Coeur d'Alene Lake Management Plan: Coeur d'Alene Lake Status Update, 2015 – 2018

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Executive Summary

This document provides an update on the status of water quality in Coeur d'Alene Lake for calendar years 2015 – 2018, relative to long-term trends in key water quality parameters previously identified in the 2008-2014 Lake Trends Analysis (DEQ and Tribe, 2016). These key parameters, or trigger criteria, are dissolved metals (cadmium, lead, zinc), total phosphorus, chlorophyll-a, and dissolved oxygen in the lake's bottom waters. The Lake Management Plan (LMP) also monitors water clarity, phytoplankton community structure, and invasive species. Trends in these parameters are not reported here. They will be assessed in future reports.

The prior 2008 – 2014 Lake Trends Analysis (DEQ and Tribe, 2016) assessed long-term trends in the lake's status relative to the 1991 – 1992 baseline established by the U.S. Geological Survey (Woods and Beckwith, 1997). The 2016 report concluded that the lake is changing in different ways, with different trends observed in different locations. The report stated that metals levels in the lake had declined, relative to the 1990's condition, but that the trophic state indicators that measure the lake's productivity were trending toward a higher trophic state. This report updates those trends with data from 2015 – 2018, and concludes the following.

1. Metals trends vary between the different metals.
   a. Dissolved zinc and cadmium levels are declining in the northern lake.
   b. Dissolved lead levels are increasing at some locations in the northern lake.
   c. Total metal levels are lower than was reported in 1991 – 1992.
2. Chlorophyll-a levels in the lake are higher than in the 1990's, but no trend is discernable over the 2004 – 2018 time period.
3. Total phosphorus levels in the lake are steadily increasing, and the rate may be accelerating. The highest recorded levels were in 2017-2018.
4. Summer hypolimnetic oxygen levels are lower than in the 1990's, but no trend is discernable over the 2004 – 2018 time period.

> Coeur d'Alene Lake trends for metals and nutrients are trending in different directions at monitoring sites north of the Coeur d'Alene River. Zinc and cadmium are declining while lead and phosphorus are increasing. No trend in chlorophyll-a or hypolimnetic oxygen is detected for 2004 – 2018. However, both parameters indicate that lake productivity is higher than it was in 1991 – 1992. The balance of nutrients in the northern lake is shifting towards greater risk of toxic cyanobacteria blooms.

The prior 2008 – 2014 Lake Trends Analysis concluded that metals levels in the lake had begun to decline, but that new challenges were emerging. The lake's trophic status is changing in ways that are not consistent with the management objectives of (i) maintaining the lake in a lower productivity state and (ii) trapping contaminant metals in the sediments by maintaining elevated oxygen levels in the lake's bottom waters and sustaining high water quality. The lake has generally continued along these trends for 2015 – 2017, with some differences. Cadmium is now declining in the northern lake, and the previously reported trends of declining oxygen and increasing chlorophyll-a are no longer present. New analyses of the nutrient balance have been conducted and indicate an increasing risk for toxic cyanobateria blooms. A "report card" for the lake status is presented on the following pages.

Metals Indicators			C1 Tubbs Hill -- Dissolved Metals			C4 University Point -- Dissolved Metals		
Calendar Year	Agency	Data Notes	Zinc (µg/L) target < 36	Lead (µg/L) target < 0.54	Cadmium (µg/L) target < 0.22 ± 0.01	Zinc (µg/L) target < 36	Lead (µg/L) target < 0.54	Cadmium (µg/L) target < 0.22 ± 0.01
1975	US EPA	survey	no data	no data	no data	no data	no data	no data
1991	USGS	only total metals	~90, estimated	~1.0, estimated	< 0.5, estimated	~110, estimated	~1.5, estimated	< 0.5, estimated
1992	USGS		~95, estimated	~0.2, estimated	< 0.5, estimated	~105, estimated	~0.3, estimated	< 0.5, estimated
1995	DEQ	summer survey data July - Oct represent minimum annual values	summer ~100	summer < 5	summer < 0.5	summer ~90	summer < 5	summer < 0.5
1996	DEQ		summer ~80	summer < 3 to 5	summer < 0.5	summer ~100	summer < 5	summer < 0.5
1997	DEQ		summer ~65	summer < 3 to 5	summer < 0.5	summer ~75	summer < 5	summer < 0.7
1998	DEQ		summer ~70	summer < 3	summer < 0.5	summer ~80	summer < 3	summer < 0.5
1999	DEQ		summer ~70	summer < 3	summer < 0.7	summer ~90	summer < 3	summer < 0.5
2000	DEQ		summer ~50	summer < 3	summer < 0.5	summer ~60	summer < 3	summer < 0.5
2001	DEQ		summer ~55	summer < 3	summer < 0.5	summer ~60	summer < 3	summer < 0.6
2002	DEQ		summer ~50	summer < 3	summer < 0.5	summer ~60	summer < 3	summer < 0.9
2003	USGS	partial year	Oct - Dec only	Oct - Dec only	Oct - Dec only	Oct - Dec only	Oct - Dec only	Oct - Dec only
2004	USGS	high quality	48	0.08	0.21	70	0.18	0.26
2005	USGS	high quality	49	0.11	0.19	61	0.21	0.24
2006	USGS	high quality	53	0.23	0.20	70	0.68	0.29
2007	DEQ	partial year	Aug - Dec only	Aug - Dec only	Aug - Dec only	Aug - Dec only	Aug - Dec only	Aug - Dec only
2008	DEQ	high quality	51	0.20	0.22	69	0.58	0.28
2009	DEQ	high quality	46	0.17	0.22	60	0.26	0.26
2010	DEQ	high quality	51	0.08	0.19	64	0.16	0.23
2011	DEQ	high quality	47	0.28	0.21	56	0.70	0.25
2012	DEQ	high quality	47	0.23	0.21	61	0.65	0.27
2013	DEQ	high quality	56	0.28	0.24	60	0.31	0.26
2014	DEQ	high quality	50	0.24	0.20	53	0.48	0.23
2015	DEQ	high quality	20	0.11	0.19	58	0.38	0.24
2016	DEQ	high quality	53	0.13	0.20	56	0.22	0.21
2017	DEQ	high quality	45	0.27	0.17	50	0.70	0.20
2018	DEQ	high quality	37	0.16	0.14	49	0.43	0.18
current trend			*Decreasing* ✓	*Some Increases* ☒	*Decreasing* ✓	*Decreasing* ✓	*Some Increases* ☒	*Decreasing* ✓

Table Key

Brown = limited data, cannot assess trigger

Green = meets criteria (no exceedance)

Yellow = close to criteria (within 10%) may meet or exceed

Orange = does not meet criteria (exceedance)

☒ denotes an undesired trend (away from target)

✓ denotes a desired trend (towards target)

Color gradients show where conditions shift between the different trigger thresholds

Unless otherwise noted, numbers are geometric mean concentration (µg/L) using all representative data for that year.

Dissolved metals for 1991 – 1992 are estimated from total metals using a Kd coefficient (dissolved / total), calculated using data from 2004 – 2018.

For Chla, range covers results from different analytical methods.

Trophic Indicators			C1 Tubbs Hill -- Trophic Status				C4 University Point -- Trophic Status			
Calendar Year	Agency	Data Notes	Hypolimnetic O2 (mg/L) target > 6	Total Phos. (µg/L) target < 8	Average Chl-a (µg/L) target < 3	Maximum Chl-a (µg/L) target < 5	Hypolimnetic O2 (mg/L) target > 6	Total Phos. (µg/L) target < 8	Average Chl-a (µg/L) target < 3	Maximum Chl-a (µg/L) target < 5
1975	US EPA	survey	no data	13	7	17	no data	16	12	26
1991	USGS	high quality	6.6	3.1	0.8 - 0.9	1.1 - 1.5	7.7	4.4	0.7 - 0.8	1.1 - 1.5
1992	USGS	high quality	6.9	< 3	0.8 - 1.0	1.3 - 1.7	7.1	< 3	0.9 - 1.1	1.4 - 1.9
1995	DEQ	summer survey data July - Oct represent minimum annual values	8.1	summer ~8	no data	no data	7.7	summer ~6	no data	no data
1996	DEQ		7.7	summer ~8	no data	no data	7.9	summer ~7	no data	no data
1997	DEQ		7.9	summer ~9	no data	no data	8.2	summer ~6	no data	no data
1998	DEQ		6.3	summer ~6	no data	no data	6.8	summer ~7	no data	no data
1999	DEQ		6.4	summer ~6	no data	no data	8.0	summer ~6	no data	no data
2000	DEQ		6.4	summer ~4	no data	no data	6.4	summer ~4	no data	no data
2001	DEQ		6.5	summer ~4	no data	no data	6.9	summer ~6	no data	no data
2002	DEQ		7.2	summer ~5	summer ~1.6	summer ~1.8	7.4	summer ~5	summer ~2.2	summer ~2.4
2003	USGS	partial year	*Oct - Dec only*	Oct - Dec only	Oct - Dec only	Oct - Dec only	Oct - Dec only	Oct - Dec only	Oct - Dec only	Oct - Dec only
2004	USGS	high quality	6.4	4.3	1.1 - 1.4	1.9 - 2.7	6.7	5.0	1.1 - 1.4	1.8 - 2.5
2005	USGS	high quality	7.3	4.7	1.1 - 1.4	1.7 - 2.3	7.4	6.1	1.1 - 1.5	1.5 - 2.1
2006	USGS	high quality	8.1	4.8	1.6 - 2.2	2.3 - 3.3	8.5	6.7	1.6 - 2.1	2.2 - 3.1
2007	DEQ	partial year	Aug - Dec only	Aug - Dec only	Aug - Dec only	Aug - Dec only	Aug - Dec only	Aug - Dec only	Aug - Dec only	Aug - Dec only
2008	DEQ	high quality	6.6	6.0	2.6 - 3.7	4.0 - 5.9	7.2	8.8	2.0 - 2.7	2.8 - 4.1
2009	DEQ	high quality	7.4	6.3	1.7 - 2.3	5.7 - 8.4	7.1	8.2	1.6 - 2.7	3.6 - 5.3
2010	DEQ	high quality	6.0	4.2	1.1 - 1.4	1.7 - 2.3	6.2	5.5	1.3 - 1.7	2.2 - 3.1
2011	DEQ	high quality	8.0	8.9	1.0 - 1.2	2.7 - 3.9	8.1	11	1.0 - 1.2	1.3 - 1.8
2012	DEQ	high quality	6.0	6.5	1.8 - 2.4	3.1 - 4.5	7.7	6.8	1.6 - 2.2	2.8 - 4.1
2013	DEQ	high quality	7.4	5.3	1.3 - 2.1	2.9 - 3.2	7.7	5.6	1.4 - 2.4	3.6 - 4.1
2014	DEQ	high quality	7.1	7.0	1.4 - 2.5	5.4 - 8.0	7.8	9.0	1.2 - 1.8	2.7 - 3.9
2015	DEQ	high quality	6.8	7.8	1.9 - 2.6	3.1 - 4.5	7.4	8.2	1.2 - 1.5	2.7 - 3.9
2016	DEQ	high quality	6.6	7.1	1.9 - 2.6	3.9 - 5.7	7.1	8.4	1.7 - 2.3	2.4 - 3.4
2017	DEQ	high quality	7.2	11	1.3 - 1.6	2.9 - 4.1	7.8	13	1.1 - 1.4	2.6 - 3.7
2018	DEQ	high quality	8.2	11	1.1 - 1.5	1.7 - 2.4	8.3	12	1.4 - 1.8	2.2 - 3.1
current trend			***No Trend ✓***	***Increasing ☒***	***No Trend ✓***	***No Trend ✓***	***No Trend ✓***	***Increasing ☒***	***No Trend ✓***	***No Trend ✓***

1 Purpose, Background, and Introduction

The Coeur d'Alene Lake Management Plan (LMP) is a collaborative effort among the Idaho Department of Environmental Quality (DEQ), the Coeur d'Alene Tribe (Tribe), and the region's many governmental and stakeholder groups to protect water quality within Coeur d'Alene Lake (DEQ and Tribe 2009). The US Environmental Protection Agency (EPA) Manchester Laboratory has provided technical support, approved annual quality assurance project plans (QAPPs), and provided chemical analyses for water quality samples collected by DEQ and the Tribe.

> *The Lake Management Plan goal is to "protect and improve lake water quality by limiting basin-wide nutrient inputs that impair lake water quality conditions, which in turn influence the solubility of mining-related metals contamination contained in lake sediments".*

This overall goal will be achieved by attempting to maintain the lake in a low nutrient status, which will lead to high levels of hypolimnetic (deep water) dissolved oxygen (DO) and low solubility of lake-bed metals. The LMP established *trigger criteria* to compare the lake's status relative to water quality standards, historic data, and the goal stated above. These trigger criteria include metals levels, hypolimnetic DO, trophic parameters such as chlorophyll-*a*, phosphorus, and a suite of bioindicators that reflect changes in trophic status and may provide more sensitive indicators. This report provides a summary update of the lake's current status relative to the quantitative triggers criteria established in the LMP.

This report provides the lake's status in for calendar years 2015 – 2018 relative to long-term trends that have been discussed in prior reports. This report answers two questions regarding the water quality status of Coeur d'Alene Lake in relation to the LMP triggers:

1. What is the status of Coeur d'Alene Lake relative to the water quality trigger criteria?
2. How do the most recent trigger criteria from CY 2015-2018 compare with trends derived from the prior datasets (1991 – 1992, 2003 – 2007, 2008 – 2014)?

This report summarizes results from statistical analyses of the quantitative LMP trigger variables and is *not* a synthesis or conclusion of what these data may imply for future lake management decisions. DEQ and the Tribe are currently collaborating to produce a series of technical synthesis reports to identifying the dynamics and mechanisms that may explain the current lake conditions and trends described in this report and prior summaries.

1.1 Data Sources

This report is primarily based on analyses of LMP trigger variables from three time periods (1991–1992, 2003–2006, and 2007–2018). Additional analyses that incorporate DO data collected from 1996–2002 are also presented. Data from the 1991–1992 period was collected by the US Geological Survey (USGS) and reported by Woods and Beckwith (1997). Data from the 2003–2006 period was collected by USGS and reported by Wood and Beckwith (2008). DO data from 1996–2002 for the northern lake were collected by DEQ, with results generally summarized in draft addendums to the 1996 Coeur d'Alene LMP (DEQ 1996; DEQ 2002; DEQ 2004). Data for the northern lake for 2007–2018 was collected by DEQ Lake Management Plan staff.

1.2 Water Quality Trigger Criteria

Section 3.1 of the LMP states:

> *There are several key water quality variables that need to be tracked in order to measure the long term health of the lake. These include, but are not limited to: levels of zinc, lead, cadmium, phosphorus, phytoplankton, and dissolved oxygen. The 2009 LMP establishes triggers for each of these variables and others, to gauge lake health. An annual comprehensive monitoring program produces trend data that provides an "early warning system" for deteriorating conditions. Ideally, this will allow corrective steps to be taken before conditions deteriorate to the point they would be very difficult and expensive to reverse, i.e., exceeding a trigger.*

Trigger criteria values for DO and trophic state indicators (total phosphorus and chlorophyll-*a*) are provided in section 2 of this report. The DO trigger is generally based on the state and Tribe water quality standards for DO levels in the hypolimnion (summer bottom waters). The oxygen criteria support beneficial use by providing suitable habitat for cold water salmonids. However, since Coeur d'Alene Lake also has metals contamination issues that can be alleviated by maintaining high oxygen levels, the DO trigger extends these values down to the sediment-water interface. This trigger condition is specific to Coeur d'Alene Lake management and is distinct from Idaho water quality criteria.

Trigger criteria values for dissolved metals are based on water quality standards for surface waters, as defined by the State of Idaho and the Coeur d'Alene Tribe. From a policy and regulatory standpoint, the triggers criteria are treated differently than state and Tribe water quality standards. State water quality criteria are used in the northern waters, generally north of the City of Harrison. Tribe water quality criteria apply to reservation waters, generally south of the City of Harrison. The Tribe incorporates water hardness into water quality standards for cadmium, lead, and zinc. The State also incorporates water hardness into standards for cadmium, lead, and zinc. However, Tribal water quality standards can be more stringent and vary with water depth to a greater extent.

1.3 Sampling Methods

Details of lake monitoring methods are provided in the QAPPs that accompany each of the LMP reports listed in section 1.1, with key information provided in the reports themselves. In general, a profile of the lake's conditions is gathered first using automated methods. These data include temperature, pH, chlorophyll-*a* fluorescence, specific conductance, turbidity, and light transmittance as a function of depth. These data are then used to establish the depth of the photic zone and the depth to bottom (lake depth varies over time). Next, samples for chemical and biological analyses are collected for a photic-zone composite (photic zone mean) and discrete samples at mid-depths and 1 meter off the bottom. These samples are preserved in the field and sent to EPA-certified laboratories for analysis. All sample collection and analysis is conducted using rigorous data-quality procedures.

1.4 Monitoring Locations and Sampling Schedule

The LMP continuously monitors water quality at the following main lake locations (

Figure 1): These sites were visited during the US Geological Survey (USGS) studies conducted in calendar year (CY) 1991–1992 and water year (WY) 2004–2006.

1. Site C1, southeast of Tubbs Hill— northern pool (pelagic zone, 40 meters deep)
2. Site C4, northeast of University Point—central pool (pelagic zone, 40 meters deep)
3. Site C5, southeast of Chippy Point—southern pool (pelagic zone, 18 meters deep)
4. Site C6, Chatcolet Lake—southern (shallow zone, 11 meters deep)

Sites C1 and C4 are monitored by DEQ technical staff and are reported here. Sites C5 and C6 are monitored by the Coeur d'Alene Tribe and water quality conditions at those sites are presented in Tribe reports. Only data from sites monitored by DEQ staff will be presented here.

Water samples are collected up to 9 times per year at the main lake stations. Samples are collected to coincide with major hydrologic and limnologic events, generally in February/March, April, May, June, July, August, September/October, and November/December. All monitoring sites are typically visited within the same week. The February/March sample is intended to capture lake conditions after a rain-on-snow event and the November/December sample is intended to capture lake conditions soon after lake turnover in late fall/early winter. Additional details about the location and frequency of lake sampling are provided in the 2009 Lake Management Plan, annual QAPP's, and technical reports. .

Coeur d'Alene Lake experiences a number of physical, chemical, and biological changes through the course of a year. Each of these seasons may have changes and trends that differ from the annual average. The term of the seasons varies with location in the lake, though the environmental characteristics are comparable. This report also provides a preliminary assessment of the seasonality of chlorophyll-a in the lake in terms of four different seasonal characteristics of the lake. These are as follows.

1. ***Fall/Winter***— the period of the year when the lake is clear and generally isothermal. It begins when the lake is in midst of fall turnover and lasts until spring run-off and rain-on snow events wash in sediment, creating turbid waters. Typically ~October thru January.
2. ***Early Spring***— the period when the lake is isothermal and turbid, generally coinciding with rain-on-snow events and peak run-off. Typically ~February thru mid-April.
3. ***Late Spring***— the period of the lake is beginning to clear, the lake is beginning to stratify, and plankton communities are blooming with the nutrients provided during early spring run-off. Typically ~mid-April thru June.
4. ***Summer***— the period of the year when the lake is clear and thermally stratified. Typically ~June/July – September/October (depending on location in the lake).

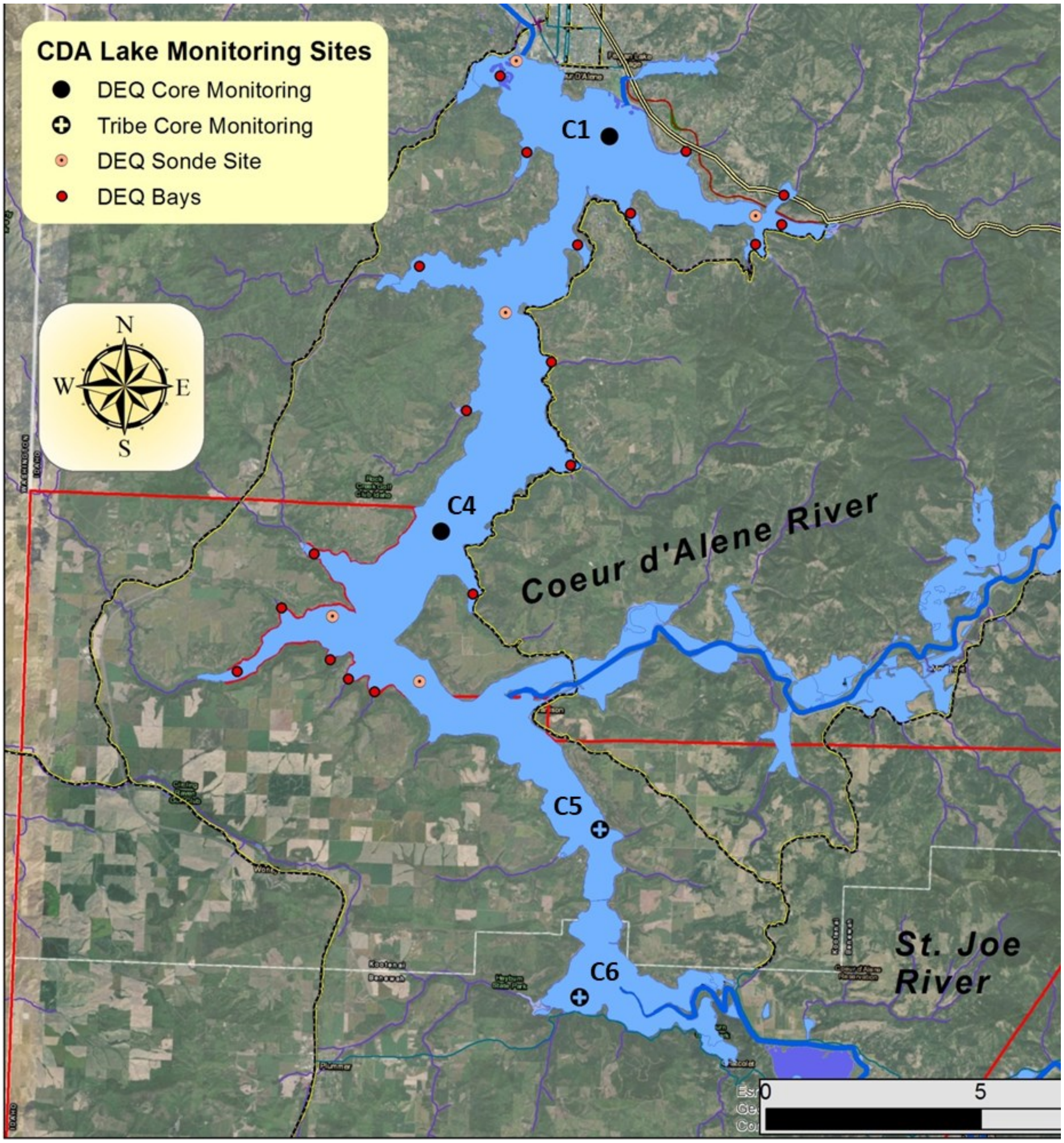


Figure 1. Map of sampling locations for core routine monitoring on Coeur d'Alene Lake.

1.5 Analysis Methods and Report Format

This report presents lake status relative to trigger criteria established in the 2009 Lake Management Plan (DEQ and Tribe, 2009), as well as long-term trends reported in the 2008-2014 Lake Trends Analysis (DEQ and Tribe, 2016). One table and two sets of figures are presented for each of the measured LMP variables.

1. The first set of figures provides bar charts that summarize the current lake status relative to long-term geometric means for different historic time periods, for each of the trigger parameters. This provides a status relative to the trigger criteria established in the 2009 Lake Management Plan (DEQ and Tribe, 2009).
2. The table provides summary results from a Mann-Kendall analysis for annual trends for both the original 2004 – 2014 time period as reported in the 2008 – 2014 Lake Trends Analysis (DEQ and Tribe, 2016) and the most recent 2004 – 2018 time period. This evaluates whether the current trend has changed relative to the previously reported trend.
3. The second set of figures provides a visualization of long-term trends for trigger parameters, for each combination of depth range and location for the core monitoring locations in the main lake. These charts show all data collected at that site and depth, the annual median for each parameter, the Theil-Sen trend lines reported in the 2008 – 2014 Lake Trends Analysis (DEQ and Tribe, 2016), and an updated Theil-Sen trend line for the 2004 – 2018 time period. These charts provide a visual representation of current lake status relative to previously identified trends.

The results for each LMP trigger variable are presented for the core LMP monitoring sites located in the northern regions of the lake that are monitored by DEQ (sites C1, C4)and depths associated with the LMP triggers as reported in the Coeur d'Alene LMP (DEQ and Tribe 2009). Different depth ranges are used for the geometric means (bar charts) and trend analyses (tables, line charts) because the trend analyses were conducted at specific depths while the original trigger criteria combined data over multiple depths. The Mann-Kendall statistical test used to evaluate long-term annual trends in the trigger criteria can only be conducted for a single depth. Similarly, the Theil Sen trend line that is derived from the difference between measured data and calculated median values is also specific to a single combination of depth and monitoring site. These depth-specific trends are more meaningful and diagnostic than the original trigger criteria established in 2009 (DEQ and Tribe, 2009). Analysis of whether current data falls along these previously described trends is also more meaningful.

Analyses of data for the bays adjacent to the northern lake are not presented in this report. The dataset for these monitoring locations is not as comprehensive and continuous as for the main lake and is consequently less informative. The bay data will be assessed in future reports.

