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State of Washington

Deep Lake (Stevens County)

Water Quality Monitoring Study

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Deep Lake (Stevens County)

Water Quality Monitoring Study

by

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Water Resource Inventory Area (WRIA) and 8-digit Hydrologic Unit Code (HUC) numbers for the study area:

WRIA
- 61 (Upper Lake Roosevelt)

HUC number
- 07020001 (Franklin D. Roosevelt Lake)

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Abstract

This report summarizes field and laboratory water quality data and flow data collected by the Washington State Department of Ecology at Deep Lake, in Stevens County, during 2014. A quality control and quality assurance analysis of the data is included.

The purpose of the study was to provide baseline water quality data in response to citizen complaints about water quality in Deep Lake.

Data were collected in Deep Lake as well as at the inlet and outlet streams of the lake. Field data included pH, conductivity, dissolved oxygen, water temperature, Secchi depth, and flow. Laboratory data included ammonia-nitrogen, nitrite-nitrate nitrogen, orthophosphate, total phosphorus, total persulfate nitrogen, fecal coliform, and total suspended solids.

Study findings include elevated fecal coliform and total suspended solids in the inlet stream, significant sediment trapping by the lake, and anoxia in the hypolimnion during the summer months.

Background

Study Area Description

Deep Lake is located approximately 10 miles southeast of Northport, Washington, in Stevens County (Figure 1). The lake is located in Water Resource Inventory Area (WRIA) 61 (Upper Lake Roosevelt), and level 8 HUC 17020001 (Franklin D. Roosevelt Lake). It has a surface area of 0.32 square mi, and a maximum depth of about 45 ft.

The lake is located along North Fork Deep Creek, which drains a mostly forested area along the western slope of a north-south range of the western Rocky Mountains. North Fork Deep Creek flows into Deep Lake at the north end of the lake, and flows out at the south end. From the outlet of Deep Lake, the creek flows southwest to join with South Fork Deep Creek, forming Deep Creek, which empties to Lake Roosevelt near Northport.

Much of Deep Lake is surrounded by residential development including vacation homes. The surrounding landscape is primarily forestland. For about four miles upstream of Deep Lake, North Fork Deep Creek flows along a fairly level valley bottom, which is dominated by livestock grazing for a part of the year. The Anderson-Calhoun Mine, an open pit mine which formerly produced lead and zinc, is located along North Fork Deep Creek, about four miles upstream of Deep Lake. However, this mine is inactive and not a likely source of the pollutants addressed by this study.

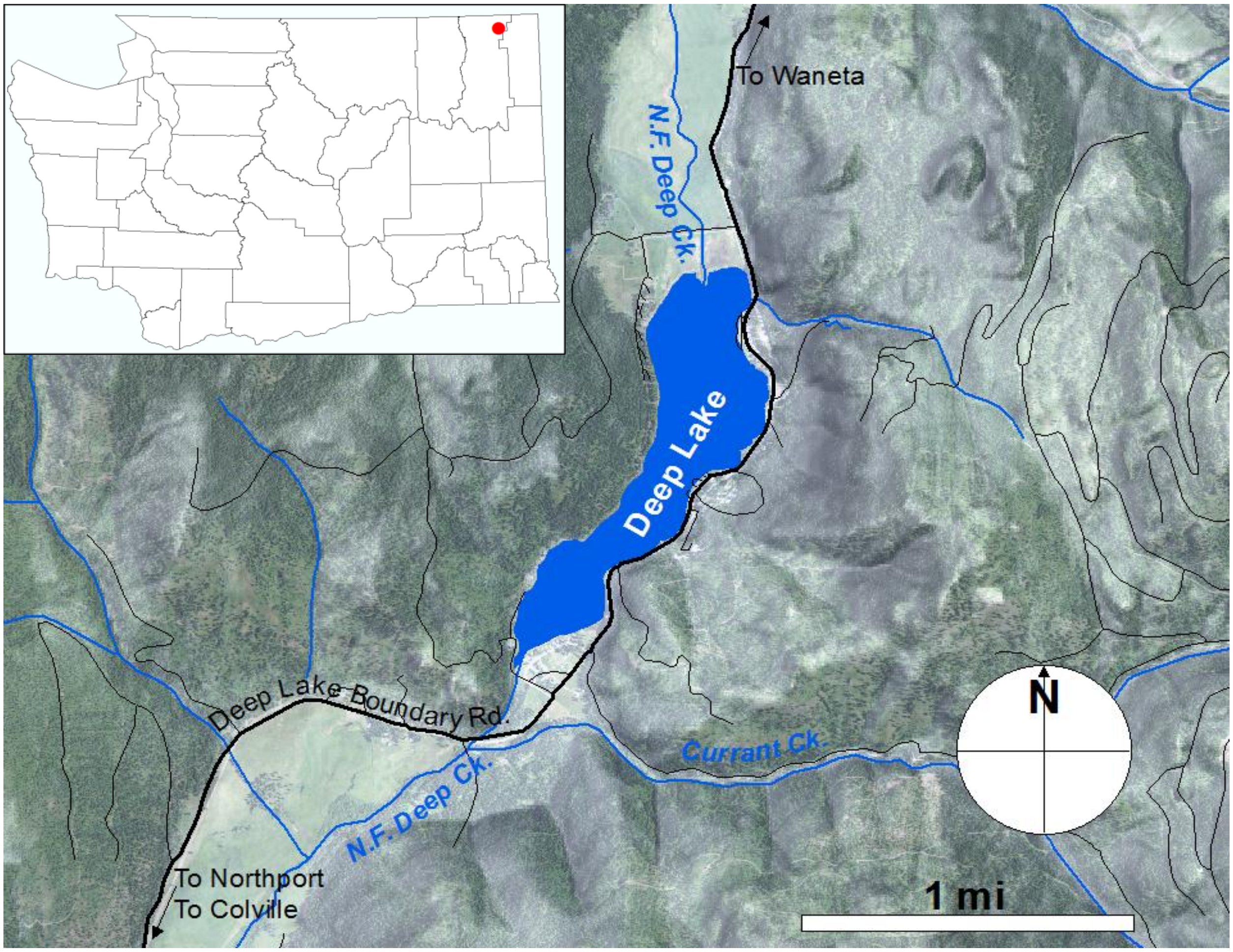


Figure 1. Location of Deep Lake in northeastern Washington.

Reported Water Quality Problems

There have been a number of complaints from local residents about water quality in Deep Lake, representing a perception that water quality in Deep Lake has been declining. Residents also expressed concerns about blue-green algae. One blue-green algae bloom was confirmed by the Washington State Department of Ecology (Ecology) in November 2012. Local residents have expressed a desire for monitoring of the lake. Potential sources of nutrients, fecal coliform, and sediment include upstream livestock activities as well as possible residential sources adjacent to the lake.

