County Line Ditch				4.7	4.7	2.0	5.1	10.6	4.4						
		Heims Lake Drainage									2.3	4.0	13.4				
		Greenway Avenue					5.9			11.2	6.7	8.3					12.3
		256th Street															n/a
	⌘	**Comfort Lake Inlet**	8.5	5.7	3.3	5.0	5.7	2.2	4.4	10.2	7.1	7.1	8.5	9.8	9.7	10.4	9.6
💧	⌘	**Comfort Lake Outlet**	7.6	2.3	2.1		2.9	0.7	2.7	9.7	3.7	4.8	9.6	5.7	5.4	6.2	7.5

💧 = Lake outlet monitoring site

⌘ = Legacy monitoring site

Table 8. Total Phosphorus Load by Stream Monitoring Site, 2004-2018 (in lb/yr)

Type		Station	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	⌘	**Bone Lake North Inlet**		226	315				53	519	207	349	917	553	398	220	188
		Bone Lake South Inlet		231	229												
💧	⌘	**Bone Lake Outlet**	339	97	49							194	271	283	652	140	53
		Sunrise R Trib @ Manning Tr					508	104									
		Sunrise R Trib @ July Avenue					431	151									
	⌘	**Little Comfort Lake Inlet**	1,283	1,023	1,551	676	1,127	418	331	481	230	330	354	543	430	504	191
		FL44 Subwatershed Drainage												85			
💧		**Shields Lake Outlet**		420	332												
💧	⌘	**Forest Lake Outlet**	1,235	457	173	253	341	43	221	1,828	411	706		701	630	321	749
		Bixby Park						179	158	285	973						
		County Line Ditch				1,212	650	85	811	1,792	930						
		Heims Lake Drainage									330	495	374				
		Greenway Avenue					1,505			3,722	6,370	2,071					2,386
		256th Street															1,978
	⌘	**Comfort Lake Inlet**	1,963	1,119	1,887	997	1,153	547	1,278	2,876	1,914	1,519	2,006	2,880	2,176	1,525	2,135
💧	⌘	**Comfort Lake Outlet**	2,065	670	563		291	134	450	1,146	924	2,129	2,099	1,160	1,124	1,068	1,303

💧 = Lake outlet monitoring site

⌘ = Legacy monitoring site

Table 9. Phosphorus Flow Weighted Mean Concentrations by Stream Monitoring Site, 2004-2018 (in µg/L)

Type		Station	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	⌘	**Bone Lake North Inlet**		257	524				155	182	273	345	297	215	134	116	151
		Bone Lake South Inlet		161	232												
💧	⌘	**Bone Lake Outlet**	82	59	33							38	40	38	55	30	25
		Sunrise R Trib @ Manning Tr					129	148									
		Sunrise R Trib @ July Avenue					85	89									
	⌘	**Little Comfort Lake Inlet**	119	110	188	63	50	66	51	52	72	88	43	75	52	58	97
		FL44 Subwatershed Drainage												79			
💧		**Shields Lake Outlet**		244	299												
💧	⌘	**Forest Lake Outlet**	85	39	30	31	34	22	27	36	42	36		34	39	15	26
		Bixby Park						130	120	149	311						
		County Line Ditch				116	62	19	71	76	94						
		Heims Lake Drainage									934	824	185				
		Greenway Avenue					104			135	389	102					79
		256th Street															69
	⌘	**Comfort Lake Inlet**	74	63	185	65	65	82	94	90	87	69	76	94	72	47	71
💧	⌘	**Comfort Lake Outlet**	49	53	49		18	35	30	21	44	80	39	36	38	31	31

💧 = Lake outlet monitoring site

⌘ = Legacy monitoring site

Table 10. In-Lake Growing Season (June through September) Average Phosphorus Concentration, 1989-2018 (in µg/L)

Lake	#	In-Lake Growing Season (June through September) Average Phosphorus Concentration (µg/L) (in order left to right from most recent to oldest)																													
		2018	2017	2016	2015	2014	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000	1999	1998	1997	1996	1995	1994	1993	1992	1991	1990	1989
Bone *	**24**	22	30	39	39	55	34	34	32	37	33	39	41	57	59	60	82	58	39		50	34	36		21		58				46
Birch	**5**	122	72										60	118	131																
Comfort *	**21**	32	31	34	31	43	25	47	32	28	27	26	19	49	29	40	48	41	29	44		43				37					
Forest (West)	**24**	37	25	40	37	37	37	38	35	31	26	37	37	38	40	33	36	33	29	36	47	29	29	36			37				
Forest (Middle)	**10**	35	34	41	35	31	30	49	33					38				24													
Forest (East)	**10**	36	46	44	28	28	25	39	42					40				26													
Forest (All Basins)	**24**	*36*	*35*	*42*	*33*	*32*	*31*	*42*	*37*	*31*	*26*	*37*	*37*	*39*	*40*	*33*	*36*	*28*	*29*	*36*	*47*	*29*	*29*	*36*			*37*				
Fourth Lake	**2**				63	127																									
Heims	**3**				33	52					37																				
Lendt	**2**				11	18																									
Little Comfort *	**15**	50	43	68	88	58	62	58	46	28	19	28	47	73								56				51					
Moody *	**12**	92	86	104	122	113	87	155	128	81			168	158	168																
Second **	**1**											54																			
School *	**6**	53	51								47		53	66	97																
Sea	**4**		45	54							122	48																			
Shields *	**24**	180	191	194	349	299	162	195					206	234	201	229	381	259	245	179	286	220	188	184	209	145	190	90	100		
Keewahtin	**22**		14	18	18	13	14	18	23	14	13	15	14		19	20	17	19	19	19	24	13		23			11				
Third Lake	**3**				17	30						14																			
Nielsen	**2**	87	102																												