All statistical tests were run using the EPA water quality statistics software ProUCL 5.0 (Singh and Maichle 2013; Singh and Singh 2013). All statistical tests were run at an alpha levels of 0.01 (99% confidence level) and 0.05 (95% confidence level. Weaker trends could potentially be present at lower confidence levels (e.g., 90% confidence), with a correspondingly higher risk of false positives and negatives. The absence of a trend at a high confidence level does not mean that a trend does not exist. This absence simply means that a trend cannot be clearly identified. A weaker, less distinct trend may still exist and merit further investigation.

2 Results

2.1 Total Phosphorus

Annual geometric mean values for total phosphorus (TP) are presented in Figure 2 for the upper 30 m and the photic zone for the core monitoring sites in the northern Lake at Tubbs Hill (C1) and University Point (C4). Most productivity occurs in the photic zone, but nutrients from the entire upper 30 m can become bioavailable. These data show the following.

1. ***Annual geometric mean in upper 30 meters***— measure of average annual phosphorus in the lake that could mix into the productive surface waters and become bioavailable
    - *Tubbs Hill*— met or exceeded the trigger criteria of 8 µg/L for 2017 – 2018.
    - *University Point*—exceeded the trigger criteria of 8 µg/L for 2015 – 2018.
    - Both locations suggest a trend of increasing total phosphorus, with the highest total phosphorus levels ever reported occurring in 2018.
    - Phosphorus levels in the upper 30 m are consistently higher at C4 University Point than at C1 Tubbs Hill.
2. ***Annual median in the photic zone***— measure of typical annual phosphorus levels in the productive surface waters
    - Generally mirrors the trend for annual geometric mean in the upper 30 m at both locations, and exceeded the annual target for 2015 – 2018 at C1 Tubbs Hill.
    - Also had the highest reported total phosphorus levels occurring in 2018.
    - Phosphorus levels in the photic zone are not consistently higher at one location. Either C1 Tubbs Hill or C4 University Point can be higher in any given year.

These data show that total phosphorus targets for the lake are being exceeded in both the photic zone and upper 30 m at both core monitoring stations in the northern lake. Phosphorus levels appear to be increasing at both sites, and observed concentrations in recent years are the highest on record. Phosphorus trigger criteria have consistently been exceeded for 2015 – 2018, and appear to be trending upward.

The presence or absence of long-term trends is assessed here via a Mann-Kendall statistical analysis. This analysis can evaluate either annual or seasonal trends. Only annual trends are assessed in this status report. Seasonality will be evaluated in other studies. Results from Mann-Kendall analysis for long-term *annual* trends in total phosphorus are provided in Table 1. Trend charts are presented in Figure 3 for C1 Tubbs Hill, and Figure 4 for C4 University Point. These trend analyses show that total phosphorus is increasing at all depths at both monitoring locations.

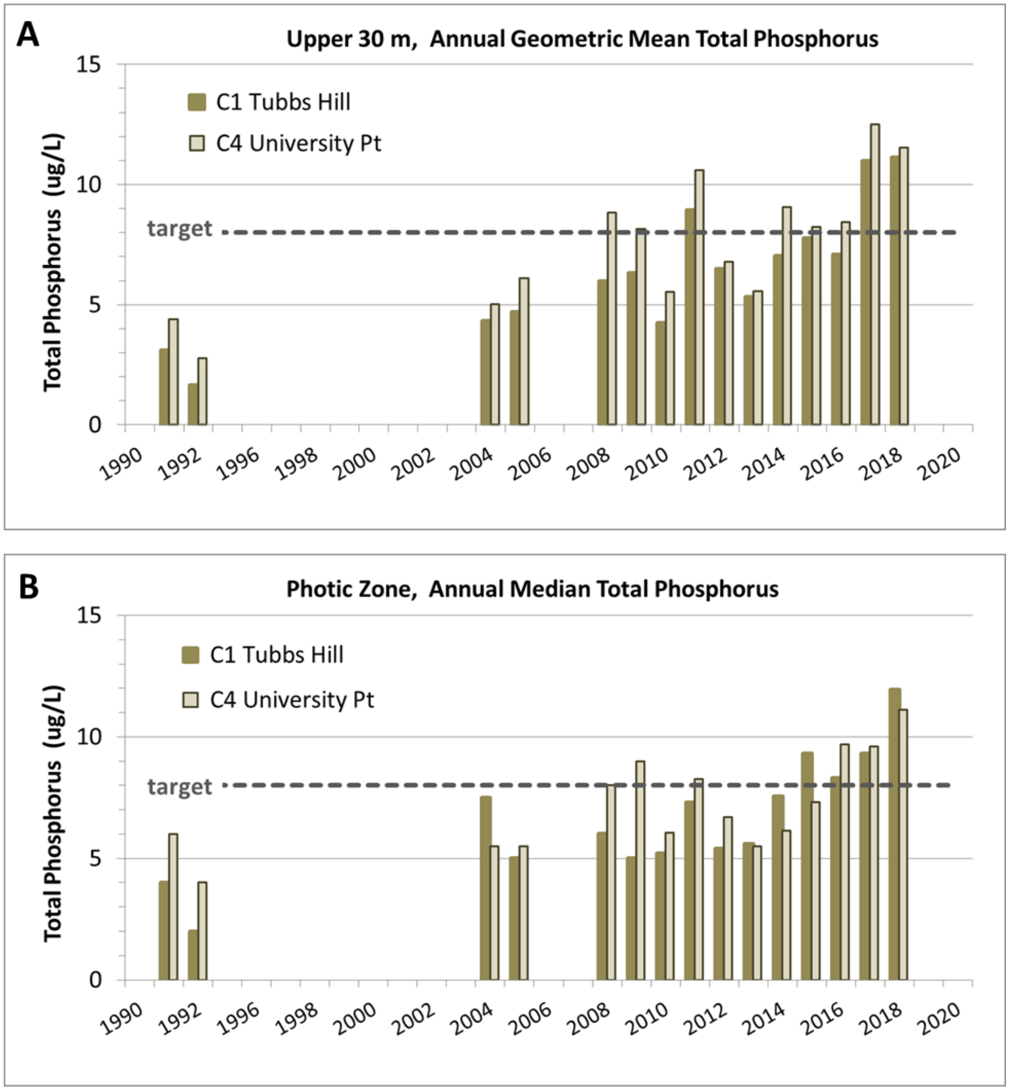


Figure 2. Total Phosphorus at C1 Tubbs Hill and C4 University Point, annual geometric mean over upper 30 m (A) and annual median in the photic zone (B).

The annual phosphorus trend analyses summarized in Table 1 demonstrate that comparable total phosphorus trends are observed at both monitoring locations in the lake's northern and central pools. Prior analyses indicated a trend of increasing total phosphorus at all depths in the northern and central pools (C1 Tubbs Hill, C4 University Point). Either neutral or decreasing trends were observed in the southern pools (C5 Chippy Point, C6 Chatcolet Lake). For the northern lake, the previously reported annual trends continue in the 2004 – 2018 time period and may be strengthening (e.g. greater increase).

1. *C1 Tubbs Hill (northern pool)*— increasing total phosphorus
    - For 2004 – 2014, a trend of increasing total phosphorus was observed at all depths. All trends were significant to greater than 95% confidence. Total phosphorus increased at an average rate of approximately 0.1 – 0.3 μg/L per year.
    - For 2004 – 2018, a trend of increasing total phosphorus is observed at all depths. All trends were significant to greater than 99.9% confidence. Total phosphorus increased at an average rate of approximately 0.3 – 0.4 μg/L per year.
    - The higher long-term rate of annual rate of total phosphorus increase observed for the 2004 – 2018 time period (relative to 2004-2014) results from rapid increases in total phosphorus in recent years (2015 – 2018). Statistically significant trends for the shorter 2015 – 2018 dataset occur at 20 m depth (1.3 μg/L per year, 95% confidence, p=0.04), and the near bottom (1.7 μg/L per year, 99% confidence, p=0.004). Phosphorus levels also increase in the photic zone, but the trend is not significant to within 95% confidence (0.8 μg/L per year, p=0.06)
2. *C4 University Point (central pool)*— increasing total phosphorus
    - For 2004 – 2014, a trend of increasing total phosphorus was only observed at 30 m depth. This trend was significant to greater than 95% confidence. Total phosphorus increased at an average rate of approximately 0.1 μg/L per year. No trends were observed at other depths.
    - For 2004 – 2018, a trend of increasing total phosphorus is observed at all depths. All trends were significant to greater than 99% confidence. Total phosphorus increased at an average rate of approximately 0.3 – 0.4 μg/L per year.
    - The higher long-term rate of annual rate of total phosphorus increase observed for the 2004 – 2018 time period (relative to 2004-2014) arises from steady increases in total phosphorus in recent years (2015 – 2018). Phosphorus levels are increasing relative to the long term dataset, but there is too much noise in the dataset to detect a statistically significant trend just for the 2015 – 2018 time period.

These trend analyses suggest that total phosphorus levels have begun to rise more rapidly in the lake and that the increase is more consistent across differences in annual hydrology. Annual average increases from 2015 – 2018 may be up to 3 times higher than what was previously reported for the 2004 – 2014 time period. The cause of this more rapid increase in recent years is unknown. These increases coincide with recent years of high wildfire activity and fire may be a contributing factor. Future analyses will assess this possibility. However, there is insufficient data to make a firm conclusion at this point. It is unknown if this change in phosphorus reflects a shift in the lake's long-term status, or arises from a shorter-term perturbation.

Table 1. Annual Mann-Kendall trend analysis for total phosphorus (TP) at core monitoring sites in the northern lake for both the 2004-2014 time period and the updated 2004-2018 time period.

Time Period	Site	Depth	Variable	Mann-Kendall Trend Test (2004–2014, 2004-2018) Total Phosphorus			
				Sample Size (n)	P-Value [1]	Theil-Sen Slope [2]	Trend
2004–2014	C1	Photic zone	TP	79	*0.025*	*0.13*	*Increasing*
	C1	20-meter depth	TP	72	**0.002**	**0.18**	**Increasing**
	C1	30-meter depth	TP	61	**0.001**	**0.27**	**Increasing**
	C1	Near bottom	TP	75	*0.018*	*0.17*	*Increasing*
2004-2018 (updated)	C1	Photic zone	TP	111	**0.000**	**0.32**	**Increasing**
	C1	20-meter depth	TP	104	**0.000**	**0.33**	**Increasing**
	C1	30-meter depth	TP	78	**0.000**	**0.46**	**Increasing**
	C1	Near bottom	TP	108	**0.000**	**0.41**	**Increasing**
2004-2014	C4	Photic zone	TP	81	0.30	0.02	None
	C4	20-meter depth	TP	76	0.26	0.06	None
	C4	30-meter depth	TP	60	*0.013*	*0.37*	*Increasing*
	C4	Near bottom	TP	81	0.016	0.12	None
2004-2018 (updated)	C4	Photic zone	TP	113	**0.001**	**0.23**	**Increasing**
	C4	20-meter depth	TP	107	**<0.001**	**0.26**	**Increasing**
	C4	30-meter depth	TP	84	**0.000**	**0.40**	**Increasing**
	C4	Near bottom	TP	112	**<0.001**	**0.39**	**Increasing**

1. Bold P-values are statistically significant at α=0.01 Italic P-values are statistically significant at α=0.05. P values between α=0.05 and α= 0.1 indicate potential trends that merit further analysis
2. Theil-Sen slope is in units of micrograms per liter (µg/L) per year. Positive slope is an increase.

Annual monitoring data for total phosphorus are plotted relative to both the 2004 – 2014 trend lines and the 2004 – 2018 trend lines in Figure 3 (Tubbs Hill) and Figure 4 (University Point). The presence or absence of a trend is assessed via a Mann-Kendall analysis. The approximate magnitude of the trend is estimated from a Theil-Sen fit to the data, which is a linear regression technique appropriate for stochastic, non-normal datasets.

Monitoring data are shown for each depth and sampling event for which there is a data record, including prior studies conducted by the U.S. Geological Survey. Photic zone survey data collected during summer months (Jun-Oct) for a DEQ study from 1995 – 2002 are also shown. These plots demonstrate that annual median total phosphorus levels are increasing, even though seasonal cycles and inter-annual variability can obscure the calculated trends. The trends are most visually apparent in the annual minimum values and annual median values. Key aspects of the trends are summarized below.

1. *Tubbs Hill (C1, northern pool)*— total phosphorus increasing at all depths.
   - The increasing trend observed for 2004 – 2018 is consistent with the previously reported increasing trend for 2004 – 2014.
   - The rate of increase in phosphorus is higher for 2004 – 2018 than was previously reported for 2004 – 2014. The statistical significance of the calculated trends has increased at all depths (lower p-value).
   - Since 2014, annual median values are at or above the trigger criteria of 8 µg/L for almost all depths for which there is monitoring data. The sole exception to this is the near bottom depth interval in 2016.
   - The highest annual median and annual minimum values on record occurred in the past two years (2017, 2018).
2. *University Point (C4, central pool)*— total phosphorus increasing at all depths.
   - The increasing trend observed for 2004 – 2018 reflects a change from previously reported trends for this site. Phosphorus is now increasing at all depths.
   - The rate and extent of increase in phosphorus is higher for 2004 – 2018 than was previously reported for 2004 – 2014. Phosphorus was only increasing at 30 m depth for the 20014 – 2014 analysis. Now, phosphorus is increasing at all depths, the rate is higher, and the statistical significance of the calculated trends has increased.
   - Since 2014, annual median values are at or above the trigger criteria of 8 µg/L for almost all depths for which there is monitoring data. The sole exceptions to this are the photic zone in 2015 and 30 m depth in 2016.
   - The highest annual median and annual minimum values on record occurred in the past two years (2017, 2018).

These analyses indicate that total phosphorus levels are increasing at all depths at both core monitoring sites in the northern lake. The rate of increase may have accelerated since 2014.

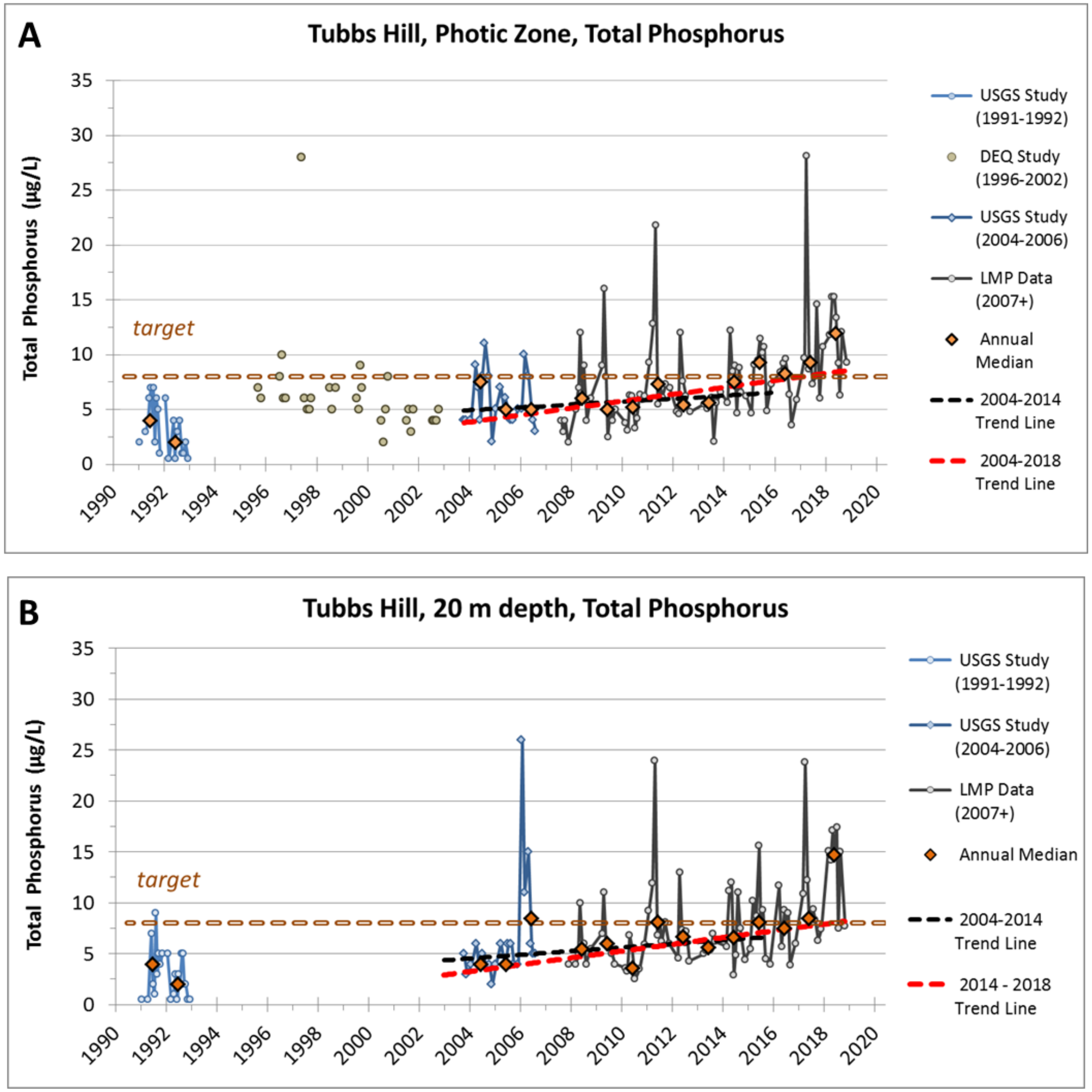
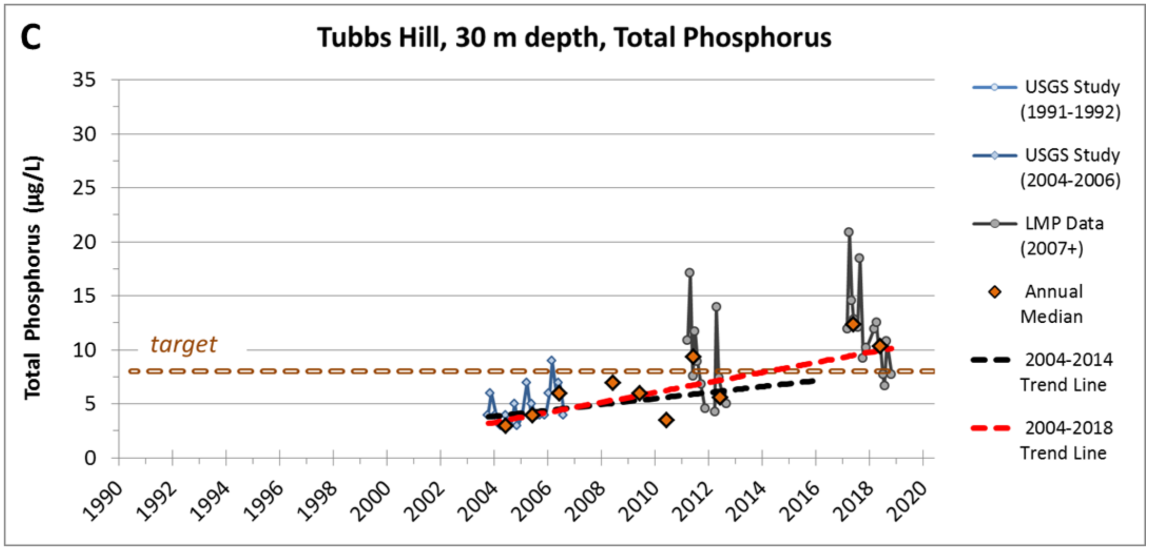


Figure 3. Total phosphorus trend data for the C1 Tubbs Hill monitoring site in the photic zone (A), 20 m depth (B), 30 m depth (C), and near bottom (D) depth intervals.



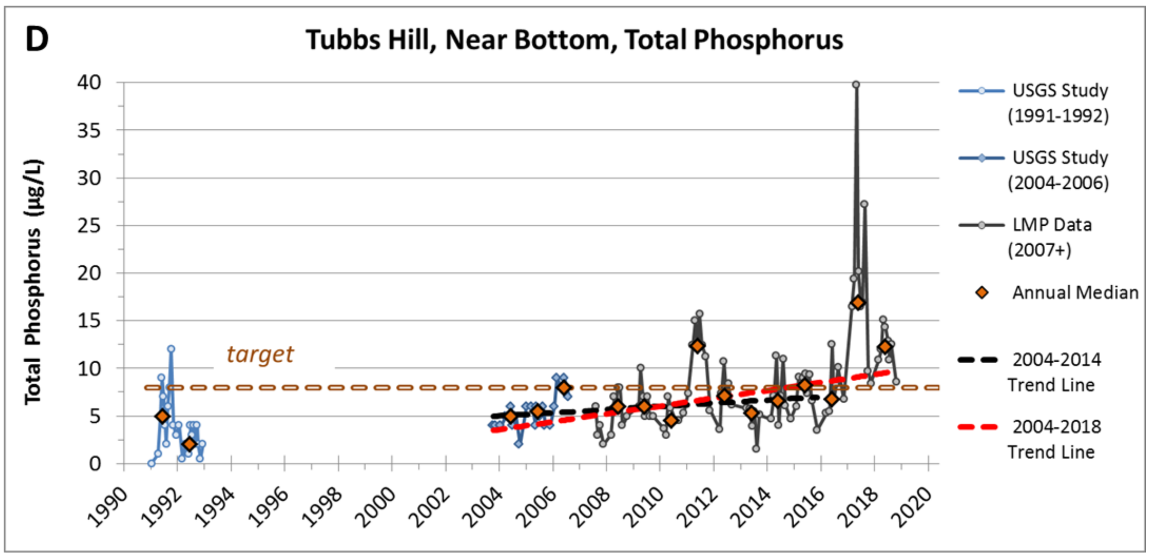
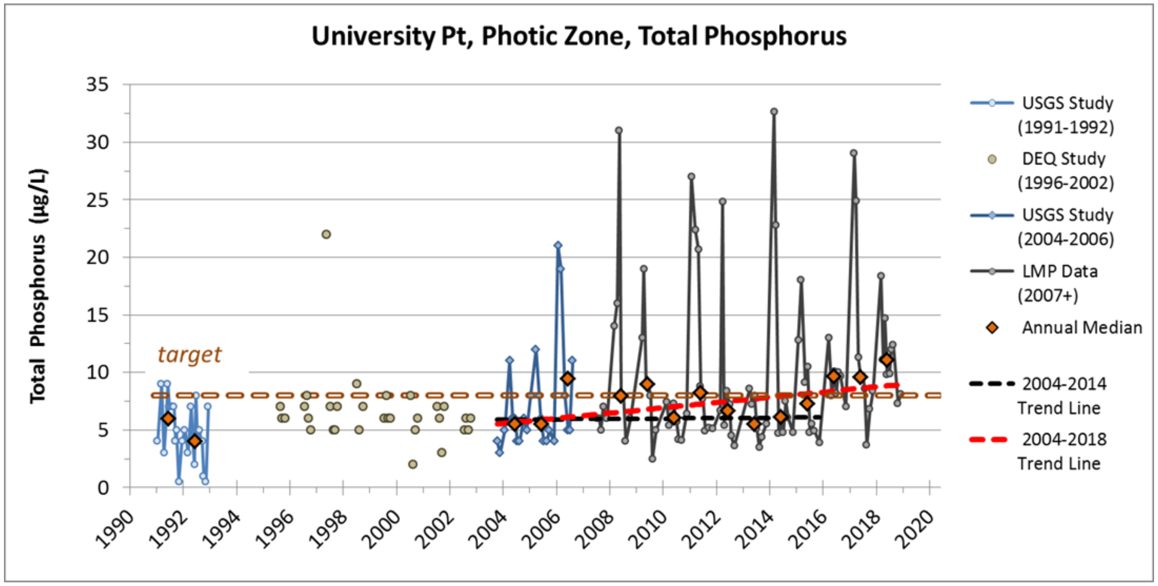


Figure 3 (continued). Total phosphorus trend data for the C1 Tubbs Hill monitoring site in the photic zone (A), 20 m depth (B), 30 m depth (C), and near bottom (D) depth intervals.