Purpose of Study

The goals of this project were to:

- Provide baseline water quality data to support future monitoring by citizen groups or other agencies.
- Assess eutrophication and fecal coliform status of Deep Lake.

Water Quality Standards and Beneficial Uses

The 2006 Water Quality Standards for Surface Waters of the State of Washington Chapter 173-201A WAC (Ecology, 2006) designates all lakes for the beneficial use of Core Summer Salmonid Habitat. This designation protects year-round uses by salmon and trout, including spawning and rearing. Lakes are also given a recreational beneficial use of Extraordinary Primary Contact Recreation. This use provides extraordinary protection against waterborne disease. Each beneficial use has associated water quality criteria.

Table 1 lists the criteria that are applicable in Deep Lake.

Table 1. Water quality criteria applicable to Deep Lake.

Parameter	Criteria
Fecal Coliform	Fecal coliform organism levels must not exceed a geometric mean value of 50 colonies /100 mL, with not more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean value exceeding 100 colonies /100 mL.
Dissolved Oxygen	Dissolved oxygen (DO) concentrations are not to fall below a 1-day minimum of 9.5 mg/L at a probability frequency of more than once every ten years on average. When a water body's DO is lower than 9.5 mg/L (or within 0.2 mg/L) and that condition is due to natural conditions, then human actions considered cumulatively may not cause the DO of that water body to decrease more than 0.2 mg/L. For lakes, human actions considered cumulatively may not decrease the DO concentration more than 0.2 mg/L below natural conditions.
pH	pH shall be within the range of 6.5 to 8.5 with a human-caused variation within above range of less than 0.2 units.
Temperature	7-day average of the daily maximum temperature (7-DADMax) is not to exceed 16°C at a probability frequency of more than once every ten years on average. When a water body's temperature is warmer than 16°C (or within 0.3°C) and that condition is due to natural conditions, then human actions considered cumulatively may not cause the 7-DADMax temperature of that water body to increase more than 0.3°C. For lakes, human actions considered cumulatively may not increase the 7-DADMax temperature more than 0.3°C above natural conditions.

Methods

Table 2 and Figure 2 present the locations of sampling sites on Deep Lake and in the inlet and outlet streams and the parameters collected at each site. All samples and measurements were collected in accordance with the Quality Assurance Project Plan (QAPP) for this project (Stuart, 2014), which provides additional detail about sampling methods.

Table 2. Description of sampling locations and parameters collected at each location.

Station ID	Station Description	Latitude	Longitude	Fecal Coliform	Nutrients[1]	Tot Susp Solids	Secchi depth	Hydrolab *profile[2]	Flow
DEEPLK-1	Deep location in northern half of lake	48.8613	-117.6029	X	X		X	*X	
DEEPLK-2	Deep location in southern half of lake	48.8534	-117.6124		X		X	*X	
DEEPLK-INLET	Inlet at Deep Lake North Shore Way	48.8691	-117.6030	X	X	X		X	X
DEEPLK-OUTLET	Outlet at Deep Lake South Shore Rd.	48.8491	-117.6168	X	X	X		X	X
DEEPLK-A	Shallow location northeast	48.8625	-117.6002	X					
DEEPLK-B	Shallow location east	48.8561	-117.6056	X					
DEEPLK-C	Shallow location west	48.8551	-117.6112	X					

[1] Nutrient parameters include total phosphorus, orthophosphate, total persulfate nitrogen, nitrate-nitrite nitrogen, and ammonia nitrogen.
[2] Parameters measured by Hydrolab® include temperature, conductivity, dissolved oxygen, and pH.

All samples and measurements taken from the inlet and outlet stream were collected as simple grab samples. Fecal coliform samples collected from locations in the lake were taken from approximately 0.5 meters (m) below the surface using a sampling pole, as the shallow portions of the lake are the most relevant for primary contact recreation. Lake profiles were collected by taking measurements of temperature, conductivity, dissolved oxygen, and pH at 1-meter intervals throughout the water column using a Hydrolab MiniSonde®. Nutrient samples in the lake were collected as composite samples. Two composite samples were collected from each sampling location, one from the epilimnion and one from the hypolimnion. Each composite sample consisted of samples taken at three evenly spaced depths in the appropriate layer.

Data quality was ensured and measured through the use of replicate samples, blank samples, post-survey calibration checks, and Winkler titrations (for dissolved oxygen). Appendix A presents an analysis of the quality of all data collected during this study.