* = Impaired, in the 2010 Six Lakes TMDL Study; ** = Impaired, in the 2014 Sunrise River Watershed TMDL Study

Lake names in bold have District Goals

Table 11. In-Lake Growing Season (June through September) Average Chlorophyll-a Concentration, 1989-2018 (in µg/L)

		In-Lake Growing Season (June through September) Average Chlorophyll-a Concentration (µg/L) (in order left to right from most recent to oldest)																													
Lake	#	2018	2017	2016	2015	2014	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000	1999	1998	1997	1996	1995	1994	1993	1992	1991	1990	1989
Bone *	18	10	20	25	30	21	20	15	6	16		18		20	23	38	48	42	34		34	20	16		7		38				28
Birch	2	25	11										21	15	44																
Comfort *	18	14	12	18	20	16	14	22	16	20	12	9		12	16	17	25	26	19	25		14				16					
Forest (West)	18	13	8	20	19	14	15	21	18	21	11	10		19	25	10	17	16	19	12	20	18	14	15			18				
Forest (Middle)	11	15	13	19	21	12	14	19	50					19				15													
Forest (East)	11	22	23	24	19	14	14	12	27					20				16													
Forest (All Basins)	18	*17*	*15*	*21*	*20*	*14*	*14*	*17*	*32*					*19*				*15*													
Fourth Lake	0				13	18																									
Heims	0				9						16																				
Lendt	0				3	1																									
Little Comfort *	13	26	26	43	28		24	17	11	14	8	10		24								18				32					
Moody *	12	75	44	46	59		32	82	87	71			80	44	60																
Second **	0											16																			
School *	2	50	31								29		40	28	48																
Sea	2		7	14							46	48																			
Shields *	14	67	64	57	77		39	31					45	59	61	48	46	49	25	26	49	40	8	9	18	23	25				
Keewahtin	16		3	5	4		4	3	3	2	3	3			3	3	4	3	5	4	6	4		3			4				
Third Lake	2				4							1																			
Nielsen	2	78	80																												

* = Impaired, in the 2010 Six Lakes TMDL Study; ** = Impaired, in the 2014 Sunrise River Watershed TMDL Study

Lake names in bold have District Goals

Table 12. In-Lake Growing Season (June through September) Average Secchi Depth Transparency, 1986-2018 (in feet)

Lake		In-Lake Growing Season (June through September) Average Secchi Depth (ft) (in order left to right from most recent to oldest)																																
	#	2018	2017	2016	2015	2014	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000	1999	1998	1997	1996	1995	1994	1993	1992	1991	1990	1989	1988	1987	1986
Bone *	29	6.5	5.8	4.2	3.9	4.1	3.9	3.7	5.2	4.9		5.1	3.7	5.9	5.2	4.1	3.1	3.2	4.1		3.5	5.0	4.9	4.4	3.5	4.2	3.7			4.2	4.3	3.5	5.3	3.4
Birch	5	3.5	5.0										5.6	5.1	3.9																			
Comfort *	27	7.7	5.8	5.5	5.5	4.2	5.7	4.3	5.4	4.4	6.8	4.8	5.6	6.6	6.3	6.0	4.2	4.1	6.2	4.9	4.5	4.1	6.3		4.3	6.3					9.3	7.9	8.4	
Forest (West)	30	4.9	6.2	4.3	4.7	4.0	4.3	3.4	6.0	5.2	5.5	4.9	3.4	5.1	5.4	6.2	4.3	5.5	5.0	4.5	3.9	4.6	5.1	4.9	5.3	4.8	5.2				6.9	5.7	5.3	5.6
Forest (Middle)	10	7.7	8.2	5.7	6.4	6.2	5.7	5.2	5.3					5.5				6.3																
Forest (East)	10	6.4	8.1	5.7	7.8	5.5	6.6	7.0	4.0					5.5				6.3																
Forest (All Basins)	29	6.3	7.5	5.2	*6.3*	*5.2*	*5.5*	*5.2*	*5.1*	*5.2*	*5.5*	*4.9*	*3.4*	*5.4*	*5.4*	*6.2*	*4.3*	*6.0*	*5.0*	*4.5*	*3.9*	*4.6*	*5.1*	*4.9*	*5.3*	*4.8*	*5.2*				*6.9*	*5.7*	*5.3*	*5.6*
Fourth Lake	2				1.7	2.3																												
Heims	2				2.8	3.8					1.7																							
Lendt	2				3.8	5.9																												
Little Comfort *	15	4.3	3.6	3.7	4.3	5.9	5.2	4.7	5.5	5.8	6.6	5.8	4.5	4.8								3.2				5.9								
Moody *	12	1.8	1.9	2.7	2.1	2.7	3.7	2.4	2.6	2.6			2.2	2.7	2.3																			
Second **	4											5.8		4.8																				
School *	6	2.5	2.8								0.2		4.3	4.0	3.8																			
Sea	4		4.2	4.8							2.1	3.9																						
Shields *	10	1.9	2.2	2.7	1.9	3.4	4.1	4.6					3.4	2.7	2.3																			
Keewahtin	32		14.2	13.7	13.9	17.7	14.4	15.0	13.9	17.0	15.5	14.7	15.3	16.1	15.5	16.7	14.0	15.3	13.8	14.2	13.3	13.9	12.6	14.4	14.6	14.9	16.0	15.8	15.9	12.4	13.6	14.8	14.3	10.6
Third Lake	2				3.8							7.1																						
Nielsen	2	1.0	1.0																															

* = Impaired, in the 2010 Six Lakes TMDL Study; ** = Impaired, in the 2014 Sunrise River Watershed TMDL Study

Lake names in bold have District Goals