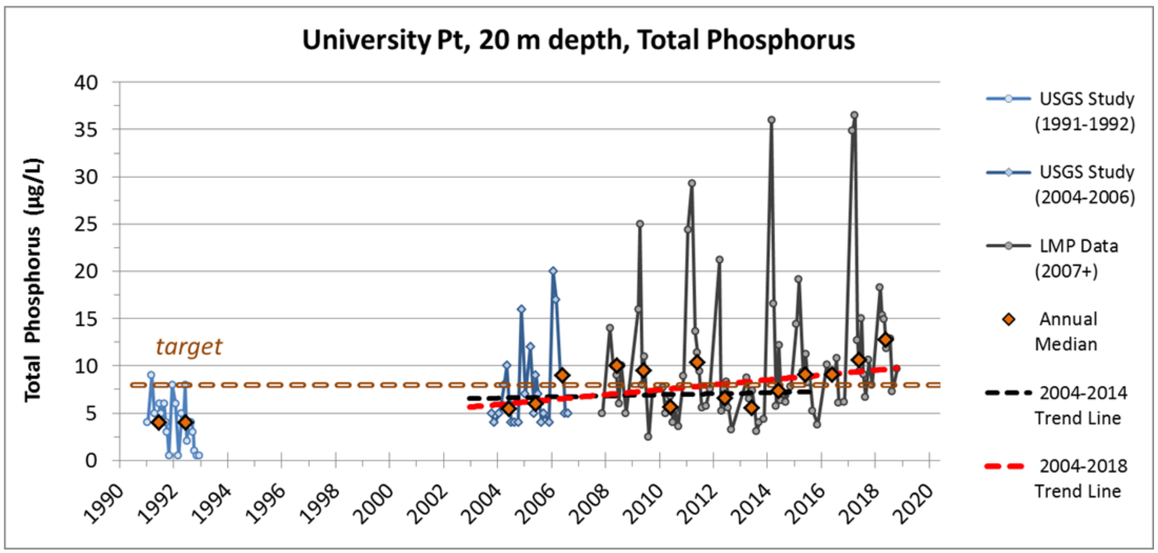
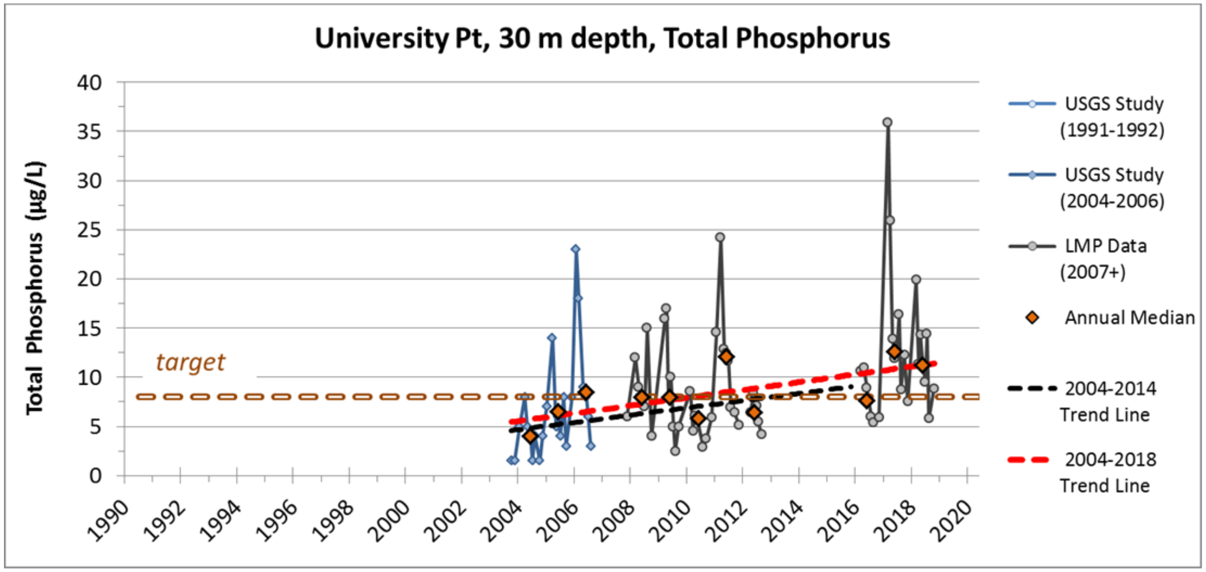


Figure 4. Total phosphorus trend data for the C4 University Point monitoring site in the photic zone (A), 20 m depth (B), 30 m depth (C), and near bottom (D) depth intervals.



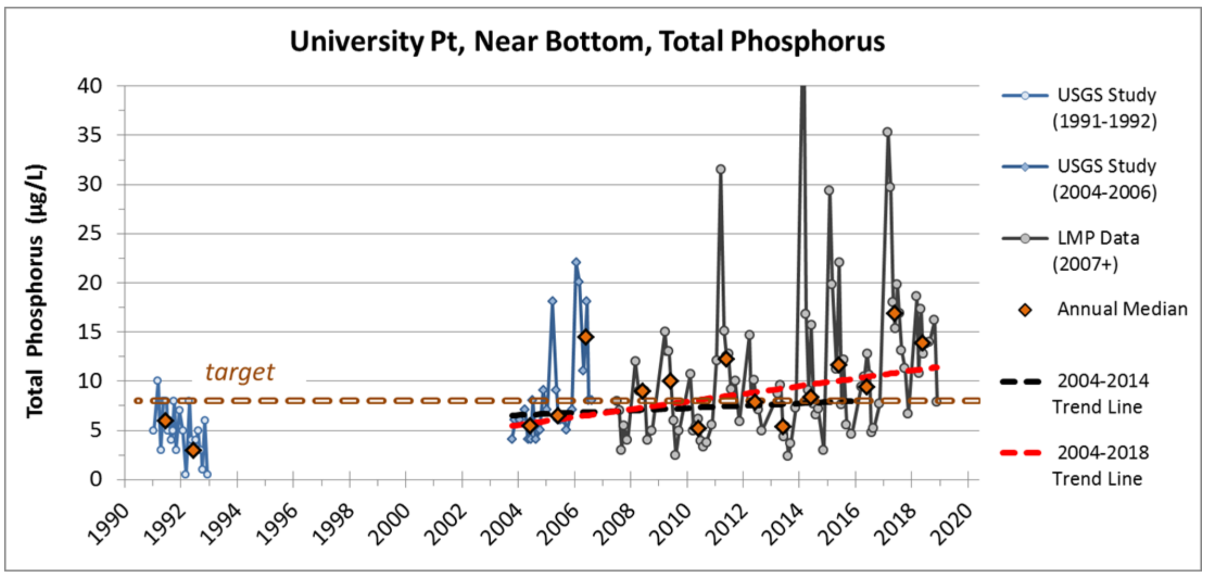


Figure 4 (continued). Total phosphorus trend data for the C4 University Point monitoring site in the photic zone (A), 20 m depth (B), 30 m depth (C), and near bottom (D) depth intervals.

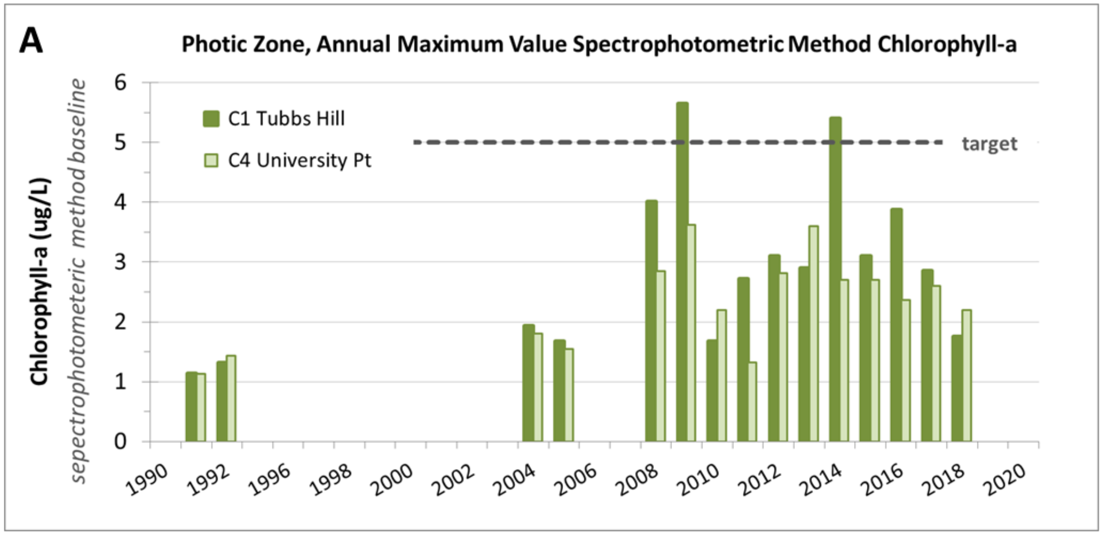
2.2 Chlorophyll *a*

Annual maximum and annual geometric mean values for chlorophyll-a are presented in Figure 5 for the photic zone at C1 Tubbs Hill and C4 University Point . The chlorophyll-a values are plotted relative to a baseline that assumes all analyses were conducted using EPA standard methods and analyzed using the spectrophotometric detection method used by the locally available analytical laboratories who have provided chlorophyll-a analyses since 2014. These spectrophotometric equivalent results are now used to assess status and trends. A comparison of what chlorophyll-a values would be if they had been analyzed via the fluorescence detection method used prior to 2014 is shown in Figure 6 and Figure 7. These data show the following.

1. ***Annual maximum chlorophyll-a***— measure of influence of seasonal blooms
   a. *Tubbs Hill*— has not exceeded the trigger criteria of 5 µg/L since 2014.
   b. *University Point*— has never exceeded the trigger criteria of 5 µg/L.
   c. The highest maximum chlorophyll-a values are seen at C1 Tubbs Hill, but neither location is consistently higher than the other.
2. ***Annual geometric mean chlorophyll-a***— measure of overall annual plankton population
   a. *Tubbs Hill*— has never exceeded the trigger criteria of 3 µg/L
   b. *University Point*— has never exceeded the trigger criteria of 3 µg/L
   c. The highest annual geometric mean chlorophyll-a values are seen at C1 Tubbs Hill, but neither location is consistently higher than the other.

Chlorophyll-a assessments for Coeur d'Alene Lake are complicated by the use of different chlorophyll-a analytical methods during the period of record. USGS data collected in 1991-1992 utilized a HPLC method (High Performance Liquid Chromatography). From 2003 – 2014, chlorophyll-a data was provided by either the USGS or USEPA Region 10 laboratory using the fluorescence method. Since 2014, data are from local analytical laboratories that use a mix of the spectrophotometric and the fluorescence method. Duplicate samples were analyzed using both of these methods from 2009 – 2014. Method intercomparison studies have shown that, for the northern regions of the lake, analyses conducted via the 2003-2014 fluorescence method are biased upwards relative to what would be measured via the spectrophotometric method (DEQ, 2017). However, equivalent values for either method can be calculated using linear relationships developed from the method intercomparison studies. Annual maximum and annual median chlorophyll-a values are shown for both method equivalents for the Tubbs Hill (Figure 6) and University Point (Figure 7) monitoring sites. In these plots, the term "F-Chla" refers to equivalent values for the fluorescence method baseline and the term "S-Chla" refers to equivalent values for the spectrophotometric method baseline.

Analysis of data from these two different methods yields similar conclusions. The maximum chlorophyll-a target is only exceeded rarely, and is most often exceeded at site C1 Tubbs Hill. The annual geometric mean target has only been exceeded once, in 2009. The only exceedance since 2014 occurs for the maximum chlorophyll-a, via the higher fluoresence method equivalent value, in 2016. A strong trend is not apparent for either dataset for 2004 – 2018.



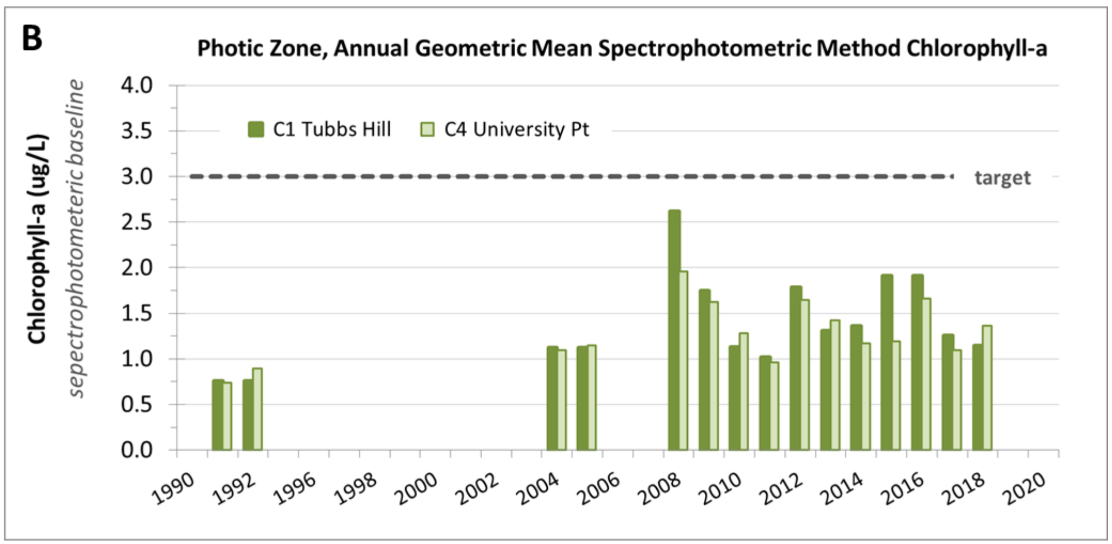


Figure 5. Annual maximum chlorophyll-a (A) and annual geometric mean chlorophyll-a (B) at the C1 Tubbs Hill and C4 University Point monitoring sites.

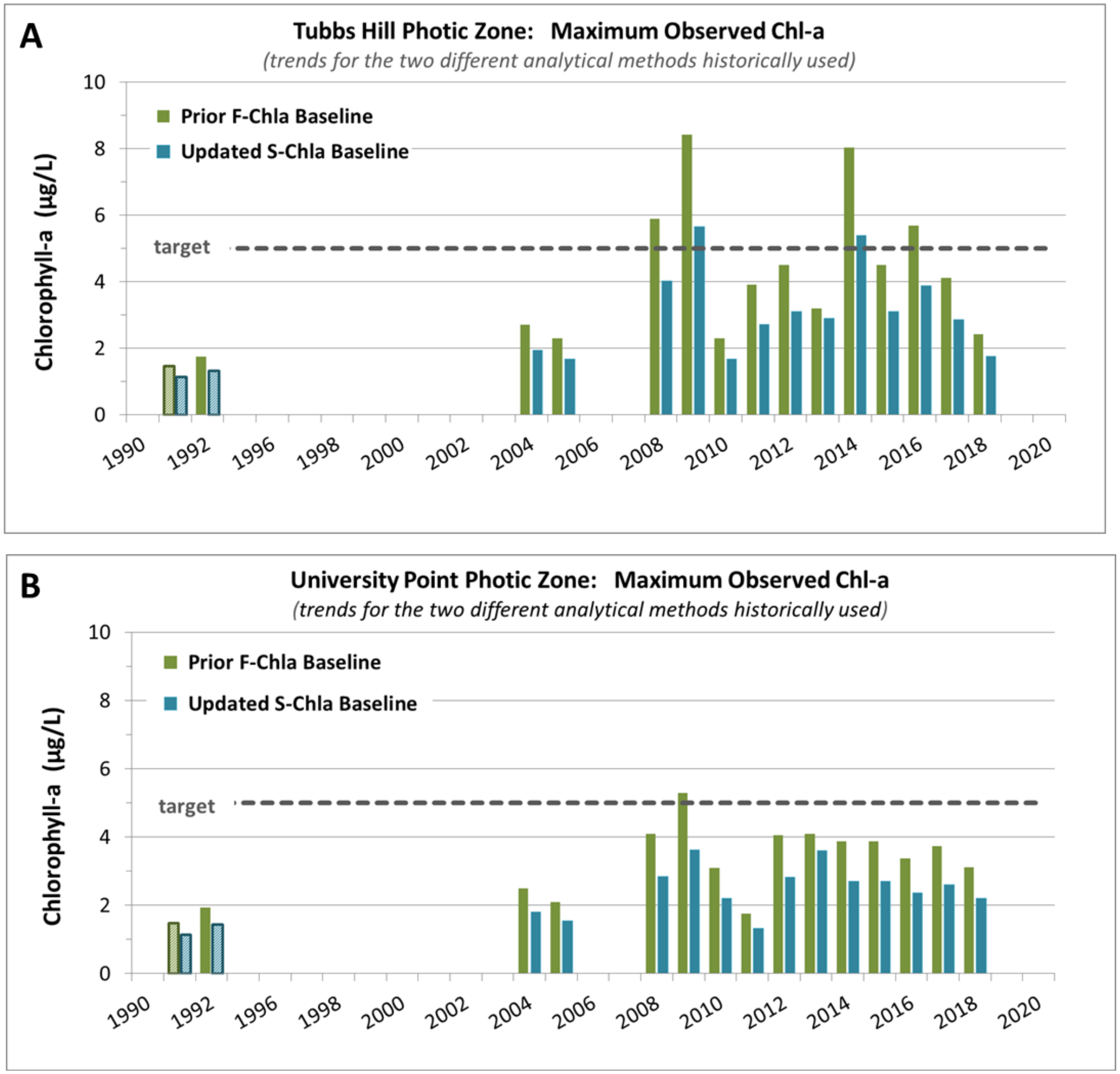
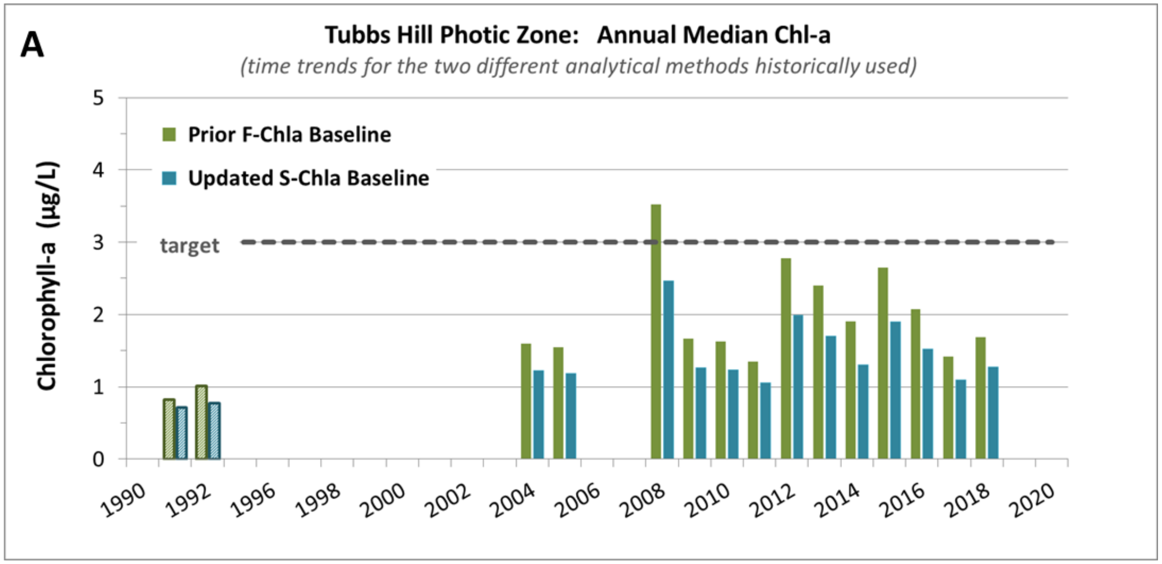


Figure 6. Comparison of annual maximum chlorophyll-a for the two different analytical methods historically used at the C1 Tubbs Hill (A) and C4 University Point (B) monitoring sites.



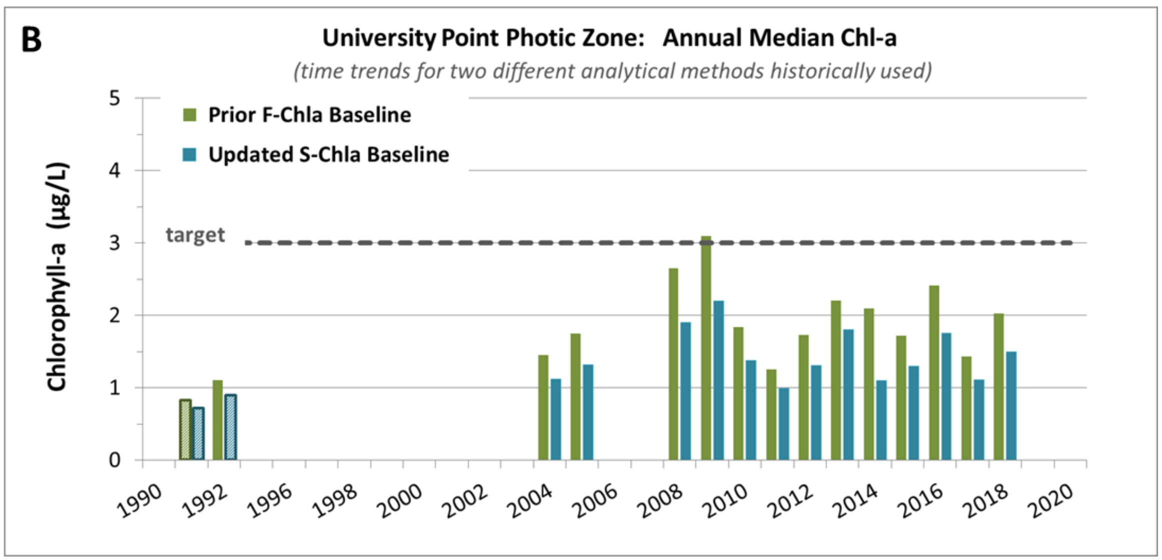


Figure 7. Comparison of annual median chlorophyll-a for the two different analytical methods historically used at the C1 Tubbs Hill (A) and C4 University Point (B) monitoring sites.

Results from annual Mann-Kendall statistical analysis of long-term annual trends in total both spectrophotometric method chlorophyll-a (S-Chla) and fluorescence method chlorophyll-a (F-Chla) are provided in Table 2. These analyses are provided for both the F-Chla and S-Chla baseline for this report. Future reports will only consider the S-Chla baseline. These data show the following.

1. ***Spectrophotometric Method Chlorophyll-a*** — current method
   a. *Tubbs Hill*— no trend observed for either 2004-2014 or 2004-2018
   b. *University Point*— no trend observed for either 2004-2014 or 2004-2018
   c. Neither location currently shows an annual trend for chlorophyll-a
2. ***Fluoresence Method Chlorophyll-a*** — historic method
   a. *Tubbs Hill*— potential for an increasing trend was observed for 2004-2014, no trend is observed for 2004-2018
   b. *University Point*— potential for an increasing trend was observed for 2004-2014, no trend is observed for 2004-2018
   c. Neither location currently shows an annual trend for chlorophyll –a

Table 2. Annual Mann-Kendall trend analysis for chlorophyll-a samples normalized to the historic fluorescence method baseline (F-Chla) and current spectrophotometric method baseline (S-Chla) for both the 2004-2014 and 2004-2018 time period at LMP core monitoring sites.

Time Period	Site	Depth	Variable	Mann-Kendall Trend Test (2004–2014, 2004-2018) Fluorescence Method Chl-a			
				Sample Size (n)	P-Value [1]	Theil-Sen Slope [2]	Trend
2004–2014 (S-Chla)	C1	Photic zone	Spec Chl-a	79	0.42	0.004	None
	C4	Photic zone	Spec Chl-a	78	0.38	0.004	None
2004-2018 (S-Chla)	C1	Photic zone	Spec Chl-a	111	0.36	0.005	None
	C4	Photic zone	Spec Chl-a	111	0.37	0.001	None
2004–2014 (F-Chla)	C1	Photic zone	Fluor Chl-a	79	0.09	0.04	Potential
	C4	Photic zone	Fluor Chl-a	78	0.08	0.04	Potential
2004-2018 (F-Chla)	C1	Photic zone	Fluor Chl-a	111	0.20	0.02	None
	C4	Photic zone	Fluor Chl-a	111	0.24	0.01	None

1. Bold P-values are statistically significant at α=0.01. Italic P-values are significant at α=0.05. P values between α=0.05 and α= 0.1 indicate potential trends that merit further evaluation.
2. Theil-Sen slope is in units of micrograms per liter (μg/L) per year. Positive slope is an increase.

Trend charts for chlorophyll-a are presented in Figure 8 for C1 Tubbs Hill, Figure 9 for C4 University Point. These charts show both the original value as measured via the analytical method used at the time, and as normalized to the spectrophotometric method baseline (S-corrected). For logistical reasons, the spectrophotometric equivalent results are now used to assess status and trends for chlorophyll-a. The presence or absence of a trend is assessed via a Mann-Kendall analysis. The approximate magnitude of the trend is estimated from a Theil-Sen fit to the data. Monitoring data are shown for each depth and sampling event for which there is a data record, including prior studies conducted by the U.S. Geological Survey. These plots demonstrate that annual median chlorophyll-a levels are not changing, to within the ability of this statistical technique to identify trends for this dataset. The presence or absence of seasonally specific trends is not assessed. Key aspects of these data are summarized below.

1. *C1 Tubbs Hill (northern pool)*— no annual trend in chlorophyll-a
    - Normalizing historic chlorophyll-a data analyzed via the fluorescence method to the equivalent spectrophotometric method value lowers chlorophyll-a by ~0.5 – 1 μg/L. The magnitude of the bias is proportional to concentration.
    - Prior analyses identified a potential trend in fluorescence method chlorophyll-a for the 2004 – 2014 time period. No trend is now observed for the 2004 – 2018 time period for either the fluorescence or spectrophotometric data.
    - Since 2014, annual median data bracket the trend line, with maximum observed concentrations remaining below 4 μg/L.
2. *C4 University Point (central pool)*— no annual trend in chlorophyll-a
    - Normalizing historic chlorophyll-a data analyzed via the fluorescence method to the equivalent spectrophotometric method value lowers chlorophyll-a by ~0.5 – 1 μg/L. The magnitude of the bias is proportional to concentration.
    - Prior analyses identified a potential trend in fluorescence method chlorophyll-a for the 2004 – 2014 time period. No trend is now observed for the 2004 – 2018 time period for either the fluorescence or spectrophotometric data.
    - Since 2014, annual median data bracket the trend line, with maximum observed concentrations remaining below 3 μg/L.

These analyses indicate that annual median chlorophyll-a levels are not experiencing a long-term trend, to within the ability of this method to resolve change. The utilization of different chlorophyll-a analytical methods over the history of lake monitoring increases the uncertainty of trend analyses. The presence or absence of a seasonally specific trend has not been evaluated.