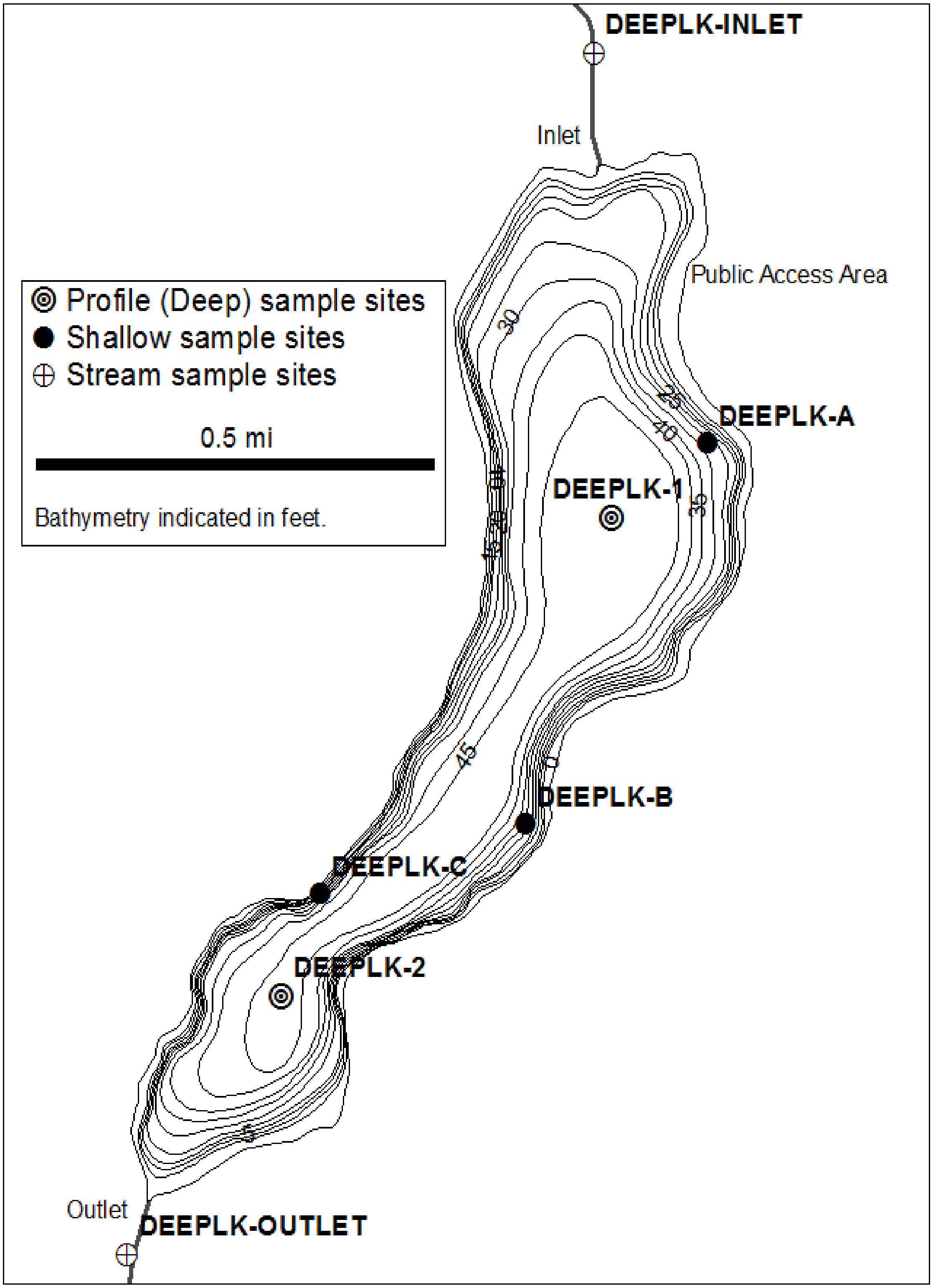


Figure 2. Sampling locations used for monitoring Deep Lake.

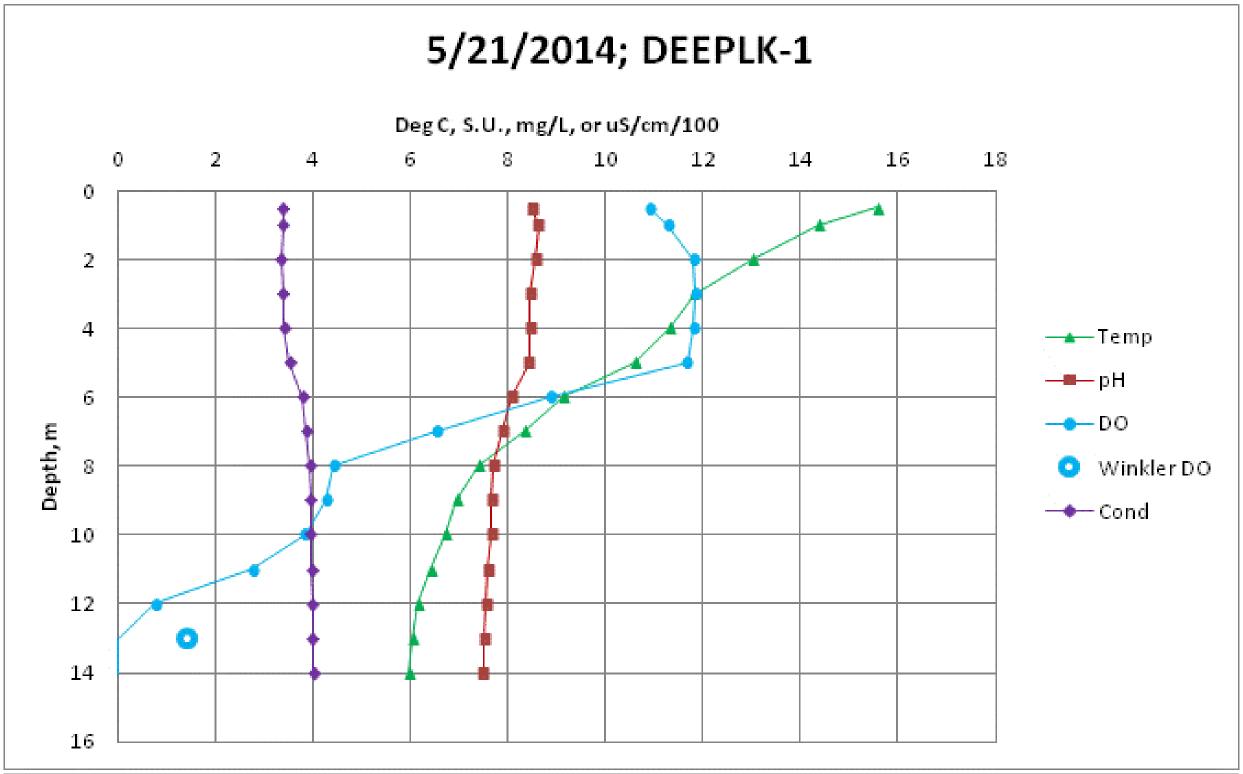
Data Results

Lake Measurement Profiles

Figure 3 (covering the next 5 pages) presents profiles of Deep Lake taken at the two deep sampling locations, DEEPLK-1 and DEEPLK-2. Profiles were collected by lowering a Hydrolab® Minisonde from the surface to the bottom of the lake, taking measurements first at 0.5-m depth, then 1-m depth, then at 1-m increments. Units of measurement are: Temperature in °C, pH in standard units (S.U.), dissolved oxygen in mg/L, and conductivity in uS/cm/100. For example, conductivity measurement of 3.00 on these graphs means 300 uS/cm. The majority of the dissolved oxygen data is corrected using Winkler titration results. Correction of dissolved oxygen data using Winkler results was done using either a bias or linear regression correction method.

The most notable feature of this data is that the hypolimnion became anoxic (devoid of oxygen) during late spring/early summer, and remained so for the remainder of the summer. During the first sampling run on May 21, the very bottom layer of the lake was anoxic, with transitional dissolved oxygen levels above that. During all other sampling runs, the hypolimnion was entirely anoxic below a depth of about 8-10 m.

Both dissolved oxygen and temperature were observed to be in exceedance of the numeric water quality criteria, with dissolved oxygen less than 9.5 mg/L and temperatures greater than 16°C. For cases such as this, the water quality standards for dissolved oxygen and temperature both include a natural conditions provision. However, it was beyond the scope of this study to determine a natural condition for dissolved oxygen or temperature. pH was not observed to exceed the water quality criteria.



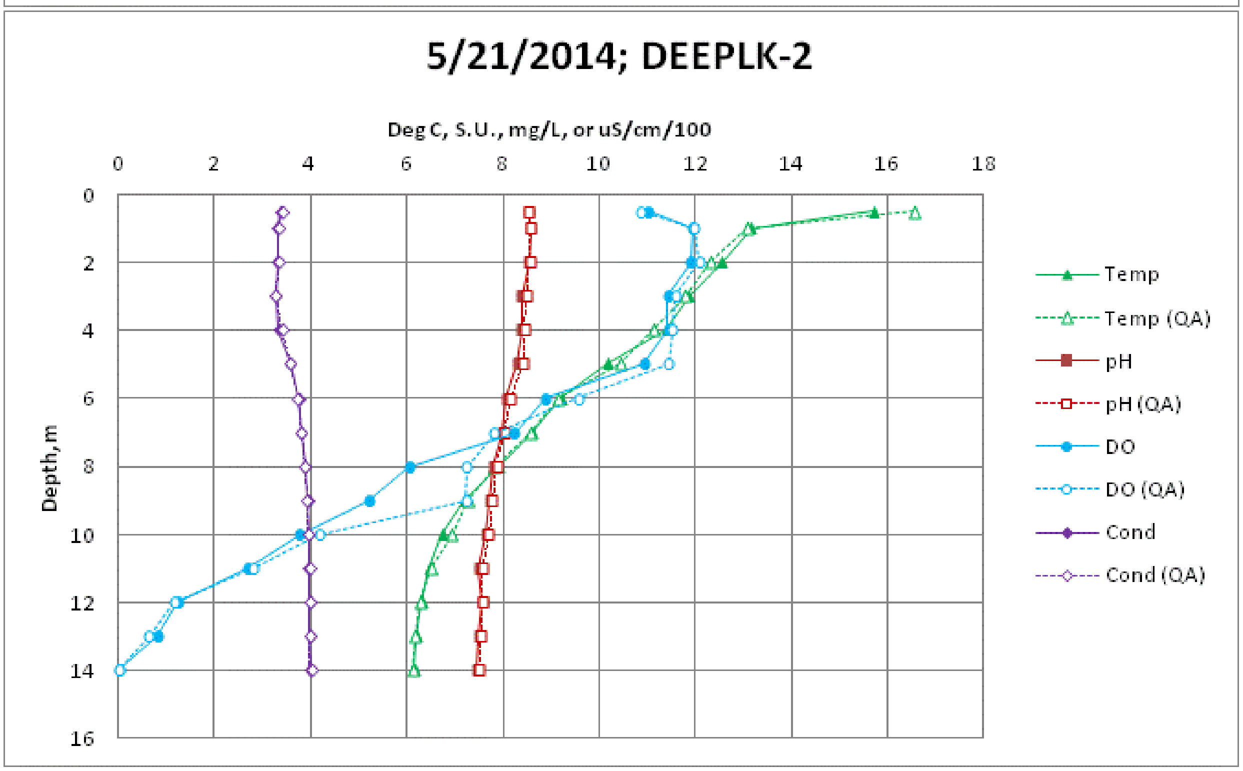
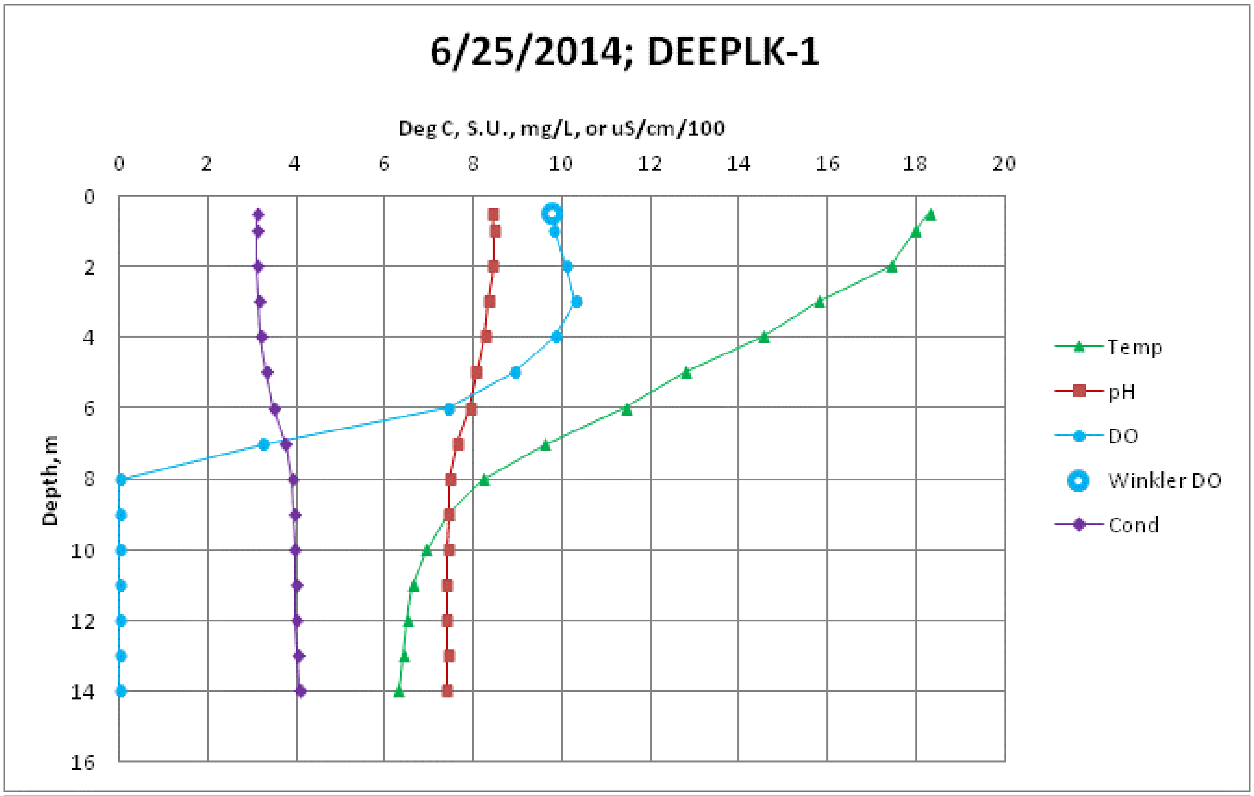


Figure 3. Lake measurement profiles showing temperature, pH, conductivity, and dissolved oxygen in Deep Lake in May-October, 2014.