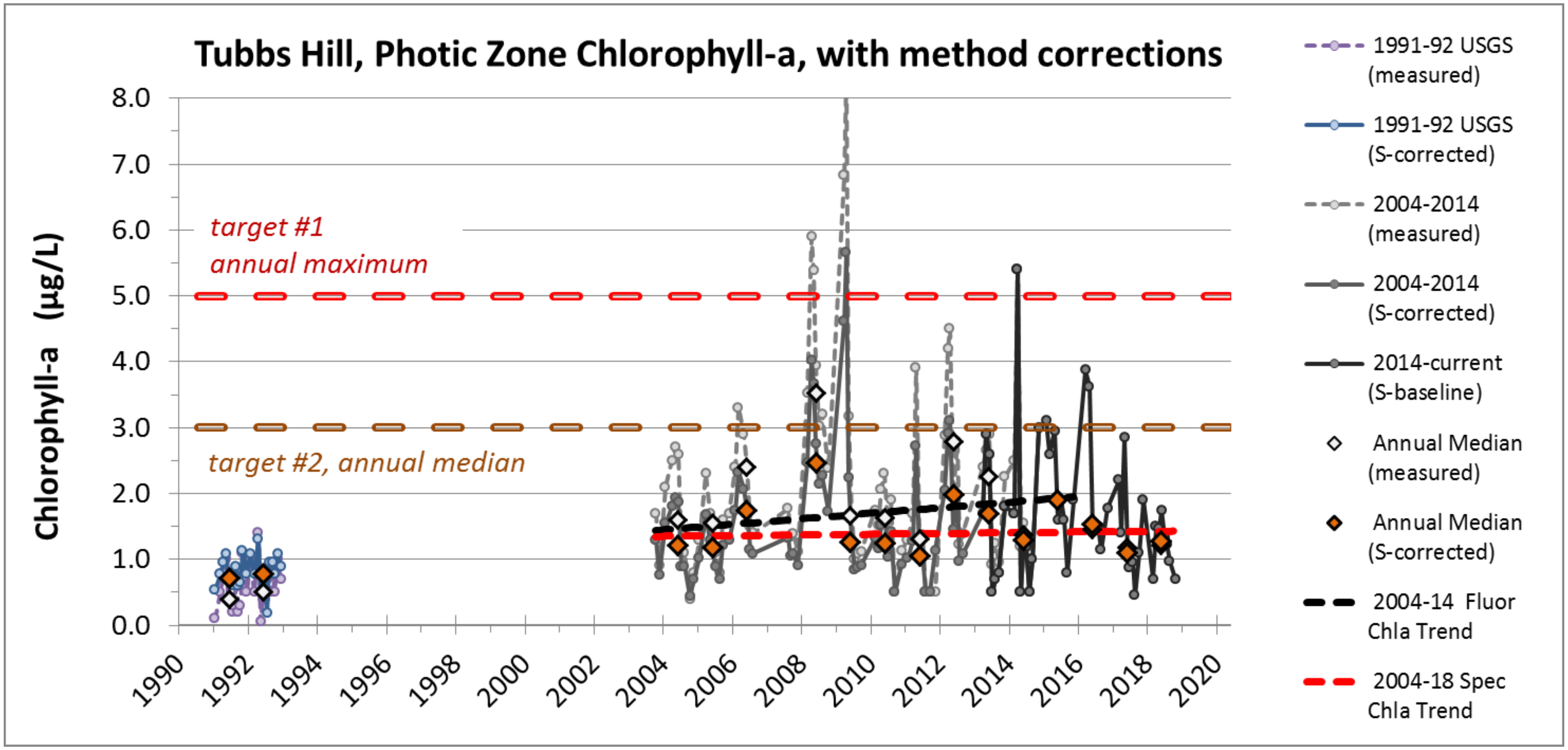


Figure 8. *C*hlorophyll-a trend data for the photic zone at the C1 Tubbs Hill monitoring site.

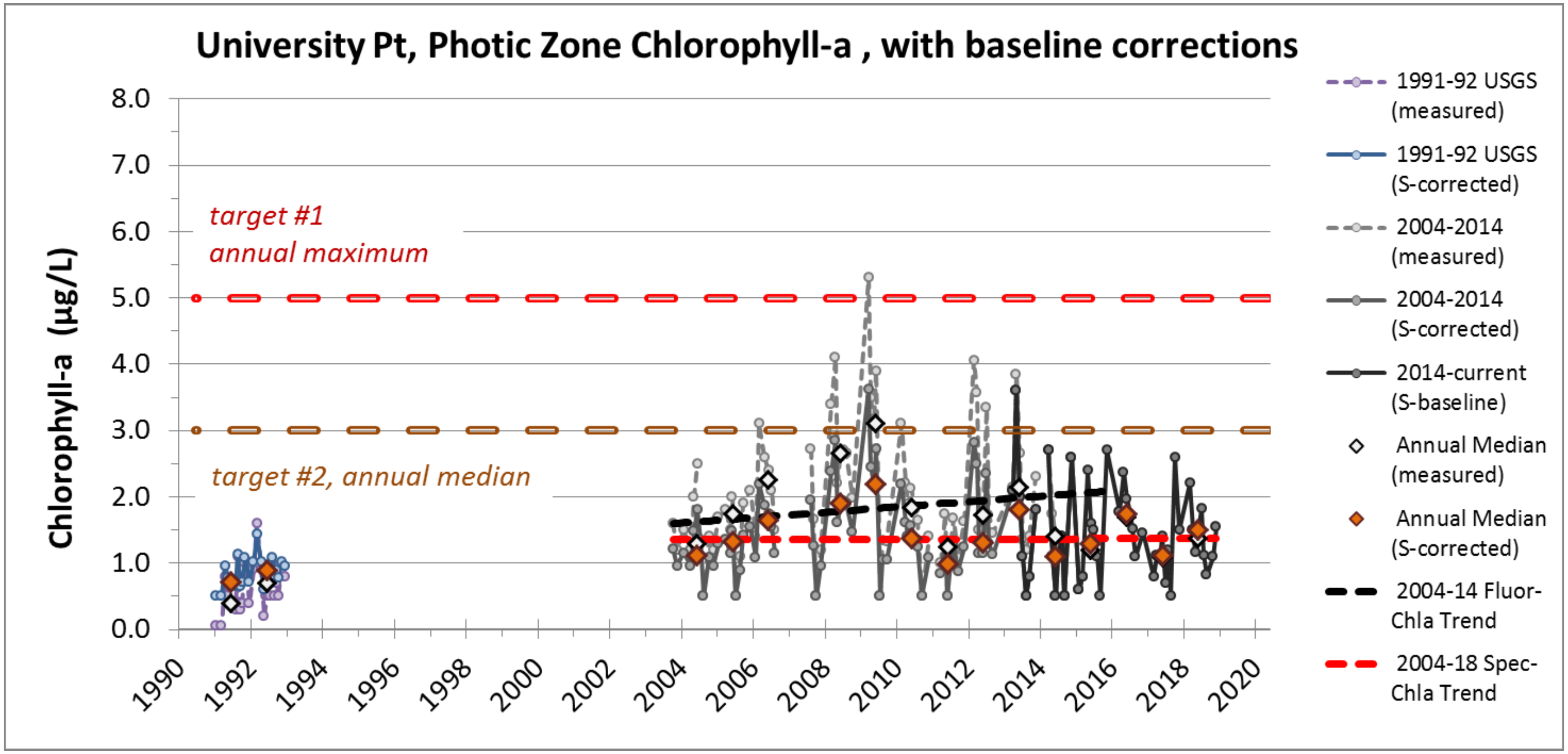


Figure 9. Chlorophyll-a trend data for the photic zone at the C4 University Point monitoring site.

2.3 Dissolved Oxygen

Observed minimum values for near bottom dissolved oxygen in the hypolimnion during the summer stratified period (July – October) are presented in Figure 11 for both the C1 Tubbs Hill and C4 University Point monitoring sites. Summer median dissolved oxygen data are also provided as an additional point of reference. These data show the following.

1. ***Summer minimum dissolved O2***— measure of risk of metals release
    - *Tubbs Hill*— has not dropped below the trigger level of 6 mg/L since 2012.
    - *University Point*— has never been below the trigger level of 6 mg/L.
    - Minimum hypolimnetic dissolved oxygen levels measured at 1.0 above the sediment surface are consistently lower at C1 Tubbs hill than at C4 University Point.
2. ***Summer median dissolved O2***— measure of overall summer oxygen levels
    - *Tubbs Hill*— has ranged from 7 – 9 mg/L since 2012.
    - *University Point*— has ranged from 8 – 9 mg/L since 2012.
    - Median hypolimnetic dissolved oxygen levels measured at 1.0 above the sediment surface, over the summer-stratified period, are consistently lower at C1 Tubbs hill than at C4 University Point.

Analysis of these complimentary datasets yield similar conclusions. The minimum dissolved oxygen target is only rarely exceeded, and then only at site C1 Tubbs Hill. The median value and minimum value vary similarly, and neither appear to display a strong trend. In recent years (2016 – 2017), median near bottom dissolved oxygen levels have been among the highest on record. This is intriguing, as total phosphorus levels during this time period have been among the highest on record and median chlorophyll-a levels have been in the typical historic range.

Results from annual Mann-Kendall statistical analysis of long-term trends in dissolved oxygen are shown in Table 3. Results are given for both the high quality dataset available since 2004 and the lower quality, longer-term dataset available since 1991. These data show the following.

1. ***Site C1 Tubbs Hill***— northern pool, most distant from Coeur d'Alene River
    - *Trend since 1991*— a weak trend of declining oxygen was previously reported for 1991 – 2015. A statistically significant trend is not observed for 1991 – 2018.
    - *Trend since 2004*— no trend is observed for either 2004-2015 or 2004-2018
2. ***Site C4 University Point*** — central pool, closer to Coeur d'Alene River
    - *Trend since 1991*— the potential for a trend of declining oxygen was reported for 1991 – 2015. A statistically significant trend is not observed for 1991 – 2018.
    - *Trend since 2004*— no trend is observed for either 2004-2015 or 2004-2018

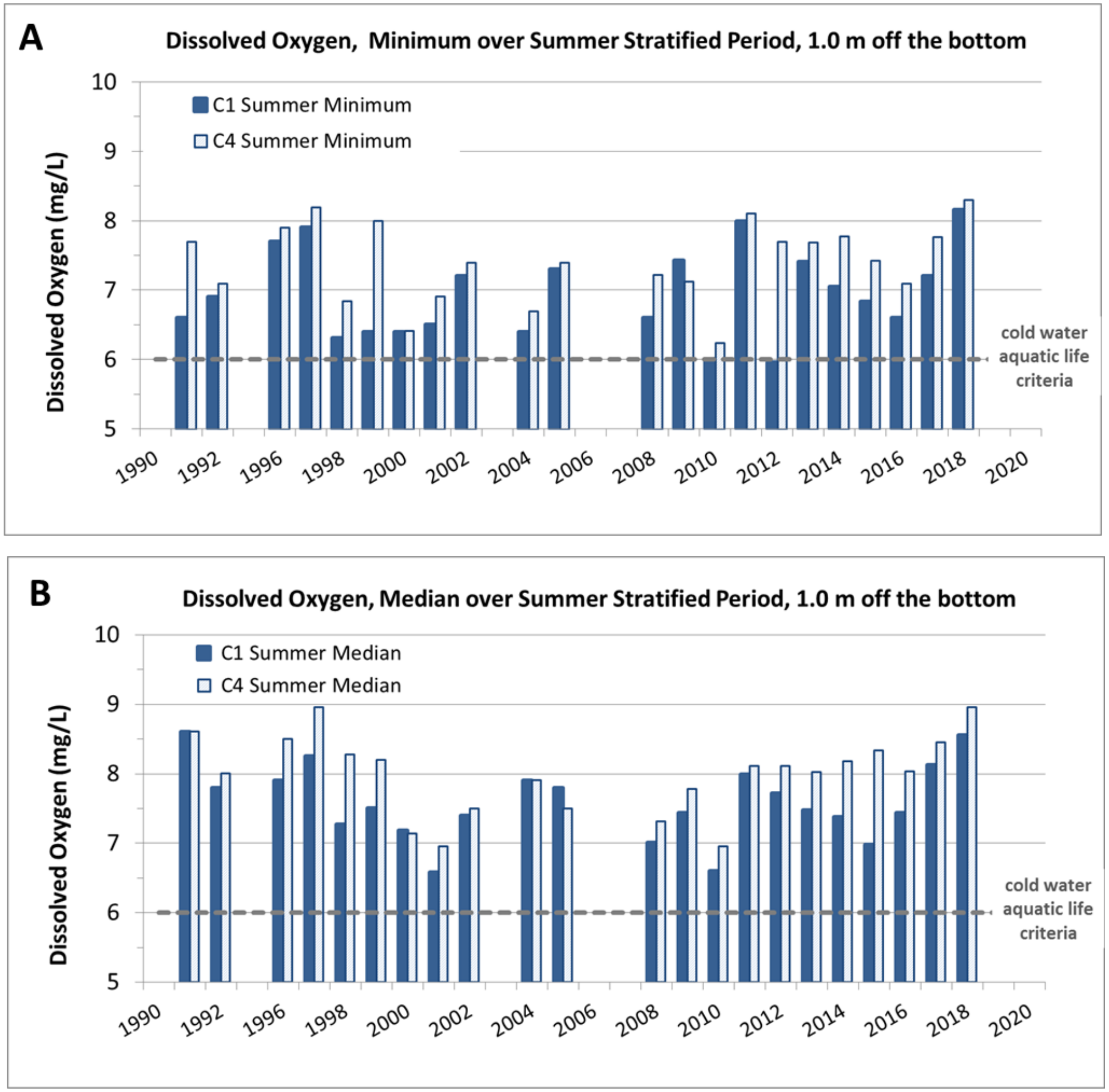


Figure 10. Annual minimum near bottom dissolved oxygen (A) and annual median near bottom dissolved oxygen (B) during the summer stratified period at the C1 Tubbs Hill and C4 University Point monitoring sites.

Table 3. Mann-Kendall trend analysis for near bottom hypolimnetic dissolved oxygen (DO) from 1991-2015, 1991 – 2018, 2004 – 2015, and 2004 – 2018 (current) during the summer stratified period at LMP core monitoring sites in the northern lake.

Time Period	Site	Depth	Variable	Mann-Kendall Trend Test (1991–2015, 1991—2018, 2004–2015, 2004—2018) Dissolved Oxygen in Hypolimnion			
				Sample Size (n)	P-Value [1]	Theil-Sen Slope [2]	Trend
1991–2015 (Jul-Oct)	C1	Near bottom	DO	77	*0.03*	*-0.03*	*Decreasing*
	C4	Near bottom	DO	73	*0.04*	*-0.02*	*Decreasing*
1991–2018 (Jul-Oct)	C1	Near bottom	DO	91	0.17	-0.01	None
	C4	Near bottom	DO	88	0.26	-0.01	None
2004–2015 (Jul-Oct)	C1	Near bottom	DO	39	0.08	-0.06	Potential Decrease
	C4	Near bottom	DO	35	0.49	0.00	None
2014–2018 (Jul-Oct)	C1	Near bottom	DO	53	0.38	0.01	None
	C4	Near bottom	DO	51	0.08	0.04	Potential Increase

1. Bold P-values are statistically significant at α=0.01. Italic P-values are statistically significant at α=0.05. P values between α=0.05 and α= 0.1 are potential trends that merit further analysis.
2. Theil-Sen slope is in milligrams per liter (mg/L) per year. Negative slope is a decrease.

Trend charts for near bottom dissolved oxygen are presented in Figure 12 for the C1 Tubbs Hill and C4 University Point monitoring sites in the northern lake. The presence or absence of a trend is assessed via a Mann-Kendall analysis. The approximate magnitude of the trend is estimated from a Theil-Sen fit to the data. Key aspects of these data are summarized below.

1. *C1 Tubbs Hill (northern pool)*— no current trend in near bottom dissolved oxygen
   - Dissolved oxygen levels since 2017 have been higher than the long-term median, and minimum observed values have remained above 7.0 mg/L.
   - A statistically significant trend is not observed for either 1991 – 2018 or 2014 – 2018.
2. *C4 University Point (central pool)*— no current trend in near bottom dissolved oxygen
   - Dissolved oxygen levels since 2017 have been higher than the long-term median, and minimum observed values have remained above 7.0 mg/L.
   - A statistically significant trend is not observed for either 1991 – 2018 or 2014 – 2018.
   - A potential trend of increasing dissolved oxygen is observed for 2014 – 2018.

These analyses indicate that median dissolved oxygen levels near the sediment surface during the summer stratified period are not experiencing a long-term trend, to within our ability to resolve change. Any potential influence of hydrology or temperature has not yet been assessed.

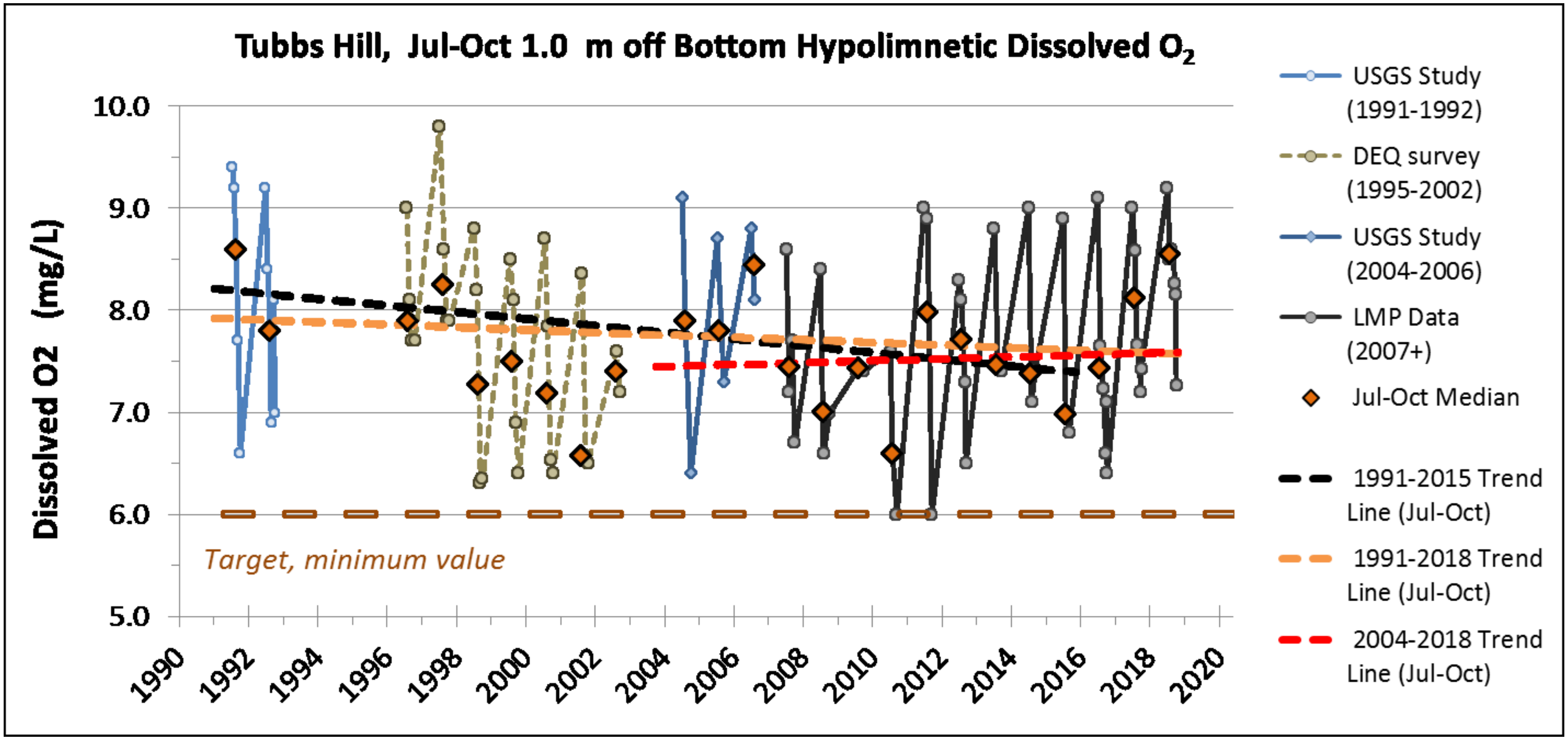


Figure 11. Near bottom dissolved oxygen trend data for the C1 Tubbs Hill monitoring site.

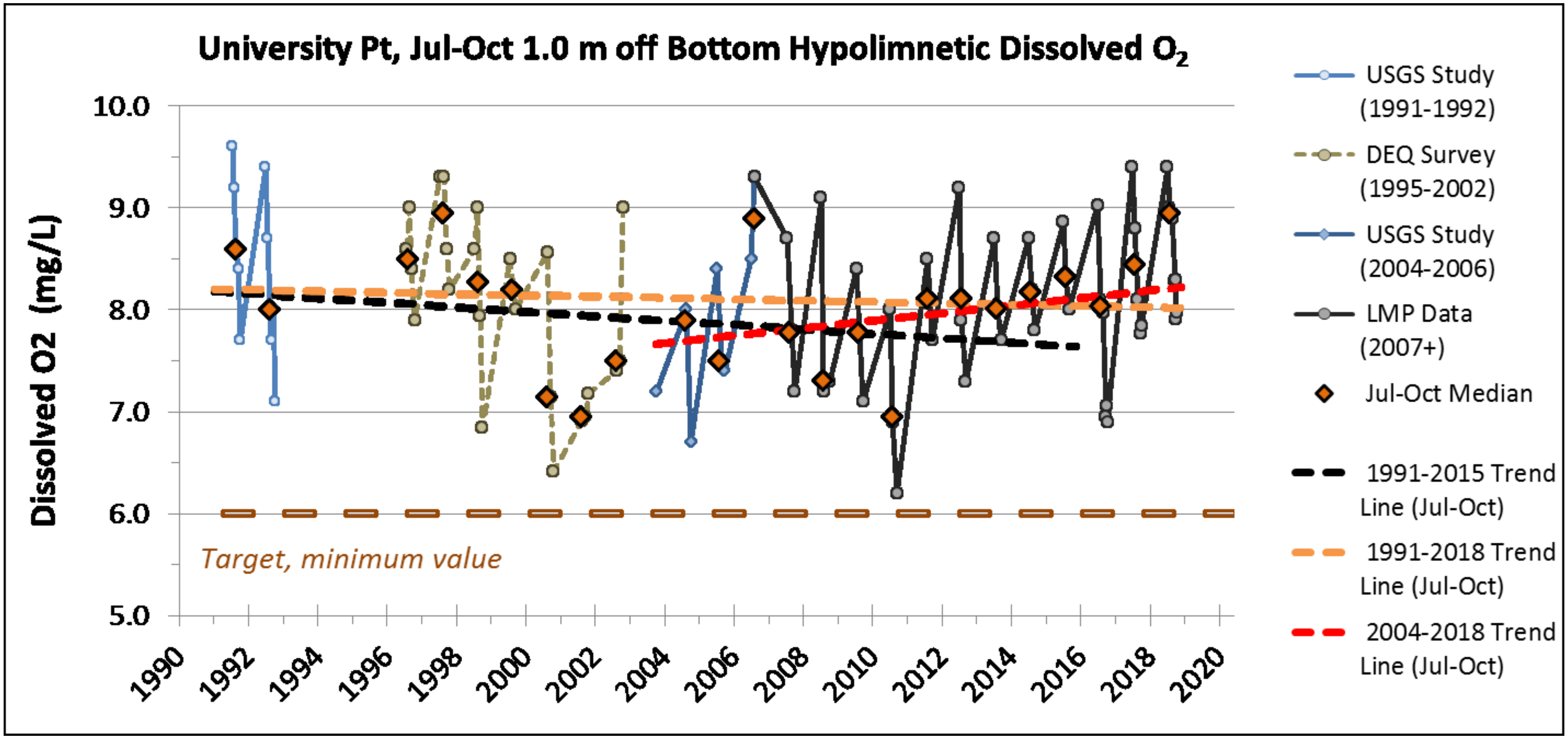


Figure 12. Near bottom dissolved oxygen trend data for the C4 University Point monitoring site.

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2.4 Dissolved Zinc

Annual geometric mean values for dissolved zinc over all depths at core monitoring sites in the northern lake are presented in Figure 13. Data for annual median dissolved zinc in the photic zone are also provided. Most productivity occurs in the photic zone, and zinc at these shallower depths has a greater impact on the overall lake ecosystem. These data show the following.

1. ***Annual geometric mean dissolved zinc over all depths***— measure of average annual dissolved zinc levels in the lake and overall status relative to water quality standards.
   a. *Tubbs Hill*—exceeded the trigger criteria of 36 µg/L for 2015 – 2018.
   b. *University Point*— exceeded the trigger criteria of 36 µg/L for 2015 – 2018.
   c. Both locations suggest a trend of decreasing dissolved zinc, with the lowest zinc levels ever reported occurring in 2018.
   d. Zinc levels averaged over all depths are consistently higher at C4 University Point than at C1 Tubbs Hill.
2. ***Annual median dissolved zinc in the photic zone***— measure of typical annual dissolved zinc levels in the productive surface waters .
   a. Generally mirrors the trend for annual geometric mean over all depths.
   b. Have historically exceeded the target at both sites, but began to meet the target in 2017 at C1 Tubbs Hill and in 2018 at C4 University Point.
   c. Zinc levels in the photic zone are also higher at C4 University Point than at C1 Tubbs Hill. The magnitude of the difference for the photic zone is less than for the average over all depths.

These data show that dissolved zinc targets for the lake are being exceeded as an average over all depths, but are beginning to be met in the photic zone. This pattern is seen at both core monitoring sites in the northern lake. Zinc levels appear to be decreasing at both sites, and observed concentrations in recent years are the lowest on record. Dissolved zinc trigger criteria have consistently been exceeded for 2015 – 2018, but appear to be trending downward.