Figure 3 is continued on the following pages.



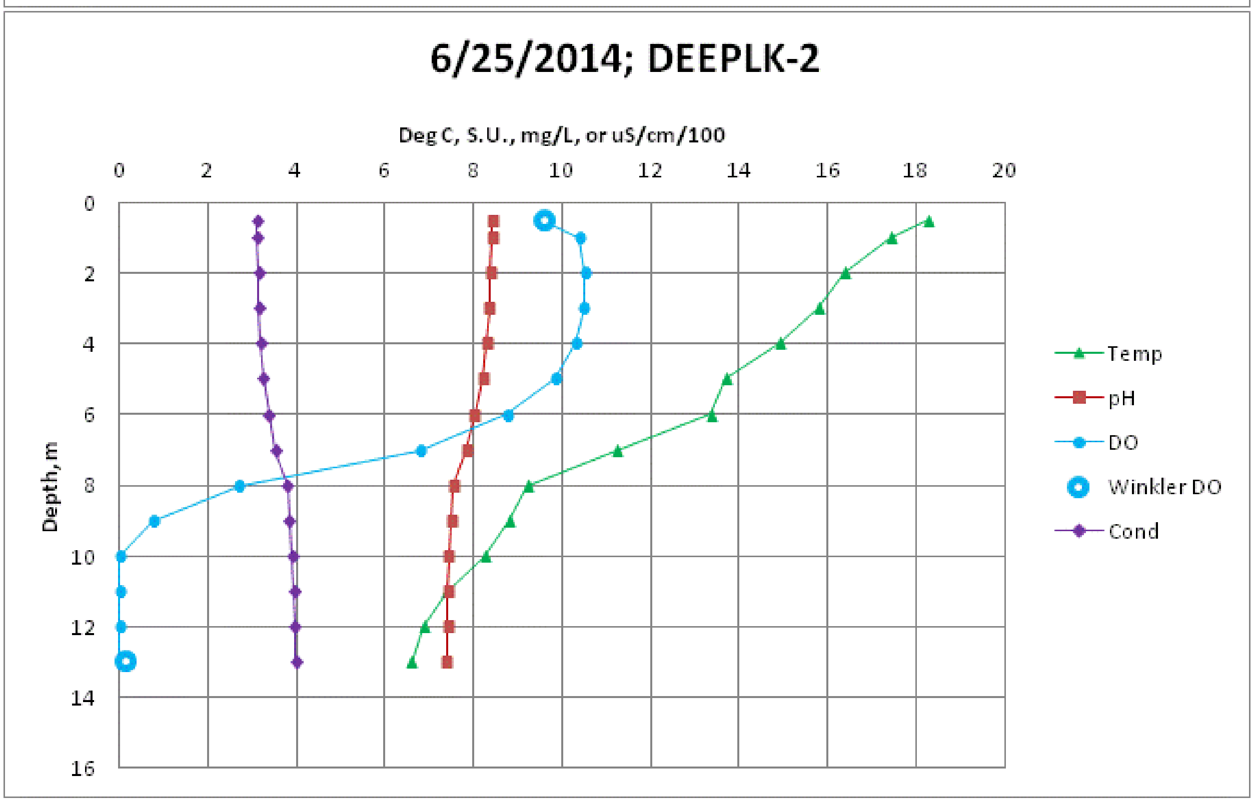
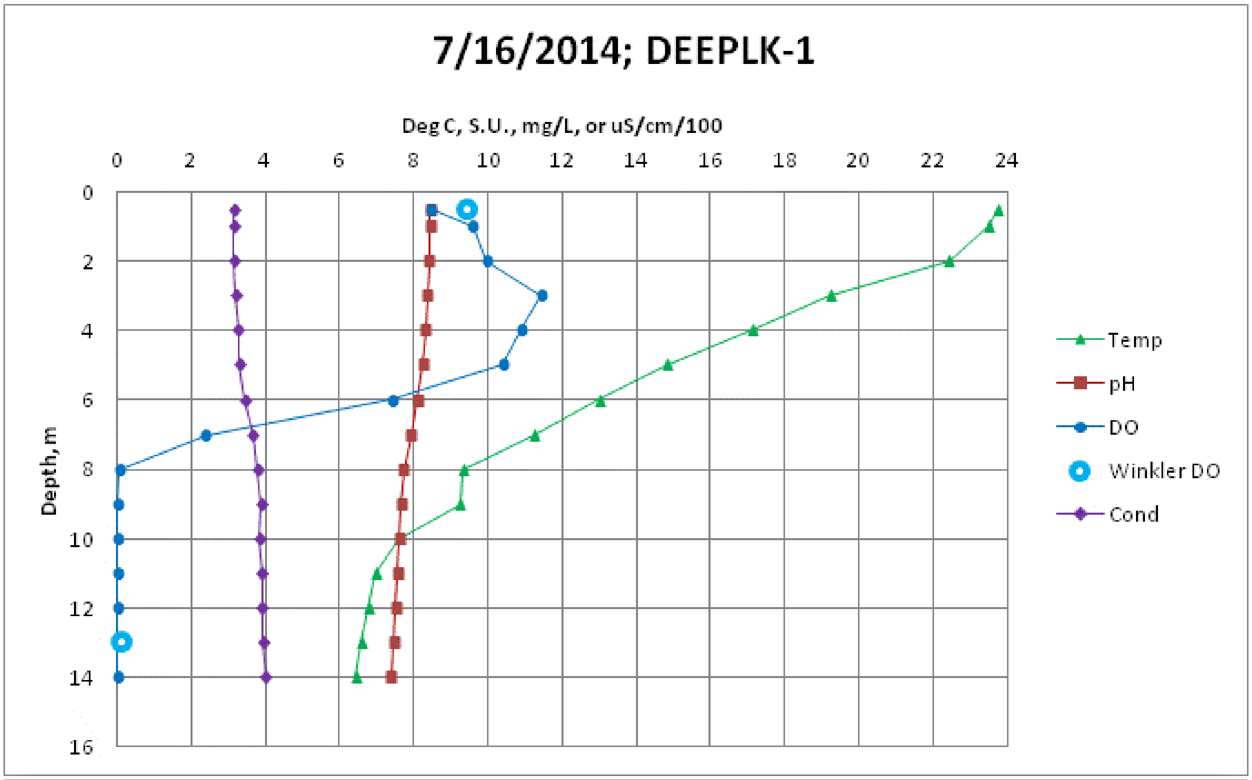


Figure 3 (continued). Lake measurement profiles showing temperature, pH, conductivity, and dissolved oxygen in Deep Lake in May-October, 2014.



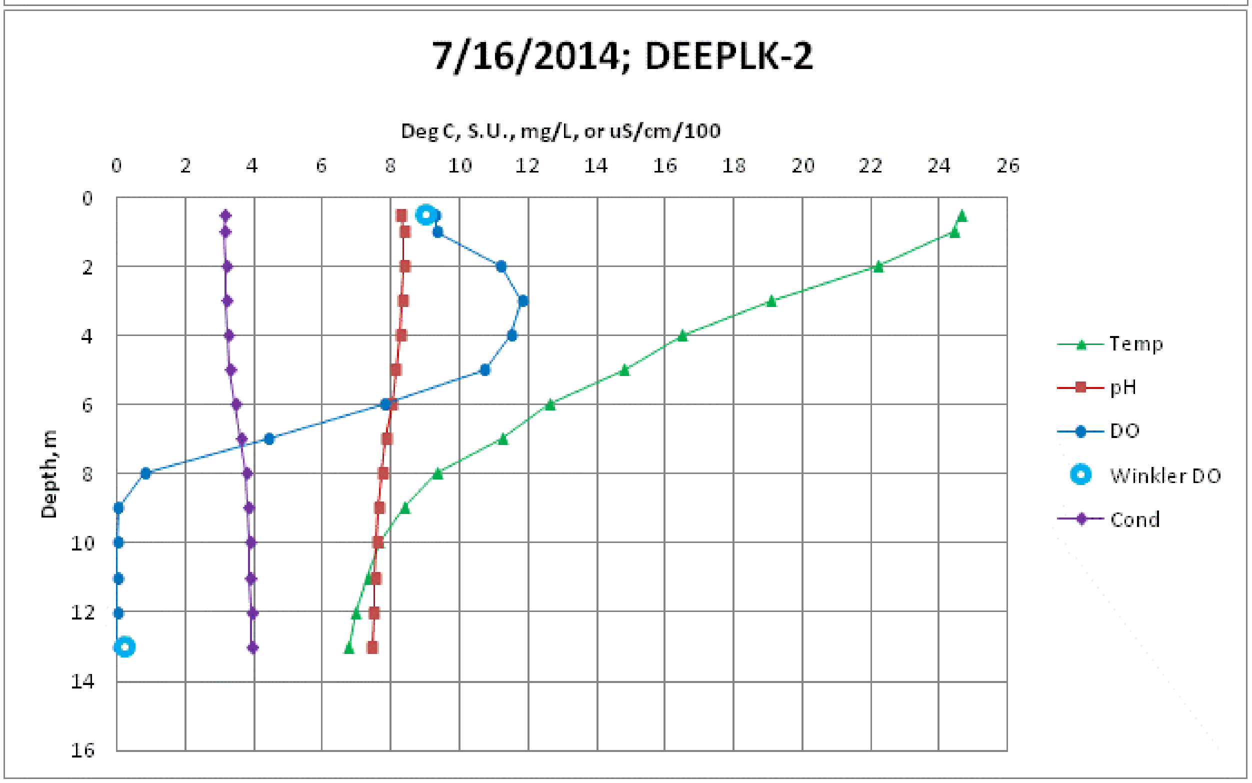
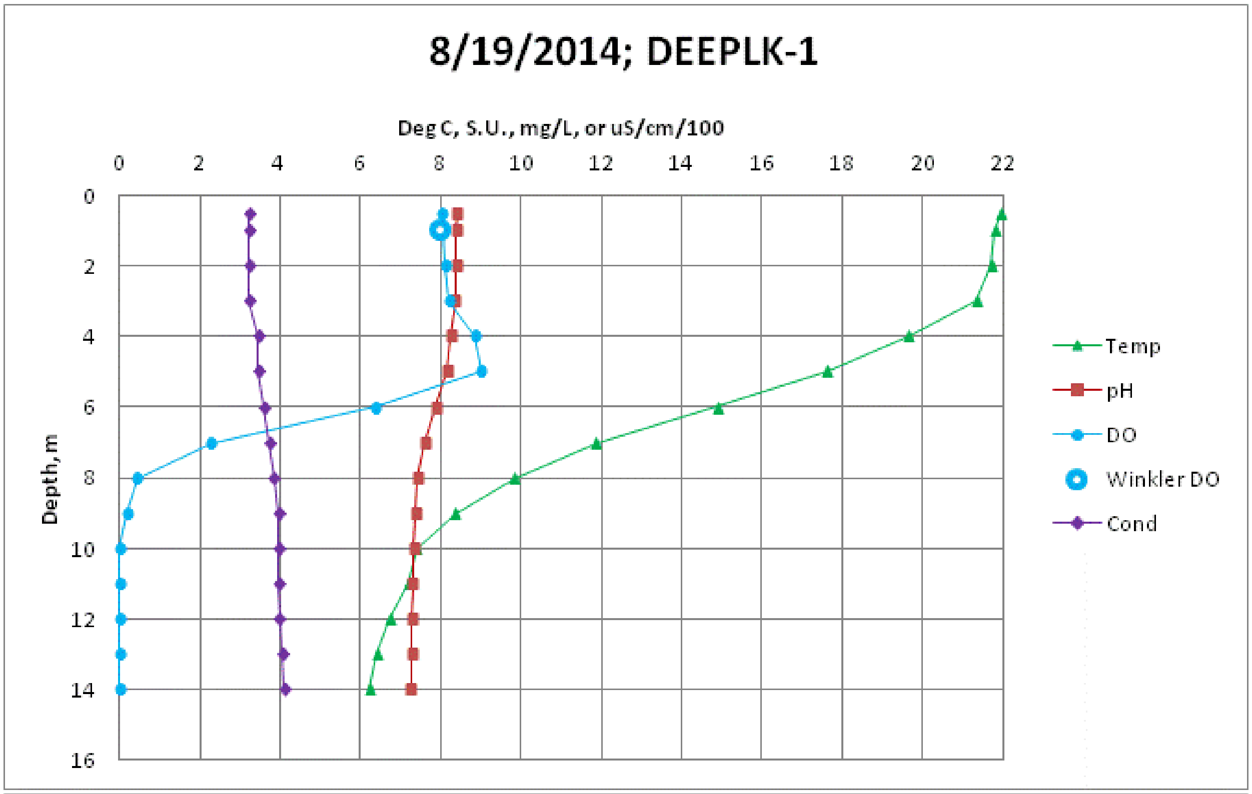
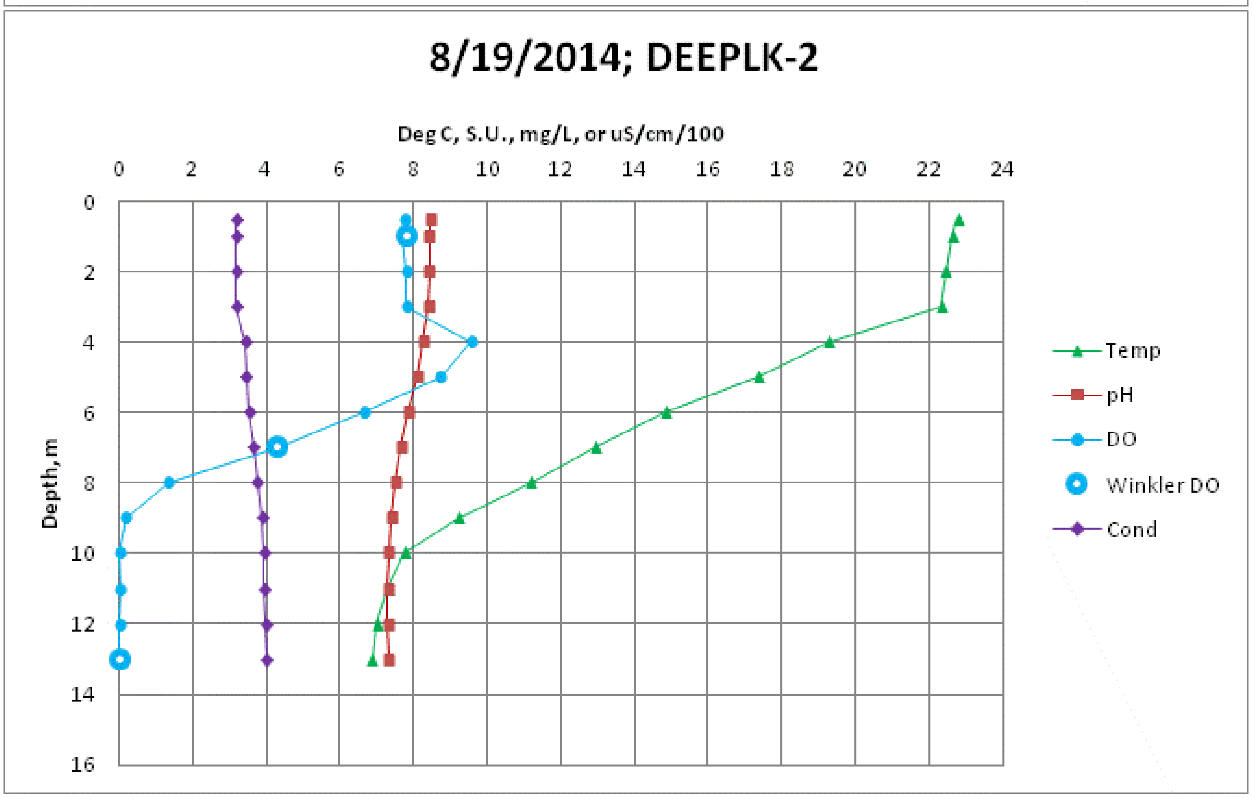