The presence or absence of long-term trends is assessed here via a Mann-Kendall statistical analysis. This analysis can evaluate either annual or seasonal trends. Only annual trends are assessed in this status report. Seasonality will be evaluated in other studies. Results from Mann-Kendall statistical analysis for long-term *annual* trends in dissolved zinc are provided in Table 4. Trend charts are presented in Figure 14 for C1 Tubbs Hill and Figure 15 for C4 University Point. These trend analyses show that dissolved zinc is decreasing at both monitoring locations.

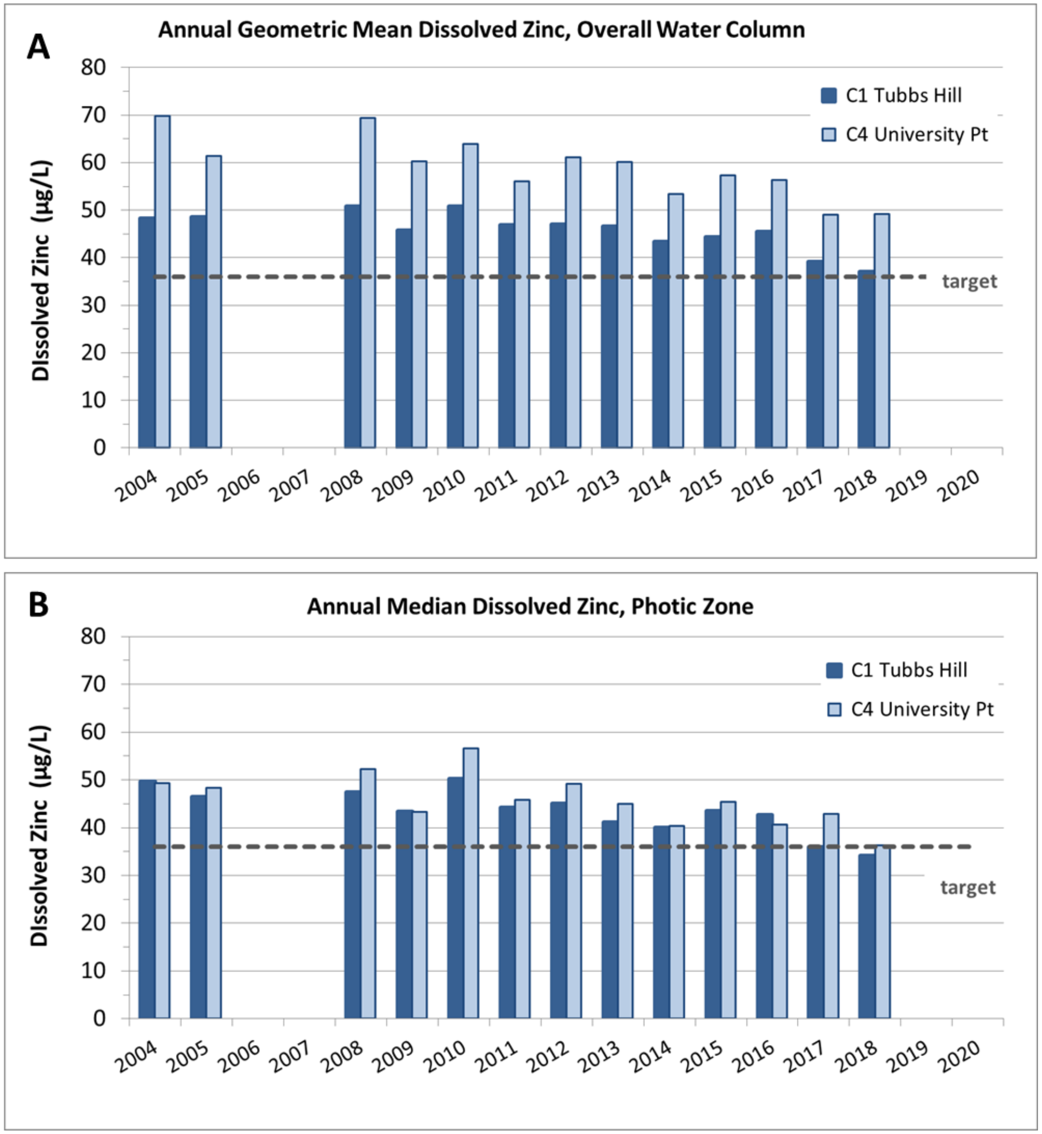


Figure 13. Dissolved zinc at C1 Tubbs Hill and C4 University Point, annual geometric mean over all depths (A) and annual median in the photic zone (B).

Table 4. Annual Mann-Kendall trend analysis for dissolved zinc (Zn) for both the 2004 – 2014 and 2004 – 2018 time periods at LMP core monitoring sites in the northern lake.

Time Period	Site	Depth	Variable	Mann-Kendall Trend Test (2004–2014, 2004-2018) Dissolved Zinc			
				Sample Size (n)	P-Value [1]	Theil-Sen Slope [2]	Trend
2004–2014	C1	Photic zone	Diss. Zn	82	**0.013**	**-0.6**	**Decreasing**
	C1	20-meter depth	Diss. Zn	62	**<0.001**	**-1.4**	**Decreasing**
	C1	30-meter depth	Diss. Zn	65	**<0.001**	**-1.3**	**Decreasing**
	C1	Near bottom	Diss. Zn	78	**0.003**	**-1.0**	**Decreasing**
2004-2018	C1	Photic zone	Diss. Zn	114	**<0.001**	**-0.8**	**Decreasing**
	C1	20-meter depth	Diss. Zn	86	**<0.001**	**-1.3**	**Decreasing**
	C1	30-meter depth	Diss. Zn	82	**<0.001**	**-1.3**	**Decreasing**
	C1	Near bottom	Diss. Zn	110	**<0.001**	**-1.1**	**Decreasing**
2004-2014	C4	Photic zone	Diss. Zn	81	**0.025**	**-0.8**	**Decreasing**
	C4	20-meter depth	Diss. Zn	78	**<0.001**	**-1.4**	**Decreasing**
	C4	30-meter depth	Diss. Zn	65	**0.001**	**-1.4**	**Decreasing**
	C4	Near bottom	Diss. Zn	81	**<0.001**	**-1.6**	**Decreasing**
2004-2018	C4	Photic zone	Diss. Zn	114	**<0.001**	**-0.9**	**Decreasing**
	C4	20-meter depth	Diss. Zn	109	**<0.001**	**-1.4**	**Decreasing**
	C4	30-meter depth	Diss. Zn	89	**<0.001**	**-1.5**	**Decreasing**
	C4	Near bottom	Diss. Zn	113	**<0.001**	**-1.6**	**Decreasing**

1. Bold P-values are statistically significant at α=0.01 Italic P-values are statistically significant at α=0.05. P values between α=0.05 and α= 0.1 are potential trends that merit further analysis.
2. Theil-Sen slope is in units of micrograms per liter (µg/L) per year. Negative slope is a decrease.

Annual monitoring data for dissolved zinc are plotted relative to both the 2004 – 2014 trend lines and the 2004 – 2018 trend lines in Figure 14 for C1 Tubbs Hill, and Figure 15 for C4 University Point. The presence or absence of a trend is assessed via a Mann-Kendall analysis. The approximate magnitude of the trend is estimated from a Theil-Sen fit to the data, which is a linear regression technique appropriate for stochastic, non-normal datasets.

Monitoring data are shown for each depth and sampling event for which there is a data record, including prior studies conducted by the U.S. Geological Survey. Photic zone survey data collected during summer months (Jun-Oct) for a DEQ study from 1995 – 2002 are also shown. These plots demonstrate that annual median dissolved zinc levels are decreasing for all depths, even though seasonal cycles and inter-annual variability can obscure the calculated trends. The trends are most visually apparent in the annual minimum values and annual median values. Key aspects of the trends are summarized below.

1. *Tubbs Hill (C1, northern pool)*— dissolved zinc is decreasing at all depths.
    - The decreasing trend observed for 2004 – 2018 is consistent with the previously reported decreasing trend for 2004 – 2014.
    - The rate of decrease for dissolved zinc is the same for 2004 – 2018 as was reported for 2004 – 2014. The statistical significance of the calculated trends has increased at all depths (lower p-value).
    - Since 2017, annual median values for the photic zone are at or below the trigger criteria of 36 µg/L. Summer minimum values have fallen below the target of 36 µg/L for May thru September (range = 31 – 35 ugL).
    - Dissolved zinc values remain above the target of 36 µg/L for all other depths.
2. *University Point (C4, central pool)*— dissolved zinc is decreasing at all depths
    - The decreasing trend observed for 2004 – 2018 is consistent with the previously reported decreasing trend for 2004 – 2014.
    - The rate of decrease for dissolved zinc is the same for 2004 – 2018 as was reported for 2004 – 2014. The statistical significance of the calculated trends has increased at all depths (lower p-value).
    - In 2018,the annual median value for the photic zone was equivalent to the trigger criteria of 36 µg/L. Summer minimum values fell below the target of 36 µg/L for June thru September (range = 29 – 32 ugL).
    - Dissolved zinc values remain above the target of 36 µg/L for all other depths.

These analyses indicate that dissolved zinc levels are decreasing at all depths at both core monitoring sites in the northern lake. The rate of decrease is the same as was previously reported for 2004 – 2014.

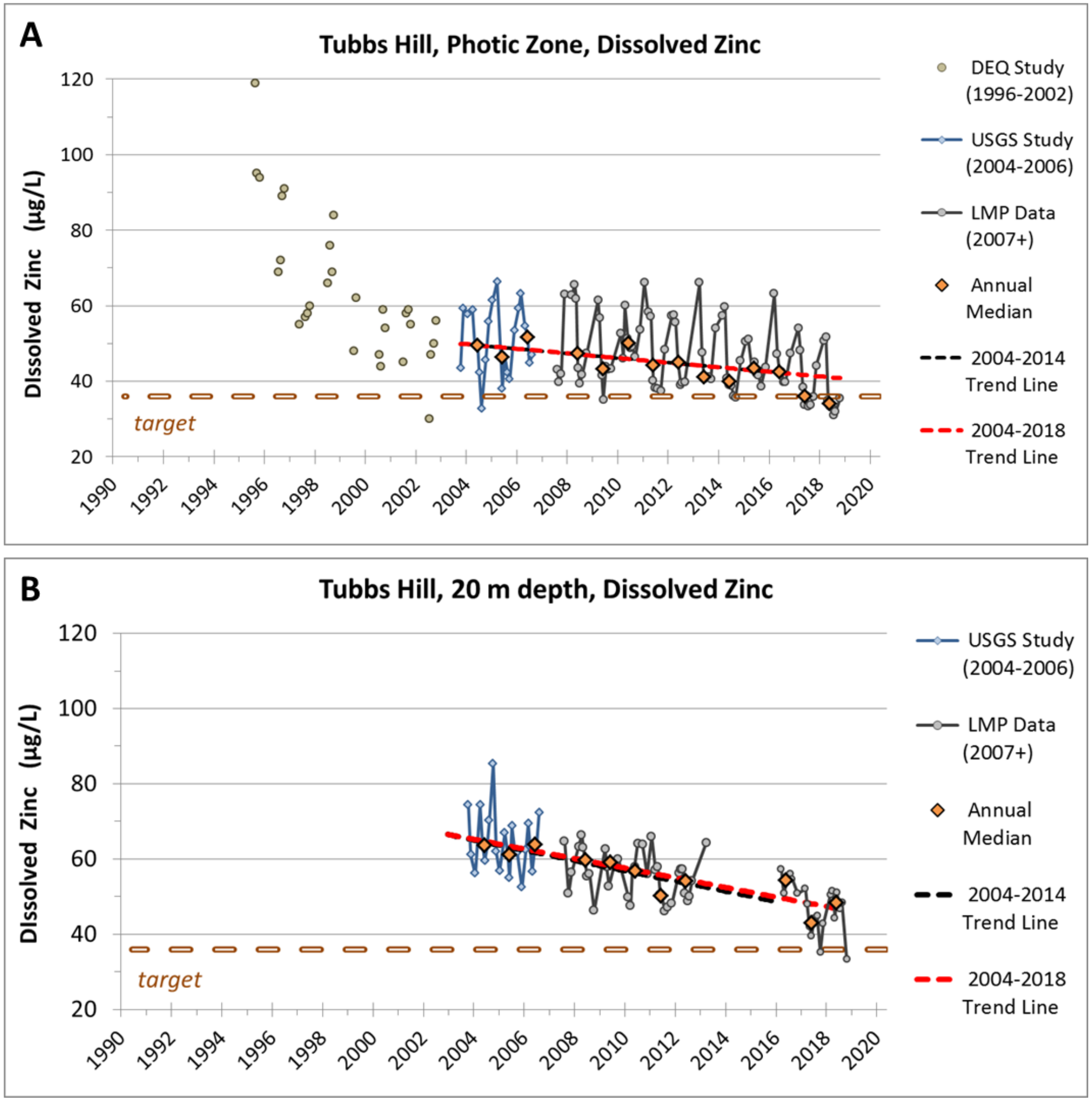
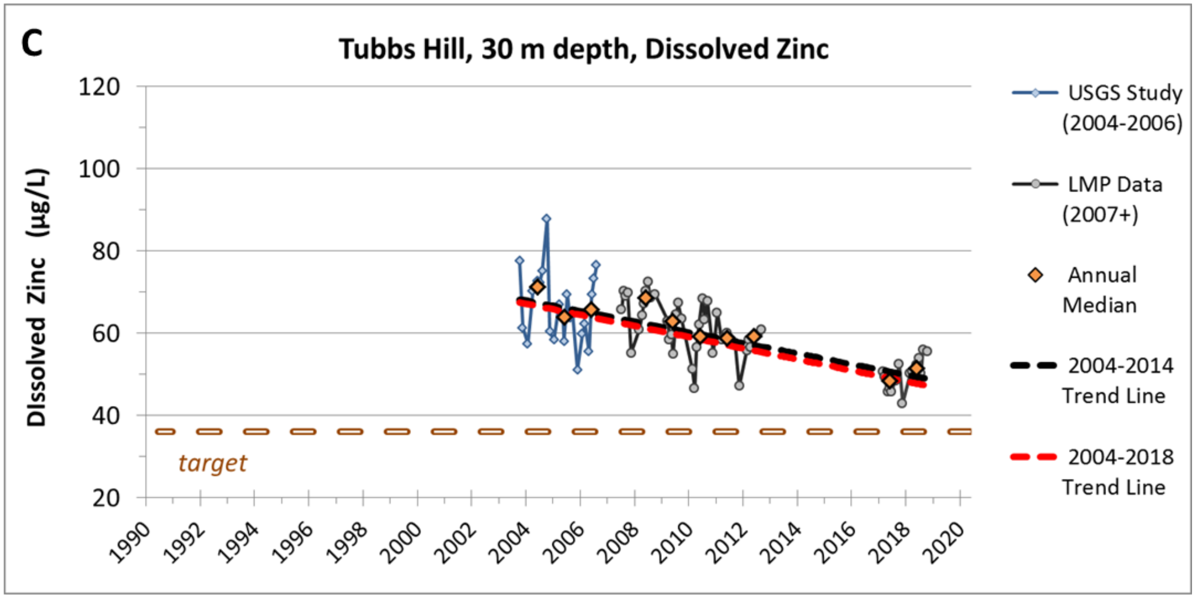


Figure 14. Dissolved zinc trends for site C1 Tubbs Hill photic zone (A), 20 m depth (B), 30 m depth (C), and near bottom (D).



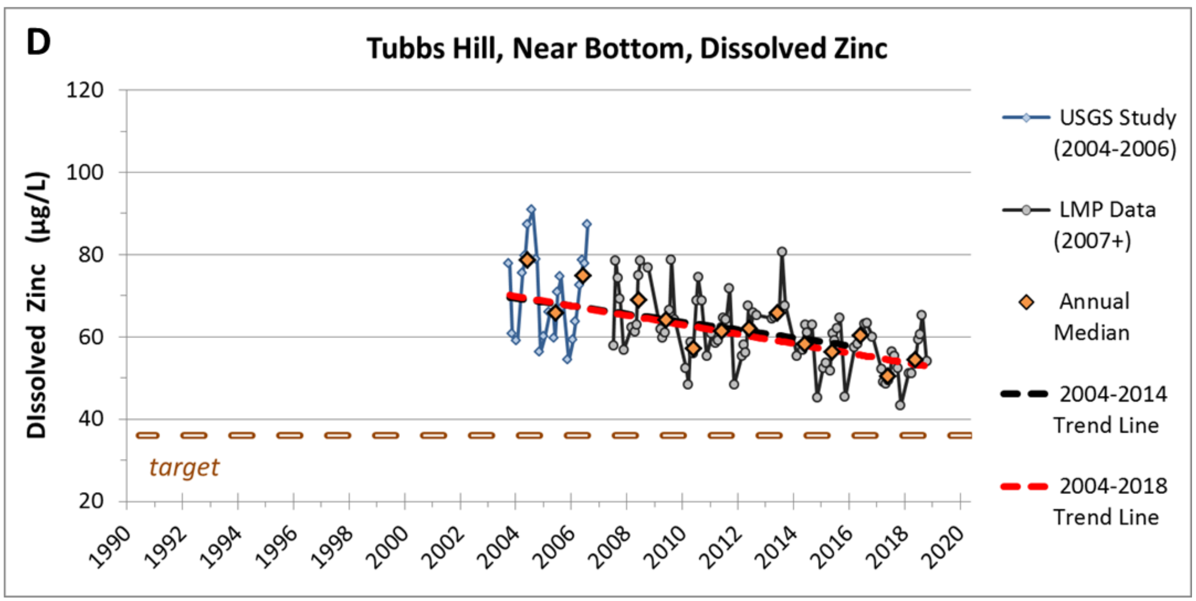
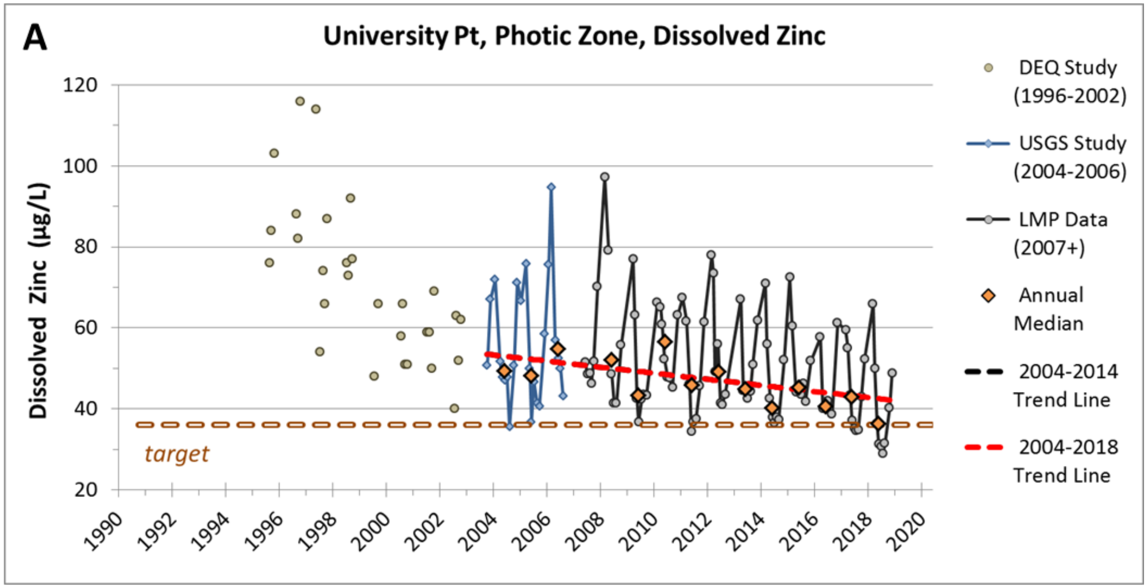


Figure14 (cont). Dissolved zinc trends for site C1 Tubbs Hill photic zone (A), 20 m depth (B), 30 m depth (C), and near bottom (D).



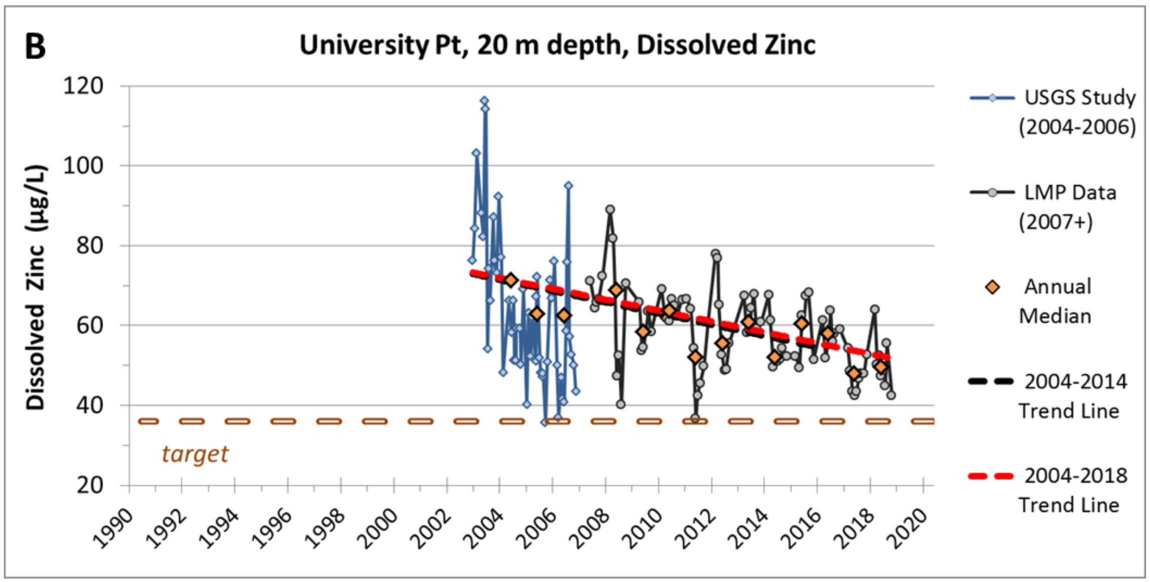
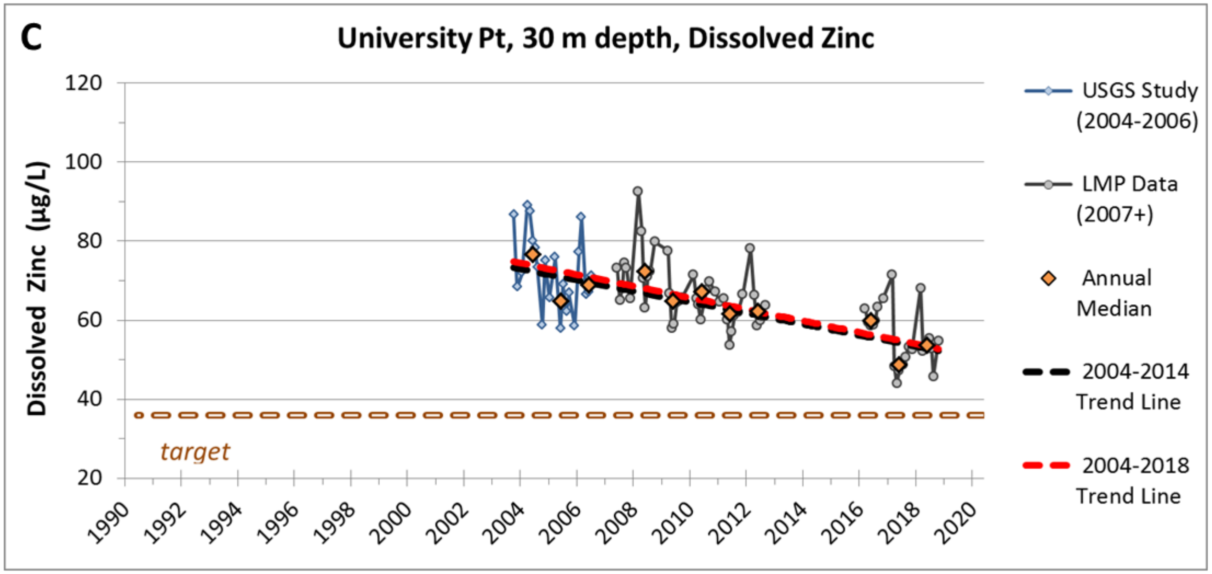


Figure 15. Dissolved zinc trends for site C4 University Point photic zone (A), 20 m depth (B), 30 m depth (C), and near bottom (D).