Figure 3 (continued). Lake measurement profiles showing temperature, pH, conductivity, and dissolved oxygen in Deep Lake in May-October, 2014.

Lake profile dissolved oxygen data from 7/16/2014 are qualified as estimates.





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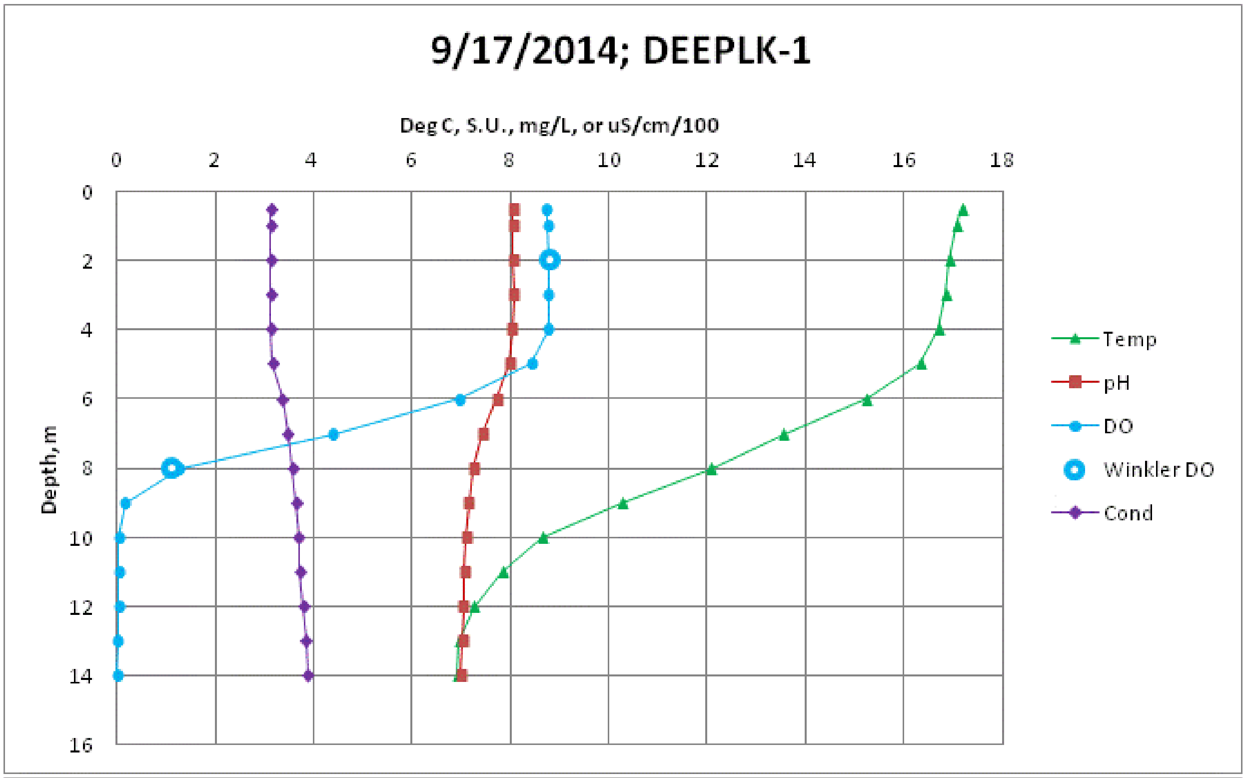