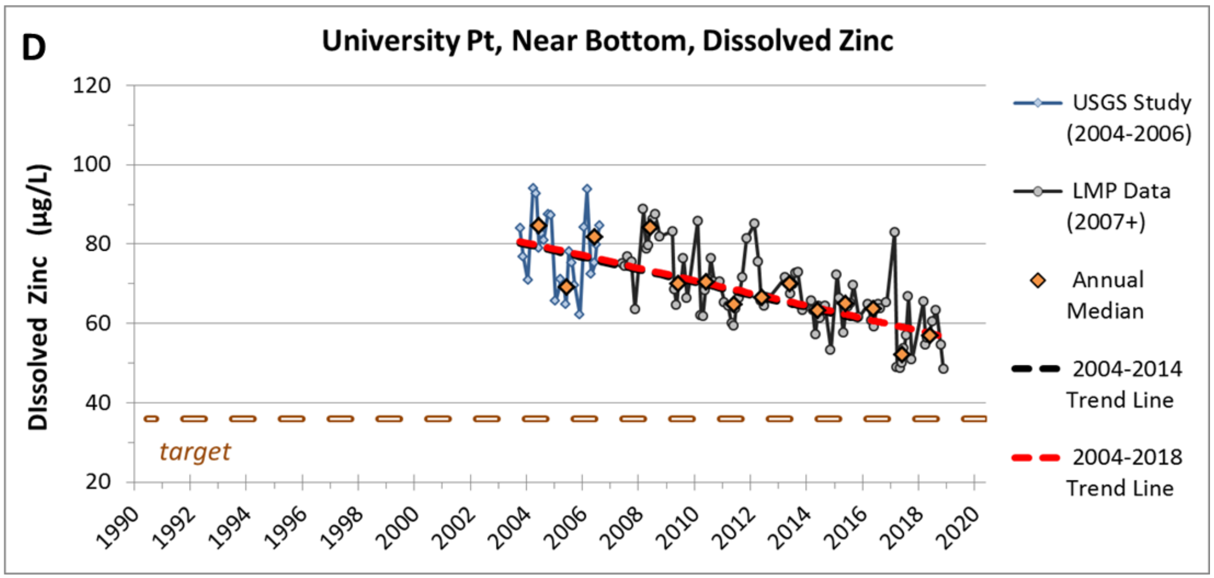


Figure 15 (cont). Dissolved zinc trends for C4 University Point photic zone (A), 20 m depth (B), 30 m depth (C), and near bottom (D).

2.5 Dissolved Lead

Annual geometric mean values for dissolved lead over all depths at core monitoring sites in the northern lake are presented in Figure 16. Data for annual median dissolved lead in the photic zone are also provided. Most productivity occurs in the photic zone, and lead at these shallower depths has a greater impact on the overall lake ecosystem. These data show the following.

1. ***Annual geometric mean dissolved lead over all depths***— measure of average annual dissolved lead levels in the lake and overall status relative to water quality standards.
    a. *Tubbs Hill*— has never exceeded the trigger criteria of 0.54 µg/L.
    b. *University Point*— exceeded the trigger criteria of 0.54 µg/L in 2017.
    c. Both locations show high variability in dissolved lead levels.
    d. Lead levels averaged over all depths are consistently higher at C4 University Point than at C1 Tubbs Hill.
2. ***Annual median dissolved lead in the photic zone***— measure of typical annual dissolved lead levels in the productive surface waters.
    a. Generally mirrors the trend for annual geometric mean over all depths.
    b. Have historically exceeded the target intermittently at C4 University Point, but have not exceeded the target at either monitoring site for 2015 – 2018.
    c. Lead levels in the photic zone are also higher at C4 University Point than at C1 Tubbs Hill. The magnitude of the difference for the photic zone is less than for the average over all depths.

These data show that dissolved lead targets for the lake are only rarely exceeded, and then only at C4 University Point. Lead levels are highly variable. A strong trend is not apparent for either the photic zone or average over all depths. Dissolved lead trigger criteria have not been exceeded during the 2015 – 2018 time period.

The presence or absence of long-term trends is assessed here via a Mann-Kendall statistical analysis. This analysis can evaluate either annual or seasonal trends. Only annual trends are assessed in this status report. Seasonality will be evaluated in other studies. Results from Mann-Kendall statistical analysis for long-term *annual* trends in dissolved lead are provided in Table 5. Trend charts are presented in Figure 17 for C1 Tubbs Hill and Figure 18 for C4 University Point. These trend analyses show that dissolved lead is currently increasing at some combinations of depth and monitoring location, but not all.

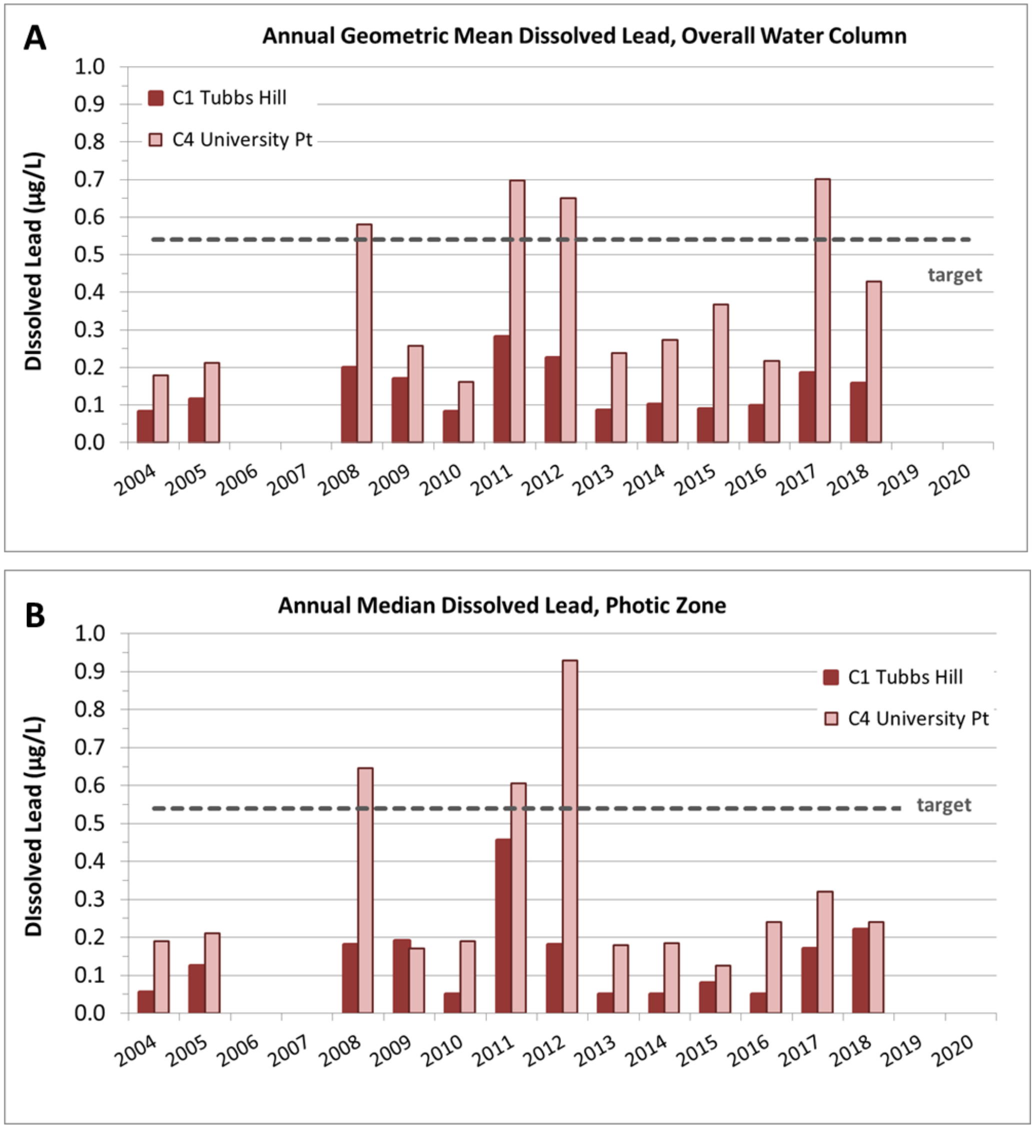


Figure 16. Dissolved lead at C1 Tubbs Hill and C4 University Point, annual geometric mean over all depths (A) and annual median in the photic zone (B).

Table 5. Annual Mann-Kendall trend analysis for dissolved lead (Pb) for both the 2004 – 2014 and 2004 – 2018 time periods at LMP core monitoring sites in the northern lake.

Time Period	Site	Depth	Variable	Mann-Kendall Trend Test (2004–2014, 2004-2018) Dissolved Lead			
				Sample Size (n)	P-Value	Theil-Sen Slope [a]	Trend
2004–2014	C1	Photic zone	Diss. Pb	82	0.30	0.000	None
	C1	20-meter depth	Diss. Pb	62	**0.001**	**0.017**	**Increasing**
	C1	30-meter depth	Diss. Pb	66	*0.014*	*0.015*	*Increasing*
	C1	Near bottom	Diss. Pb	78	*0.043*	*0.006*	*Increasing*
2004-2018	C1	Photic zone	Diss. Pb	114	0.34	0.000	None
	C1	20-meter depth	Diss. Pb	86	*0.011*	*0.006*	*Increasing*
	C1	30-meter depth	Diss. Pb	83	**0.001**	**0.014**	**Increasing**
	C1	Near bottom	Diss. Pb	110	**<0.001**	**0.011**	**Increasing**
2004-2014	C4	Photic zone	Diss. Pb	81	0.26	0.003	None
	C4	20-meter depth	Diss. Pb	79	0.33	0.000	None
	C4	30-meter depth	Diss. Pb	66	*0.045*	*0.022*	*Increasing*
	C4	Near bottom	Diss. Pb	81	0.50	0.000	None
2004-2018	C4	Photic zone	Diss. Pb	114	0.41	0.000	None
	C4	20-meter depth	Diss. Pb	110	0.16	0.004	None
	C4	30-meter depth	Diss. Pb	90	*0.015*	*0.016*	*Increasing*
	C4	Near bottom	Diss. Pb	113	0.20	0.005	None

1. Bold P-values are statistically significant at α=0.01 Italic P-values are statistically significant at α=0.05. P values between α=0.05 and α= 0.1 are potential trends that merit further investigation.
2. Theil-Sen slope is in units of micrograms per liter (µg/L) per year. Positive slope is an increase.

Annual monitoring data for dissolved lead are plotted relative to both the 2004 – 2014 trend lines and the 2004 – 2018 trend lines in Figure 17 for C1 Tubbs Hill and Figure 18 for C4 University Point. The presence or absence of a trend is assessed via a Mann-Kendall analysis. The approximate magnitude of the trend is estimated from a Theil-Sen fit to the data, which is a linear regression technique appropriate for stochastic, non-normal datasets.

Monitoring data are shown for each depth and sampling event for which there is a data record, including prior studies conducted by the U.S. Geological Survey. Photic zone survey data was collected during summer months (Jun-Oct) for a DEQ study from 1995 – 2002, but are not shown here. Almost all lead concentrations were less than the detection limit of 3 µg/L for the methods used in that 1995 – 2002 survey study. These plots demonstrate that annual median dissolved lead levels are decreasing, even though seasonal cycles and inter-annual variability can obscure the calculated trends. The trends are most visually apparent in the annual maximum values and annual median values. Key aspects of the trends are summarized below.

1. *Tubbs Hill (C1, northern pool)*— dissolved lead is increasing at all depths lower than the photic zone, with the greatest increases at or below 30 m depth.
    - The increasing trend observed for 2004 – 2018 is consistent with the previously reported increasing trend for 2004 – 2014.
    - The rate of increase for dissolved lead is the same for 2004 – 2018 as was reported for 2004 – 2014. The statistical significance of the calculated trends has increased for 30 m depth and 10 meter above the lake bottom (lower p-value).
    - Dissolved lead values typically only exceed the target of 0.54 µg/L during spring and fall below the detection limit of 0.05 µg/L during summer, fall, and winter.
2. *University Point (C4, central pool)*— dissolved lead is increasing at 30 m depth.
    - The increasing trend observed for 2004 – 2018 is consistent with the previously reported increasing trend for 2004 – 2014.
    - The rate of increase for dissolved lead is the same for 2004 – 2018 as was reported for 2004 – 2014. The statistical significance of the calculated trends has increased for 30 m depth (lower p-value).
    - Dissolved lead values typically only exceed the target of 0.54 µg/L during spring and fall below the detection limit of 0.05 µg/L during summer, fall, and winter.

These analyses indicate that dissolved lead levels are increasing at some depths, but not all, at both core monitoring locations in the northern lake. The rate of increase is the same as was previously reported for 2004 – 2014.

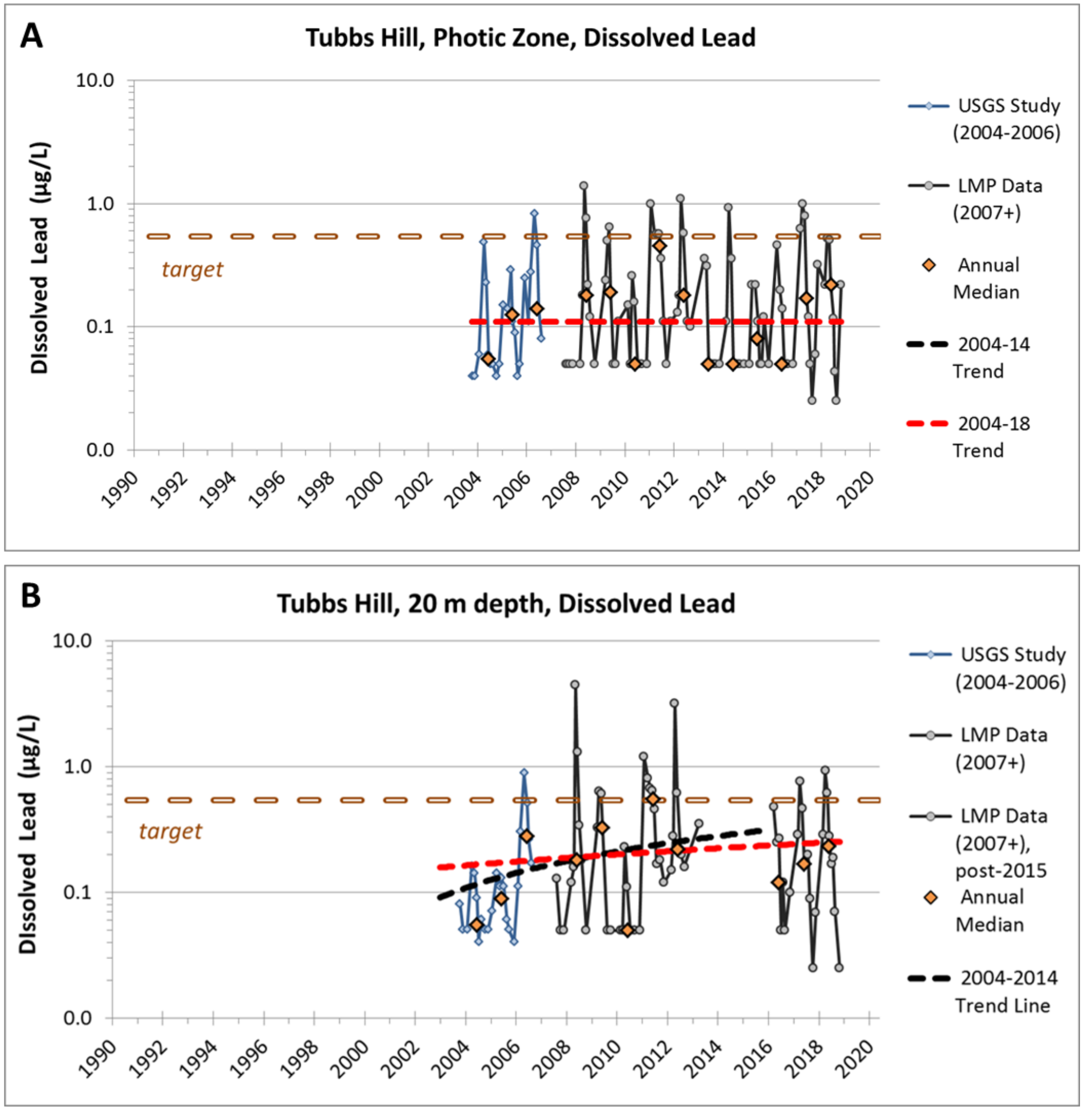
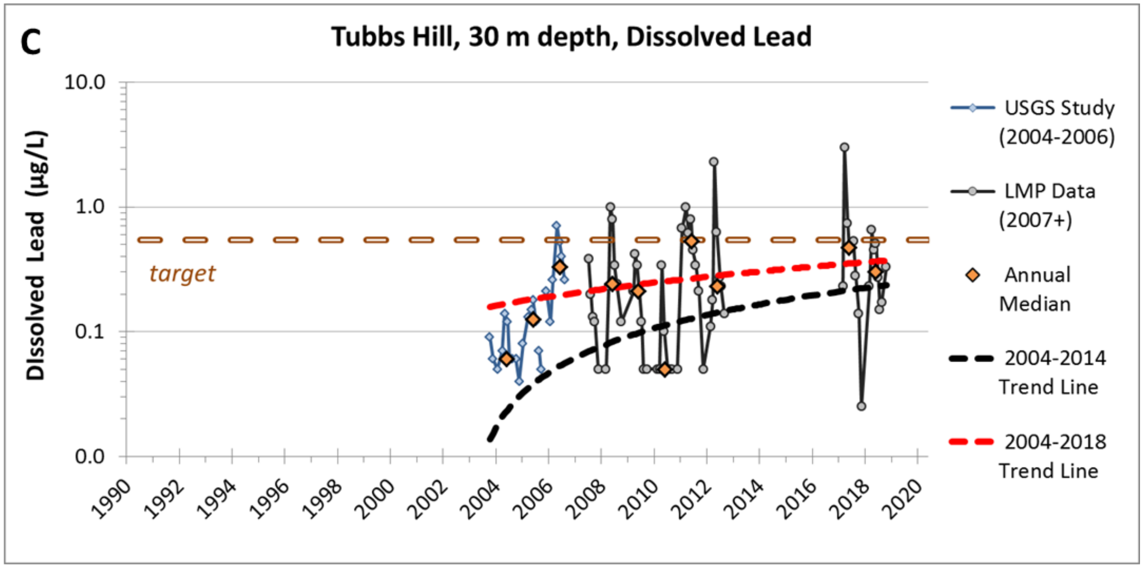


Figure 17. Dissolved lead trend data for site C1 Tubbs Hill photic zone (A), 20 m depth (B), 30 m depth (C), and near bottom (D). Note the logarithmic scale for dissolved lead concentrations.



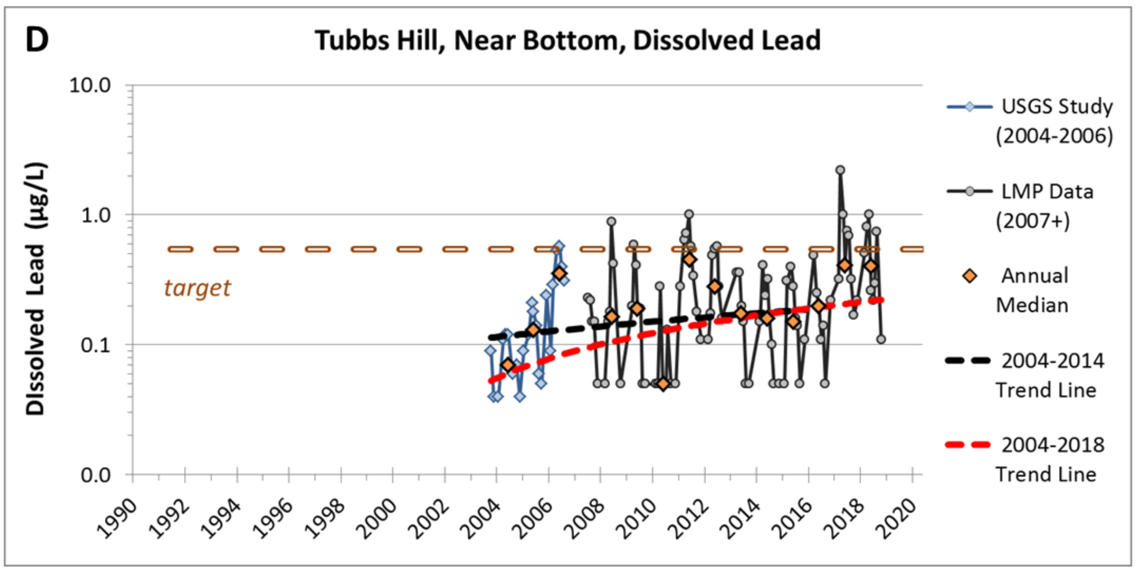
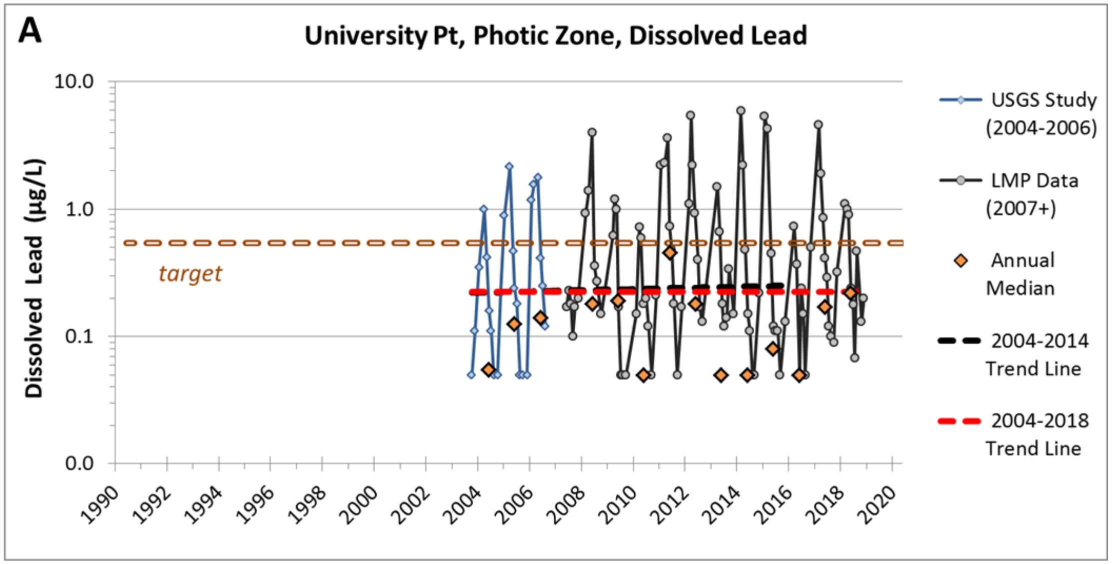


Figure 17 (continued). Dissolved lead trend data for site C1 Tubbs Hill photic zone (A), 20 m depth (B), 30 m depth (C), and near bottom (D). Note the logarithmic scale for dissolved lead concentrations.



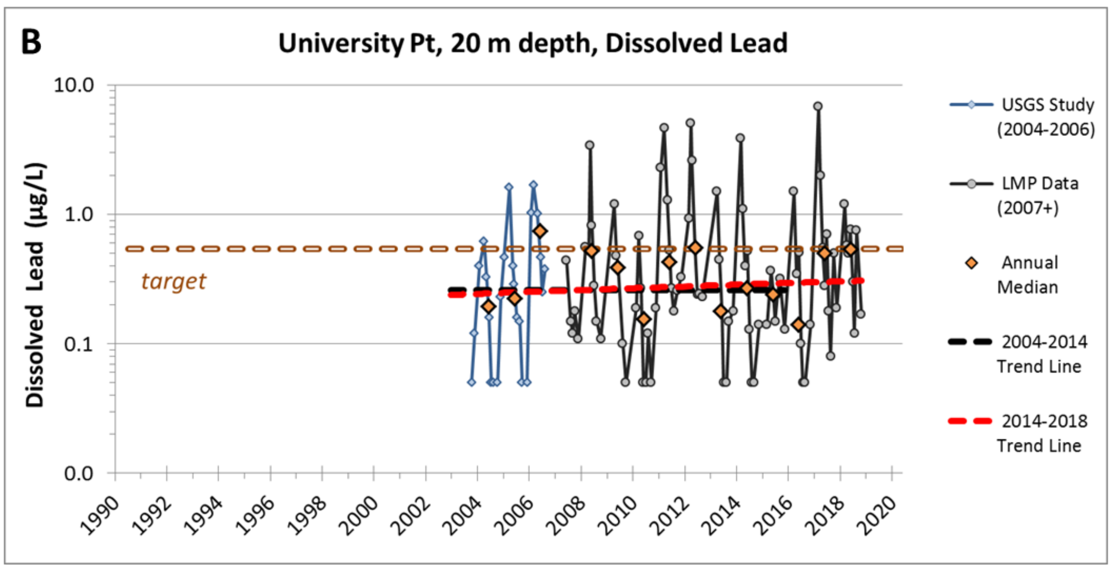
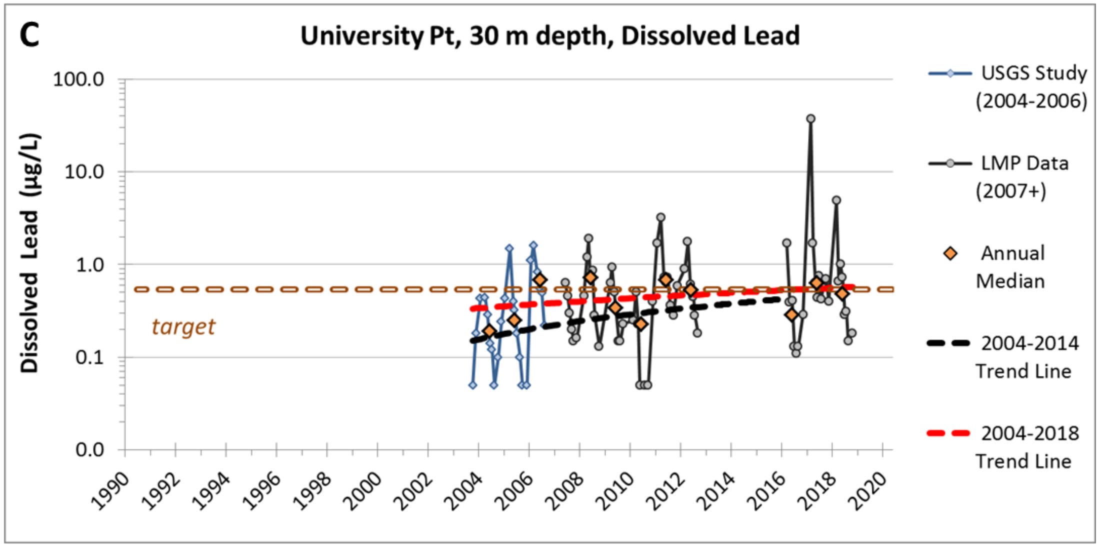


Figure 18. Dissolved lead trend data for site C4 University Point photic zone (A), 20 m depth (B), 30 m depth (C), and near bottom (D). Note the logarithmic scale for dissolved lead concentrations.



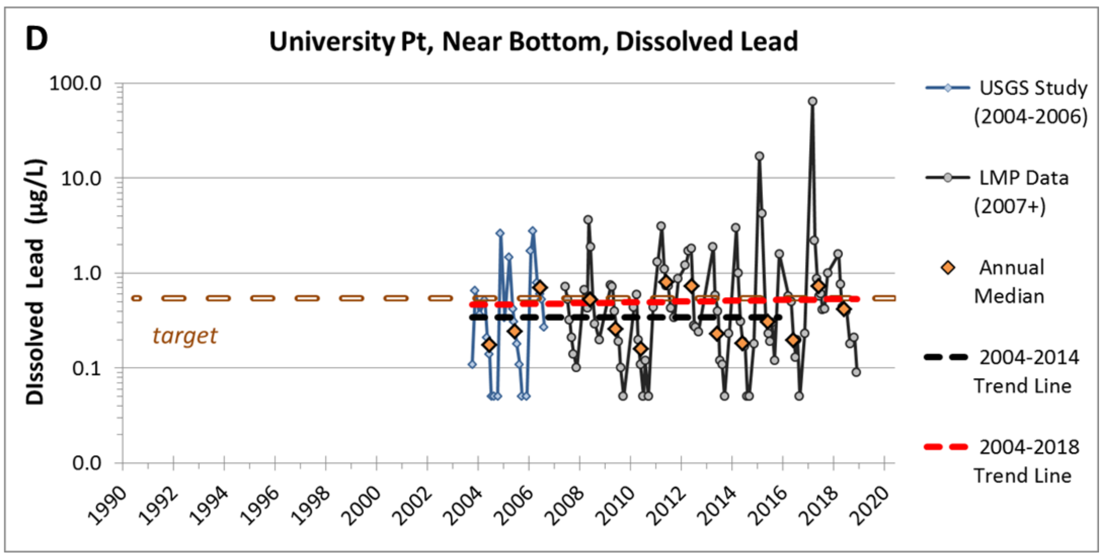


Figure 18 (continued). Dissolved lead trend data for site C4 University Point photic zone (A), 20 m depth (B), 30 m depth (C), and near bottom (D). Note the logarithmic scale for dissolved lead concentrations.

2.6 Dissolved Cadmium

Annual geometric mean values for dissolved cadmium over all depths at core monitoring sites in the northern lake are presented in Figure 13. Data for annual median dissolved cadmium in the photic zone are also provided. Most productivity occurs in the photic zone, and cadmium at these shallower depths has a greater impact on the overall lake ecosystem. These data show the following.

1. ***Annual geometric mean dissolved zinc over all depths***— measure of average annual dissolved cadmium levels in the lake and status relative to water quality standards.
    a. *Tubbs Hill*—did not exceed the trigger criteria for 2015 – 2018.
    b. *University Point*— exceeded the harness-adjusted trigger criteria of 0.22 µg/L in 2015, and was below the trigger for all other years..
    c. Both locations suggest a trend of decreasing dissolved cadmium, with the lowest cadmium levels ever reported occurring in 2018.
    d. Cadmium levels averaged over all depths are consistently higher at C4 University Point than at C1 Tubbs Hill.
2. ***Annual median dissolved cadmium in the photic zone***— measure of typical annual dissolved cadmium levels in the productive surface waters.
    a. Generally mirrors the trend for annual geometric mean over all depths.
    b. Intermittently exceeded the target C4 University Point prior to 2013, and has never exceeded the target at C1 Tubbs Hill. Has met the target every year since 2013.
    c. Cadmium levels in the photic zone are also higher at C4 University Point than at C1 Tubbs Hill. The magnitude of the difference for the photic zone is less than for the average over all depths.

These data show that dissolved cadmium targets for the lake are met, both as an average over all depths and also in the photic zone. This pattern is seen at both core monitoring sites in the northern lake. Cadmium levels appear to be decreasing at both sites, and observed concentrations in recent years are the lowest on record. Dissolved zinc trigger cadmium have only been exceeded once for 2015 – 2018 (C4 University Point in 2015), and appear to be trending downward.

The presence or absence of long-term trends is assessed here via a Mann-Kendall statistical analysis. This analysis can evaluate either annual or seasonal trends. Only annual trends are assessed in this status report. Seasonality will be evaluated in other studies. Results from Mann-Kendall statistical analysis for long-term *annual* trends in dissolved cadmium are provided in Table 6. Trend charts are presented in Figure 14 for C1 Tubbs Hill and Figure 21 for C4 University Point. These trend analyses show that dissolved cadmium is decreasing at both monitoring locations.

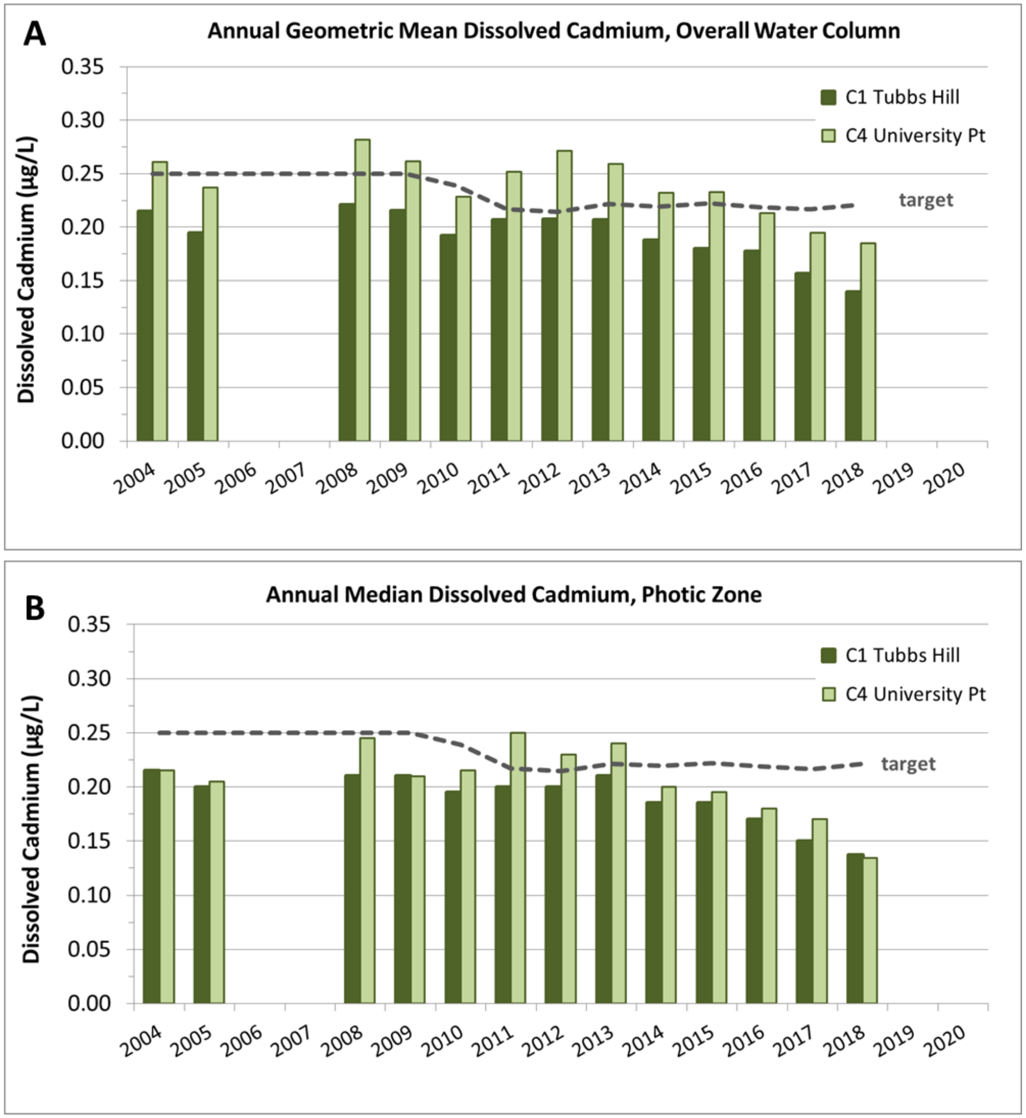


Figure 19. Dissolved cadmium at C1 Tubbs Hill and C4 University Point, annual geometric mean over all depths (A) and annual median in the photic zone (B).

Table 6. Annual Mann-Kendall trend analysis for dissolved cadmium (Cd) for both the 2004 – 2014 and 2004 – 2018 time periods at LMP core monitoring sites in the northern lake.

Time Period	Site	Depth	Variable	Mann-Kendall Trend Test (2003–2014, 2003-2017) Dissolved Cadmium			
				Sample Size (n)	P-Value	Theil-Sen Slope [a]	Trend
2004–2014	C1	Photic zone	Diss. Cd	81	0.11	0.000	None
	C1	20-meter depth	Diss. Cd	62	0.22	0.000	None
	C1	30-meter depth	Diss. Cd	66	0.24	0.000	None
	C1	Near bottom	Diss. Cd	78	0.49	0.000	None
2004-2018	C1	Photic zone	Diss. Cd	113	**<0.001**	**-0.004**	**Decreasing**
	C1	20-meter depth	Diss. Cd	86	**<0.001**	**-0.003**	**Decreasing**
	C1	30-meter depth	Diss. Cd	83	**<0.001**	**-0.004**	**Decreasing**
	C1	Near bottom	Diss. Cd	110	**0.001**	**-0.004**	**Decreasing**
2004-2014	C4	Photic zone	Diss. Cd	81	0.35	0.000	None
	C4	20-meter depth	Diss. Cd	79	0.18	-0.001	None
	C4	30-meter depth	Diss. Cd	66	0.11	-0.002	None
	C4	Near bottom	Diss. Cd	81	*0.021*	*-0.0025*	*Decreasing*
2004-2018	C4	Photic zone	Diss. Cd	114	**0.002**	**-0.004**	**Decreasing**
	C4	20-meter depth	Diss. Cd	110	**<0.001**	**-0.005**	**Decreasing**
	C4	30-meter depth	Diss. Cd	90	**<0.001**	**-0.005**	**Decreasing**
	C4	Near bottom	Diss. Cd	113	**<0.001**	**-0.006**	**Decreasing**

1. Bold P-values are statistically significant at α=0.01 Italic P-values are statistically significant at α=0.05. P values between α=0.05 and α= 0.1 are potential trends that merit further investigation.
2. Theil-Sen slope is in units of micrograms per liter (μg/L) per year. Positive slope is an increase.

Annual monitoring data for dissolved cadmium are plotted relative to both the 2004 – 2014 trend lines and the 2004 – 2018 trend in Figure 14 for C1 Tubbs Hill and Figure 21 for C4 University Point.. The presence or absence of a trend is assessed via a Mann-Kendall analysis. The approximate magnitude of the trend is estimated from a Theil-Sen fit to the data, which is a linear regression technique appropriate for stochastic, non-normal datasets.

Monitoring data are shown for each depth and sampling event for which there is a data record, including prior studies conducted by the U.S. Geological Survey. Photic zone survey data collected during summer months (Jun-Oct) for a DEQ study from 1995 – 2002 are also shown. These plots demonstrate that annual median dissolved cadmium levels are decreasing for all depths, even though seasonal cycles and inter-annual variability can obscure the calculated trends. The trends are most visually apparent in the annual minimum values and annual median values. Key aspects of the trends are summarized below.

1. *Tubbs Hill (C1, northern pool)*— dissolved cadmium is decreasing at all depths.
    - The decreasing trend observed for 2004 – 2018 is a new trend, and is significant to >99% confidence. Analyses of data from 2004 – 2014 showed no trend.
    - The data suggest that this new trend began in 2013 – 2014.
    - Since 2017, annual median values have been below the trigger criteria of ~0.22 µg/L for all depths where there is monitoring data.
2. *University Point (C4, central pool)*— dissolved zinc is decreasing at all depths
    - The decreasing trend observed for 2004 – 2018 is a new trend, and is significant to >99% confidence. Analyses of data from 2004 – 2014 showed no trend.
    - The data suggest that this new trend began in 2013 – 2014.
    - Since 2017, annual median values have been below the trigger criteria of ~0.22 µg/L for all depths where there is monitoring data.

These analyses indicate that dissolved cadmium levels are decreasing at all depths at both core monitoring sites in the northern lake. This is a new trend that was not previously observed for 2004 – 2014.

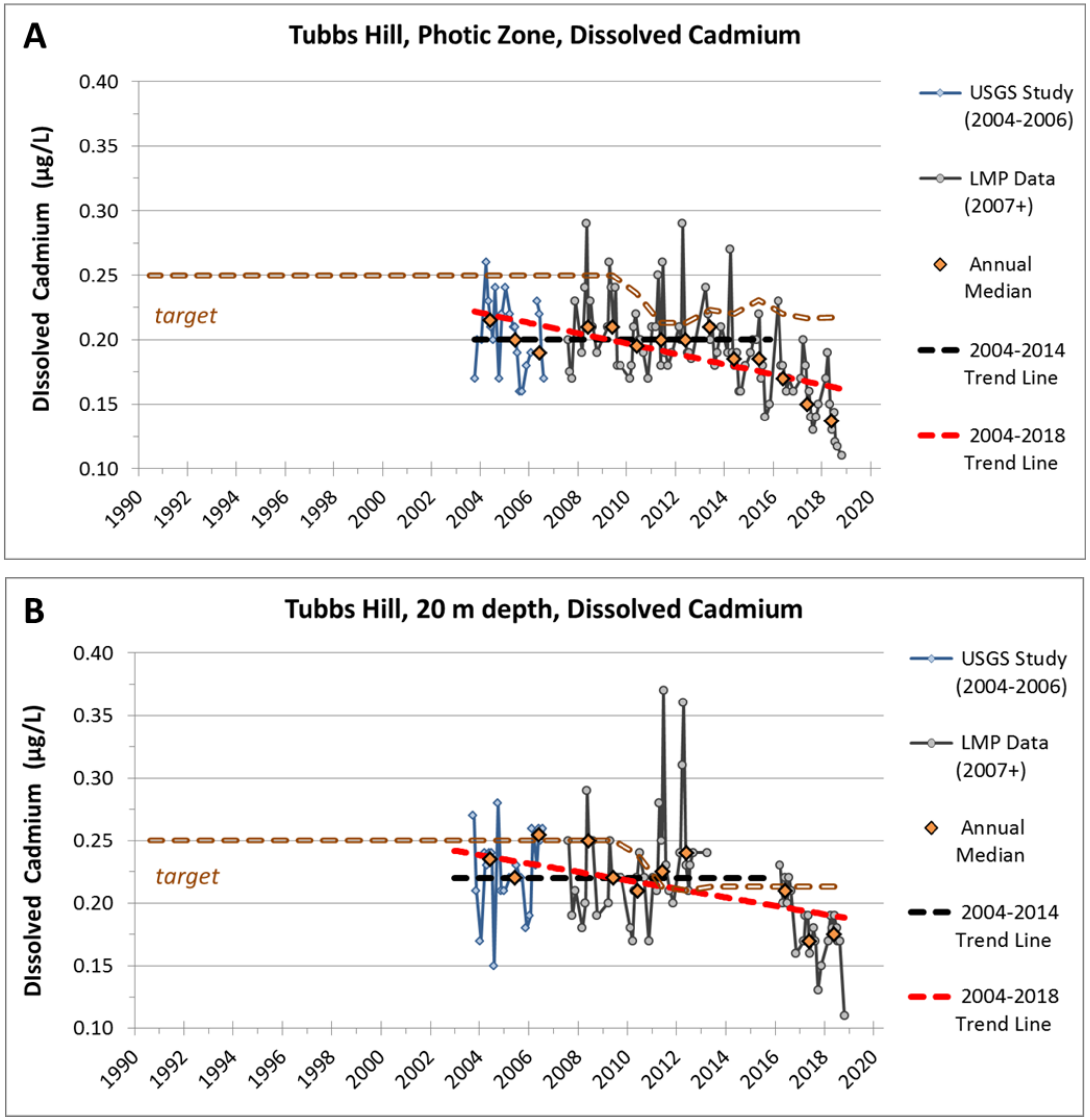
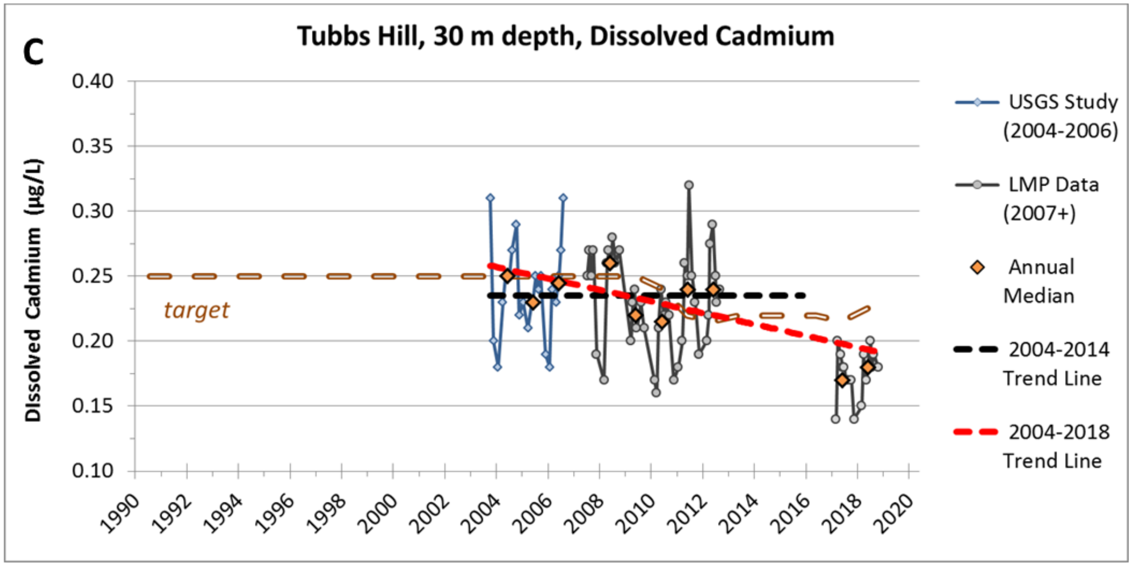


Figure 20. Dissolved cadmium trend data for site C1 Tubbs Hill photic zone (A), 20 m depth (B), 30 m depth (C), and near bottom (D).



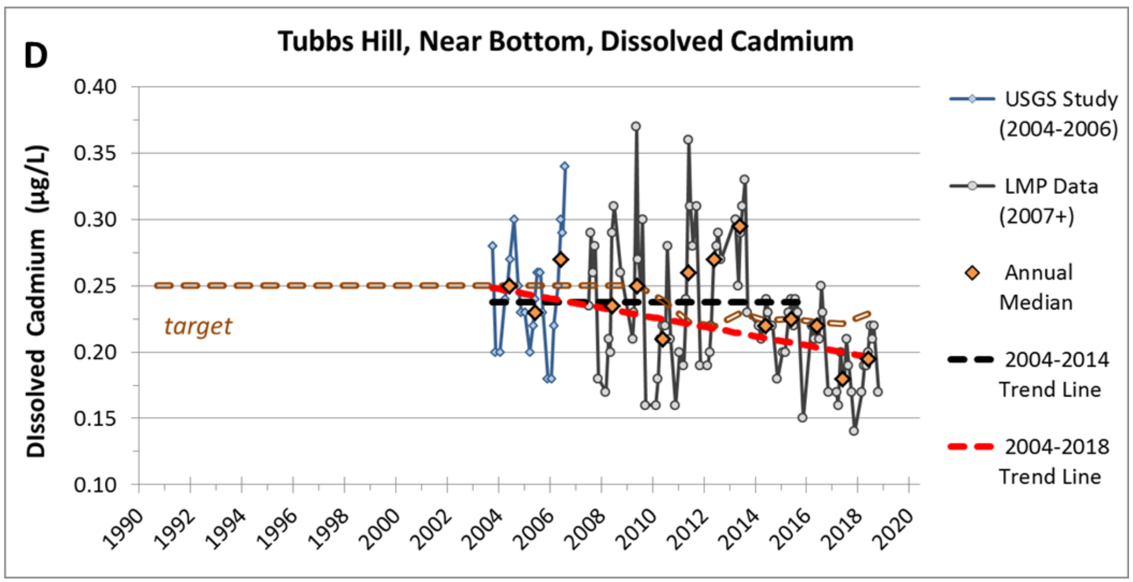


Figure 20 (continued). Dissolved cadmium trend data for site C1 Tubbs Hill photic zone (A), 20 m depth (B), 30 m depth (C), and near bottom (D).

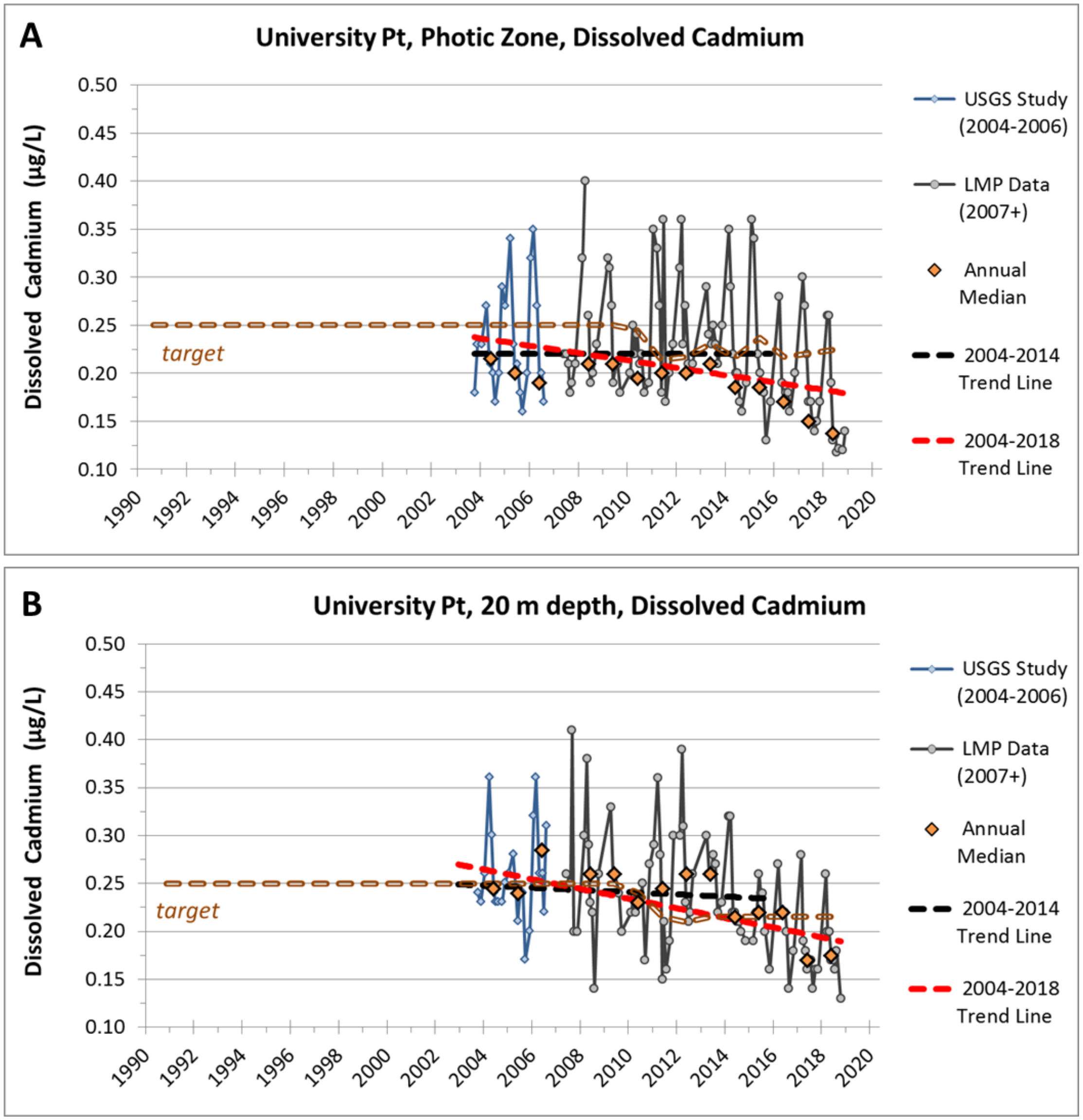
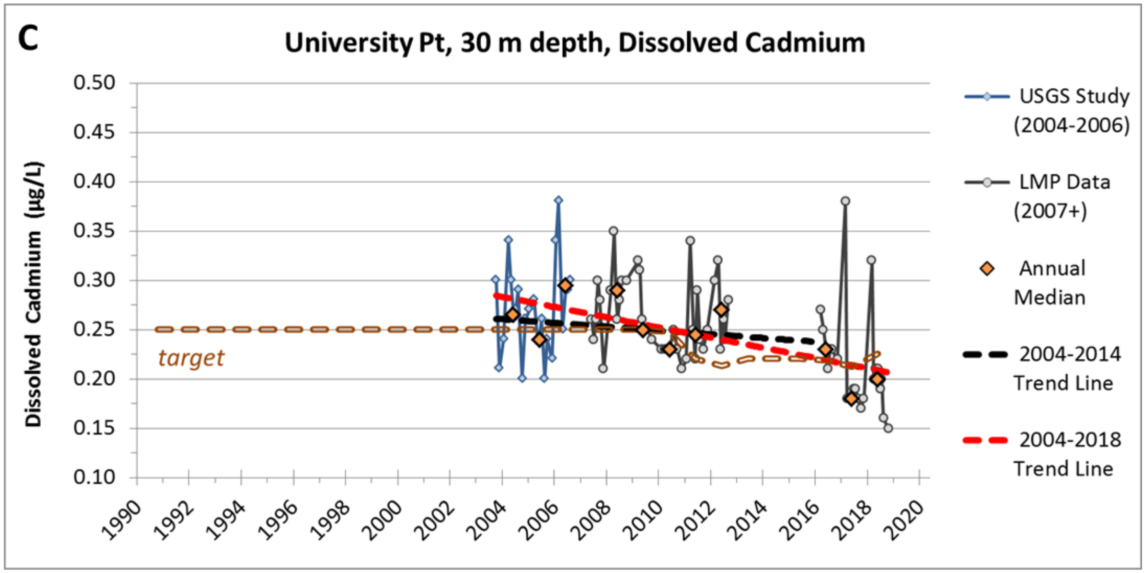


Figure 21. Dissolved cadmium trend data for site C4 University Point photic zone (A), 20 m depth (B), 30 m depth (C), and near bottom (D).



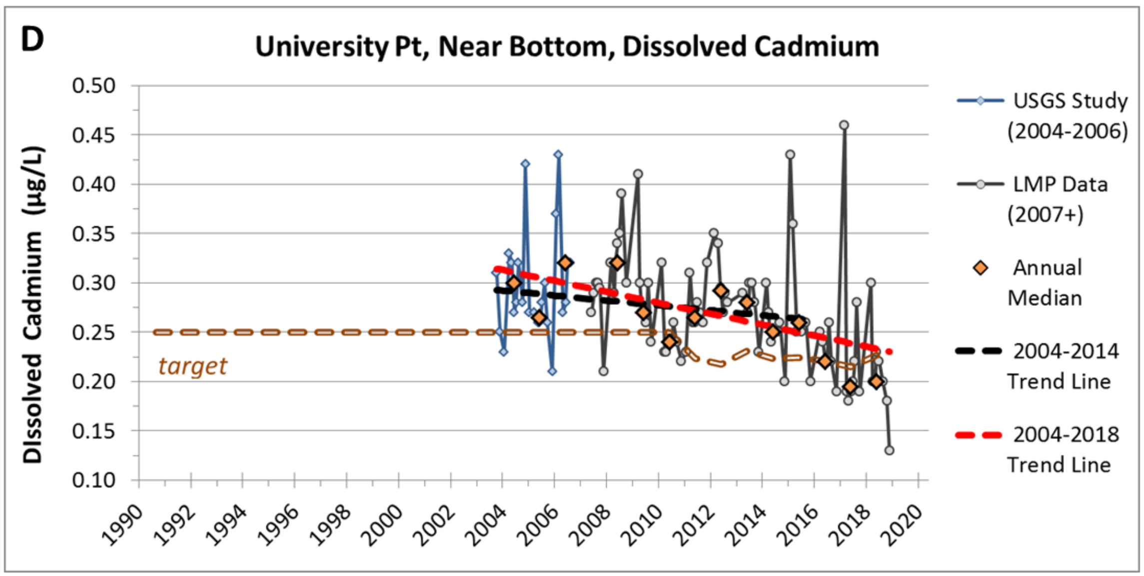


Figure 21 (continued). Dissolved cadmium trend data for site C4 University Point photic zone (A), 20 m depth (B), 30 m depth (C), and near bottom (D).

3 Summary of Lake Status

The previous 2004 – 2014 Lake Trends Analysis (DEQ and Tribe, 2016) reported that water quality conditions in Coeur d'Alene Lake have notably changed since the prior USG S studies of 1991 – 1992 and 2004 – 2006. Some of those reported changes reflected improvements in water quality. Others reflected the emergence of new management challenges. This report updates lake status for 2015 – 2018, relative to these previously identified trends.

The lake experienced a range of hydrologic conditions from 2015 – 2018, including both higher flow and lower flow water years. Annual average flows for the Coeur d'Alene River at Cataldo ranged from the 20th percentile relative to the record maintained since 1921 (2015) to approximately the 75th percentile (2017). These conditions encompass the middle 60% of the hydrograph and are balanced between lower flow and higher flow years. They are not overtly biased relative to the long-term range of hydrographic conditions.

Thel trends observed for 2004 – 2018 are broadly similar to those observed for 2004 – 2014. Metals levels have declined since the 1990's and the lake's status relative to cadmium and zinc is improving. Lead levels have declined since the 1990's, but have increased since 2004 at deeper depths. Phosphorus levels are steadily increasing. Trophic indicators are mixed. There is not a strong trend for oxygen or chlorophyll-a. However, the available data and annual trend assessments used in this study are not sensitive to changes that are small magnitude, highly sensitive to variance in the hydrograph, or seasonal in nature. Additional analyses that account for seasonality, hydrographic variability, and/or more sensitive indicators are merited.

3.1 Dissolved Metals

Prior analyses (DEQ and Tribe, 2016) concluded that total zinc levels had declined since the 1990s and total lead levels had also declined at most locations. There was insufficient data for total cadmium to make a definitive conclusion. Dissolved zinc levels had steadily declined in the northern lake since 2003, when monitoring data became available. Dissolved lead and cadmium levels showed mixed results during the 2004 – 2014 time period, with levels declining at some locations and increasing or showing "no change" at others. Some of these metal trends continue for 2004 – 2018, others have changed.

- *Dissolved cadmium*— previously reported to have no trend. Is now decreasing at all depths at both monitoring sites in the northern lake. Dissolved cadmium was beneath trigger criteria after peak runoff ended (Apr-Dec) for 2017 – 2018 at both sites.
- *Dissolved lead*— previously reported to be increasing at some depths at both monitoring locations in the northern lake. Lead is still increasing at those depths, at approximately the same rate. The trend has become more statistically significant.
- *Dissolved zinc*— previously reported to be decreasing at all depths at both monitoring locations in the northern lake. Decreasing at the same rate as previously reported. Dissolved zinc was below trigger criteria in the photic zone during the summer stratified period at both sites for 2017 – 2018.

The declines in dissolved cadmium and zinc levels are consistent with lake management objectives. The increases in dissolved lead are an emerging concern that merits further investigation and analysis.

3.2 Dissolved Oxygen

Prior analyses (DEQ and Tribe, 2016) concluded that that hypolimnetic DO levels during the summer stratified season have slightly declined from the 1990's levels in the northern lake. Trigger criteria for hypolimnetic dissolved oxygen for the near bottom depth interval (1.0 meter off the lake bottom during stratified months) had intermittently dropped below trigger criteria in for the colder and less productive regions of the northern lake. Dissolved oxygen data collected in 2015 and 2016 were consistent with this trend but data for 2017 and 2018 are higher than the historic average. There is no longer a statistically significant trend for 1991 – 2018 or 2004 – 2018 (95% confidence level or better). Dissolved oxygen levels do not show a declining trend and are currently holding steady relative to both 1991 and 2004. Minimum observed oxygen levels in the northern lake did not drop below the 6 mg/L trigger at either monitoring site in the northern lake from 2015 – 2018.

Minimum and median dissolved oxygen for the July – October hypolimnion are consistently lower at C1 Tubbs Hill than at C4 University Point. At C4 University Point, high oxygen levels for 2017 and 2018 have shifted the trend such that there are signs of an increase in dissolved oxygen for 2004 – 2018 at that site. A range of factors in addition to nutrient enhanced productivity impacts dissolved oxygen levels in oligotrophic lakes. These factors can include bottom water temperature, timing of stratification, timing of spring runoff, a deep photic zone that extends beneath the epilimnion, and ecosystem structure and dynamics. Additional analyses that account for these factors are needed to better assess oxygen data.

3.3 Trophic Status

Prior analyses (DEQ and Tribe, 2016) concluded that trophic indictors (total phosphorus, chlorophyll-a) were trending away from the lake's preferred oligotrophic state, for the colder, deeper waters of the northern lake. The shallower, warmer waters of the southern lake remained in a higher, mesotrophic status. Total phosphorus had intermittently exceeded the trigger criteria (8 µg/L annual geometric mean) in the northern lake and concentrations were steadily increasing. Maximum chlorophyll-a, as measured by the fluorescence method (F-Chla) that is more sensitive at lower concentrations had intermittently exceeded criteria, and there was a weak potential trend of increasing chlorophyll-a at both sites in the northern lake. Some of these trophic trends continue for 2004 – 2018, others have changed.

- *Total Phosphorus*— previously reported to have an increasing. Phosphorus is still increasing at all depths at both sites. The rate of increase appears to have increased and the trend is now significant to > 99.9% confidence.

- *Maximum chlorophyll-a*— previously reported to intermittently exceed criteria at both locations in the northern lake. This criteria has not been exceeded for 2015 – 2018.
- *Median chlorophyll-a*— previously reported to potentially be increasing at both sites in the northern lake (weak signal). Chlorophyll-a is no longer increasing at either site. This is true for both method baselines (fluorescence, spectrophotometric).

The increasing trend for total phosphorus is not consistent with lake management objectives of keeping phosphorus levels below the target of 8 µg/L annual geometric mean. The rate of increase appears to have accelerated since 2014, though it is still unclear whether this is a shift in the long-term trend or a shorter term perturbation. The increased total phosphorus does not appear to have translated into a corresponding increase in chlorophyll-a or decrease in hypolimnetic oxygen within the northern lake. However, annual assessments of chlorophyll-a and hypolimnetic oxygen do not provide high sensitivity, and are not ideal as leading indicators of trophic change. Additional assessments that account for seasonality, plankton community structure, and the impact of seasonal stream flows are needed. It is also important to assess the extent to which phosphorus increases may have increased the risk for blooms of toxin producing cyanobacteria (blue-green algae) by shifting the nitrogen/phosphorus nutrient balance.

3.4 Key Findings

The water quality of the northern region of Coeur d'Alene Lake, north of the Coeur d'Alene River continues to improve with respect to zinc and cadmium. Concentrations of these soluble metals are declining. For cadmium, trigger criteria have not been exceeded for April – December of 2017 and 2018. Lead levels meet criteria for most of the year, but levels are slowly increasing in the deeper waters and lead is a growing concern.

Phosphorus levels in the lake are increasing, and the pace of increase may be accelerating. This has not yet translated into a statistically significant impact on traditional measures of the lake's productivity and trophic status (e.g. chlorophyll-a, bottom water oxygen). More sensitive and targeted analyses are needed. The risk of nutrient impairment is growing. For example, the increasing phosphorus is shifting the nutrient balance between nitrogen and phosphorus lower, towards an ecosystem structure that favors cyanobacteria (blue-green algae) that can recover nitrogen from both the air and water (Figure 22). Some species of these cyanobacteria produce toxins that are harmful to human health and undergo seasonal blooms that impair lake aesthetics and beneficial uses. Harmful algae blooms have been observed in other regional lakes, and records of plankton community structure in Coeur d'Alene Lake show that small blooms of toxin producing cyanobacteria have occurred in the past. These risks are increasing for Coeur d'Alene Lake. Nutrient pollution is a growing metals management issue, and is also an issue for other key aspects of water quality and beneficial use. The rapid increases in phosphorus seen since 2015 have placed the lake at greater risk.

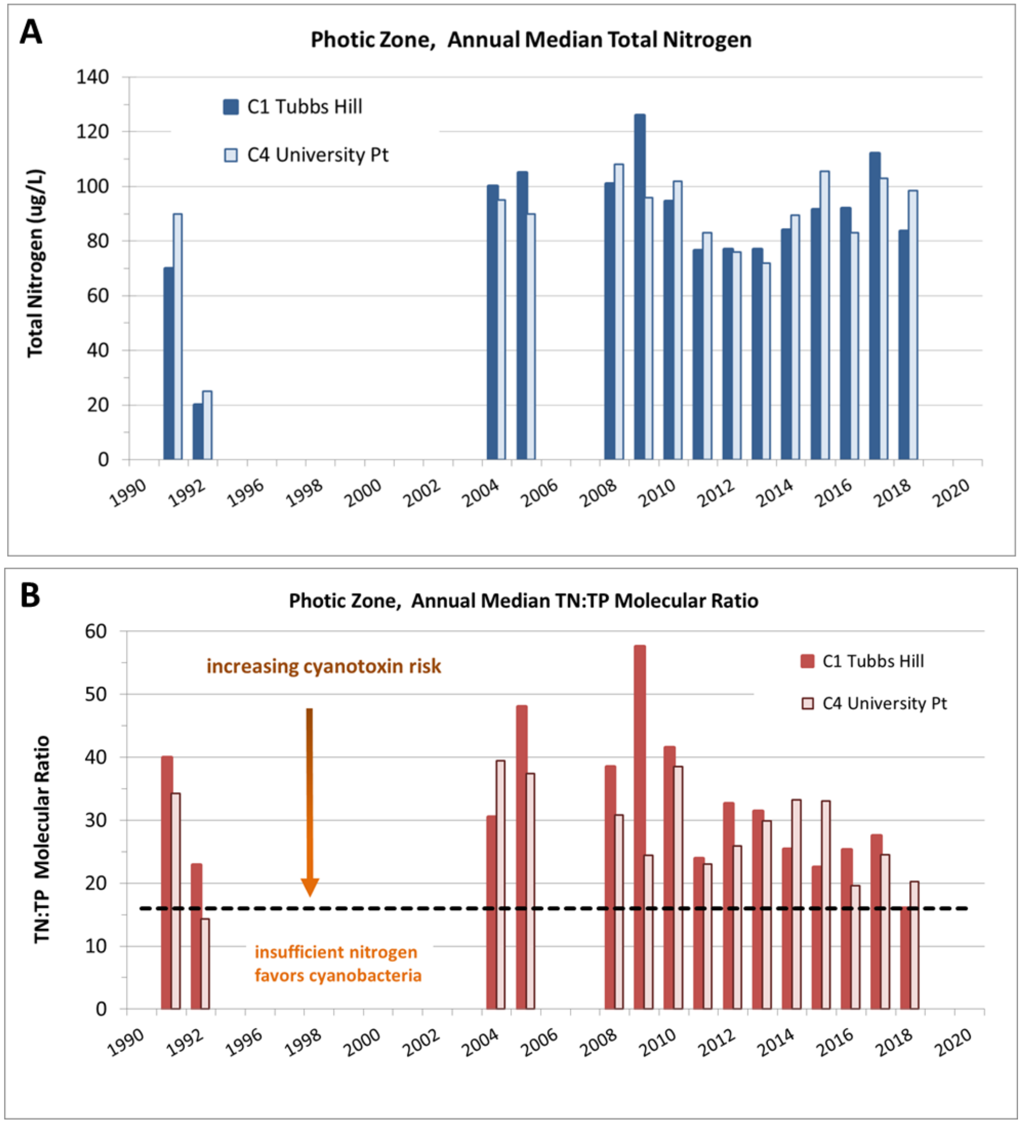


Figure 22. Total nitrogen (A) and total nitrogen to total phosphorus ratio (B) at C1 Tubbs Hill and C4 University Point. The black line is the global average ratio of nitrogen to phosphorus for phytoplankton (Redfield Ratio).

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Appendix A: Lake Management Plan Trigger Criteria for the Northern Lake

Table 3. Water Quality Triggers for Station C1: SE of Tubbs Hill – Northern Pool, North End at 40 meters (see Appendix A, Figure A1 for map of stations)

Variables	CY91-92 Condition[a]	WY04-06 Condition[a]	Idaho WQ Standards Criteria (IDAPA 58.01.02)	Desired Condition	Trigger Condition
Total phosphorus 1 m – 30 m depth[b]	2.7 µg/L geomean[c]	5.0 µg/L geomean	nutrient narrative (200.06)	no greater than WY04-06 condition	8.0 µg/L annual geomean[d]
Dissolved oxygen in hypolimnion	minimum >6.0 mg/L	minimum >6.0 mg/L	hypolimnion exempt (250.02.a.iii)	minimum >6.0 mg/L	minimum <6.0 mg/L
Chlorophyll *a* in photic zone	0.46 µg/L (0.92 µg/L)[e] geomean 1.3 µg/L max (1.7 µg/L max)[e]	1.57 µg/L geomean 3.3 µg/L max	nutrient narrative(200.06)	no greater than WY04-06 condition	3.0 µg/L annual geomean[f] 5.0 µg/L max
Blue-green algae (cyanobacteria) blooms	blue-greens minor component	not measured	nutrient narrative (200.06)	blue-greens minor component	blue-greens are dominant algal group with seasonal blooms
Water clarity Secchi depth July – October	8.3 m geomean	9.4 m geomean	none	no less than CY91-92 condition	clarity trigger may reflect chlorophyll *a* trigger
Dissolved zinc 1 m ≈ 39 m[g] (1 m off bottom)	only total zinc measured	62 µg/L geomean 33-91 range	36 µg/L CCC[h] (210.02 & 210.03)	meet Idaho WQS	already consistently exceeds WQS
Dissolved lead 1 m ≈ 39 m (1 m off bottom)	only total lead measured	0.12 µg/L geomean 0.05-0.88 rng	0.54 µg/L CCC (210.02 & 210.03)	meet Idaho WQS	when WQS are exceeded
Diss. cadmium 1 m ≈ 39 m (1 m off bottom)	only total cadmium measured	0.23 µg/L geomean 0.15-0.52 rng	0.25 µg/L CCC (210.02 & 210.03)	meet Idaho WQS	already occasionally exceeds WQS

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Table Footnotes for both site C1 and site C4 are given after the trigger Table for site C4.

Table 4. Water Quality Triggers for Station C4: NE of University Point – Northern Pool, South End at 40 meters

Variables	CY91-92 Condition[a]	WY04-06 Condition[a]	Idaho WQ Standards Criteria (IDAPA 58.01.02)	Desired Condition	Trigger Condition
Total phosphorus 1 m – 30 m depth[b]	3.8 µg/L geomean[c]	6.2 µg/L geomean	nutrient narrative (200.06)	no greater than WY04-06 condition	8.0 µg/L annual geomean[d]
Dissolved oxygen in hypolimnion	minimum >6.0 mg/L	minimum >6.0 mg/L	hypolimnion exempt (250.02.a.iii)	minimum >6.0 mg/L	minimum <6.0 mg/L
Chlorophyll *a* in photic zone	0.48 µg/L (0.94 µg/L)[e] geomean 1.5 µg/L max (1.8 µg/L max)[e]	1.55 µg/L geomean 3.1 µg/L max	nutrient narrative (200.06)	no greater than WY04-06 condition	3.0 µg/L annual geomean[f] 5.0 µg/L max
Blue-green algae (cyanobacteria) blooms	blue-greens minor component	not measured	nutrient narrative (200.06)	blue-greens minor component	blue-greens are dominant algal group with seasonal blooms
Water clarity Secchi depth July – October	7.7 m geomean	8.6 m geomean	none	no less than CY91-92 condition	clarity trigger may reflect chlorophyll *a* trigger
Dissolved zinc 1 m ≈ 39 m[g] (1 m off bottom)	only total zinc measured	68 µg/L geomean 36-104 range	36 µg/L CCC[h] (210.02 & 210.03)	meet Idaho WQS	already consistently exceeds WQS
Dissolved lead 1 m ≈ 39 m (1 m off bottom)	only total lead measured	0.27 µg/L geomean 0.05-2.76 rng	0.54 µg/L CCC (210.02 & 210.03)	meet Idaho WQS	already occasionally exceeds WQS
Diss. cadmium 1 m ≈ 39 m (1 m off bottom)	only total cadmium measured	0.26 µg/L geomean 0.16-0.43 rng	0.25 µg/L CCC (210.02 & 210.03)	meet Idaho WQS	already frequently exceeds WQS

Table Footnotes for both Site C1 and Site C4

a = CY91-92 - USGS baseline study, annual sampling from January 1991 – December 1992.
WY04-06 - USGS study, annual sampling from October 2003 – August 2006.

b = Data combined for composite photic zone samples and discrete samples at 20 m and 30 m.

c = Geometric mean - used by USGS to summarize data in the CY91-92 studies. A geometric mean dampens the effect of a few very high or very low sample results as compared to an arithmetic mean.

d = A consistent annual trend of 8 µg/L geometric mean for total phosphorus would be a statistically significant upward departure from the CY91-92 data set.

e = Chlorophyll *a* analysis methods changed from CY91-92 to WY04-06. Thus, the USGS did a paired study of chlorophyll *a* samples using the two analytical methods and derived a statistical relationship that adjusts the original chlorophyll *a* values for CY91-92 (first listed value) to values comparable to the WY04-06 data (values in parenthesis).

f = Based on a transitioning between the current oligotrophic condition and a meso-oligotrophic condition. An annual geometric mean of 3 µg/L chlorophyll *a* would be a doubling of the mean from the WY04-06 data set.

g = Data combined for composite photic zone samples and discrete samples at 20 m, 30 m, and 1 m off bottom.

h = CCC is Criterion Continuous Concentration – 4 day average concentration that ensures adequate protection of sensitive species of aquatic organisms from chronic toxicity. The CCC is not to be exceeded more than once every 3 years. The CCC was calculated with a total hardness of 25 mg/L as $CaCO_3$ (Idaho WQS uses a lower hardness cap of 25 mg/L to calculate CCC for dissolved metals).

Table 5. Water Quality Triggers for Shallow Bays of Northern Pool – Shoreline to ≈ 20 meters

Variables	Summer 91-92 and July – Oct 95-02[a]	WY04-06 Condition[b]	Idaho WQ Standards Criteria (IDAPA 58.01.02)	Desired Condition	Trigger Condition
Nearshore periphyton & aquatic plants[c]	periphyton production in bays - 1992	not measured	nutrient narrative (200.06)	to be determined by nearshore LMP studies	to be determined by nearshore LMP studies
Eurasian milfoil	not present	not present	none	not present	present
Total phosphorus water column	5.7 µg/L geomean 1991 - 2002	5.8 µg/L geomean	nutrient narrative (200.06)	no greater than current condition	9.0 µg/L annual geomean[d]
Dissolved oxygen to near bottom	minimum >6.0 mg/L 1991 - 2002	dissolved oxygen data not reported	min. >6.0 mg/L bottom 20% of depth exempt (250.02.a.iii)	minimum >6.0 mg/L	minimum <6.0 mg/L
Chlorophyll *a* in photic zone	0.40 µg/L (0.90 µg/L)[e] geomean 1.7 µg/L max (2.0 µg/L max)[e] 1991 - 1992	1.2 µg/L geomean 3.5 µg/L max	nutrient narrative (200.06)	no greater than current condition	3.0 µg/L annual geomean[f] 5.0 µg/L max
Water clarity Secchi depth 10 m and deeper July – Oct.	8.1 m geomean 1991 - 2002	not measured	none	no less than current condition	clarity trigger may reflect chlorophyll *a* trigger
Blue-green algae (cyanobacteria) blooms	not measured	not measured	nutrient narrative (200.06)	blue-greens - minor component	blue-greens are dominant algal group with season blooms
Coliform bacteria	not measured	not measured	126 *E. coli*/100 ml geomean of 5 samples/30 days (251.01.c[g])	meet Idaho WQS	when WQS are exceeded
Dissolved zinc water column	58 µg/L geomean 28-272 range 1995 - 2002	49 µg/L geomean 25-98 µg/L range	36 µg/L CCC (210.02 & 210.03)	meet Idaho WQS	already consistently exceeds WQS
Dissolved lead water column	samples <det. limit of 3 µg/L 1995 - 2002	0.17 µg/L geomean 0.05-1.24 range	0.54 µg/L CCC (210.02 & 210.03)	meet Idaho WQS	already occasionally exceeds WQS
Diss. cadmium water column	samples <det. limit 0.5 µg/L 1995 - 2002	0.19 µg/L geomean 0.10-0.35 range	0.25 µg/L CCC (210.02 & 210.03)	meet Idaho WQS	already occasionally exceeds WQS

Footnotes for Table 5

a = These data are from USGS sampling in summer months for 1991-92 baseline study, and DEQ sampling for July – Oct., 1995–2002.

b = WY04-06 – these data are from USGS study with periodic sampling within littoral bay areas from October 2003 – October 2005. Data was combined for littoral stations NS3 through NS12 (see Appendix A, Figure A1 for map of sampling stations).

c = Periphyton is attached algae growing on natural and artificial substrates.

d = Based on a numerical total phosphorus target established for the nutrient TMDL of near shore waters of Pend Oreille Lake, Idaho (Tetra Tech, 2002).

e = Chlorophyll *a* analysis methods changed from CY91-92 to WY04-06. Thus, the USGS did a paired study of chlorophyll *a* samples using the two analytical methods and derived a statistical relationship that adjusts the original chlorophyll *a* values for CY91-92 (first listed value) to values comparable to the WY04-06 data (values in parenthesis).

f = Based on a transitioning between the current oligotrophic condition to a meso-oligotrophic condition. An annual geometric mean of 3 µg/L chlorophyll *a* would be a doubling of the mean from the WY04-06 data set.

g = For areas that are specified as public swimming beaches, the criteria is 235 *E. coli*/100 ml for a single sample (251.01.a).