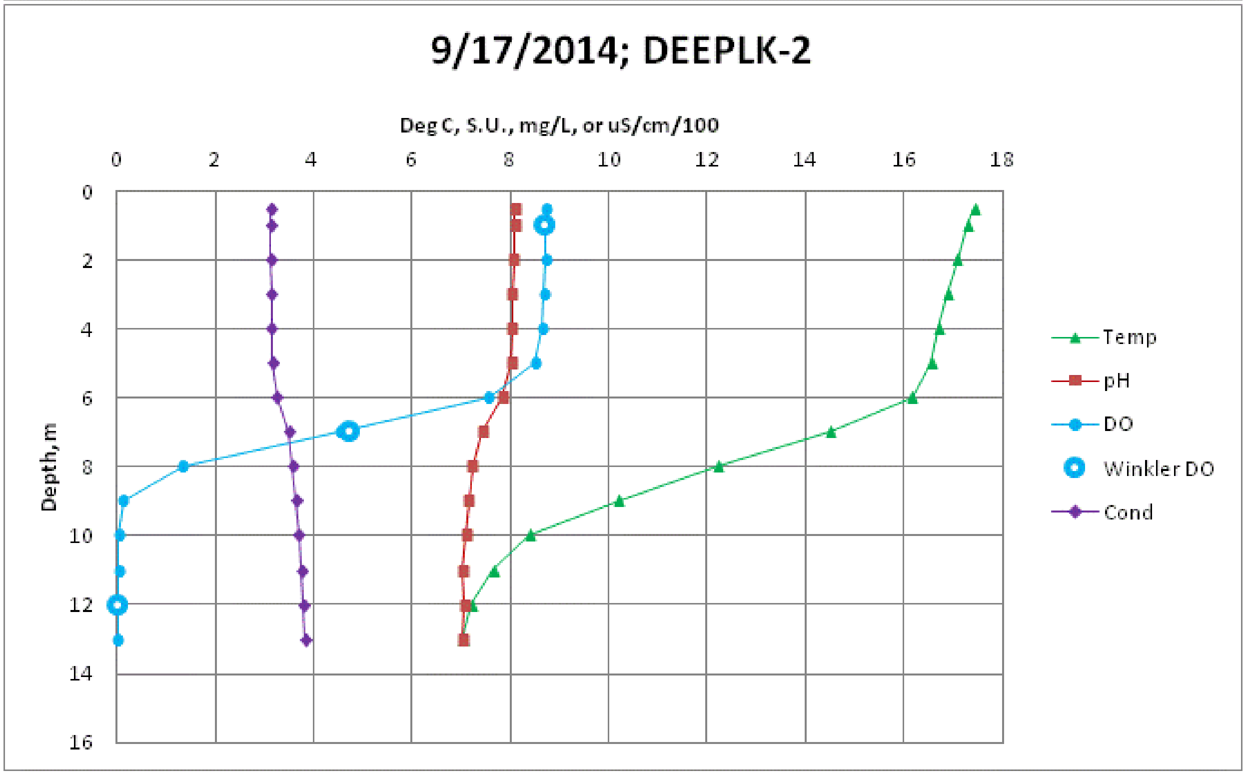
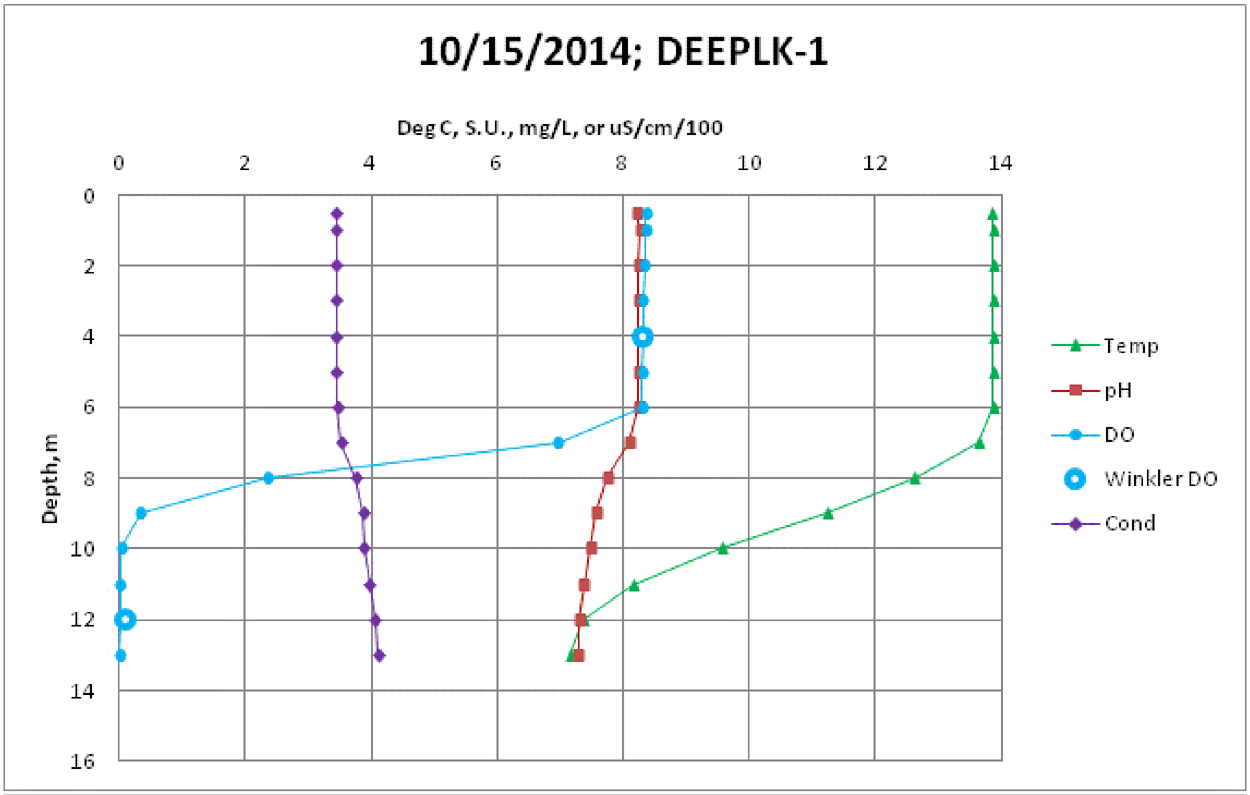


Figure 3 (continued). Lake measurement profiles showing temperature, pH, conductivity, and dissolved oxygen in Deep Lake in May-October, 2014.

Lake profile pH data from 9/17/2014 are qualified as estimates.



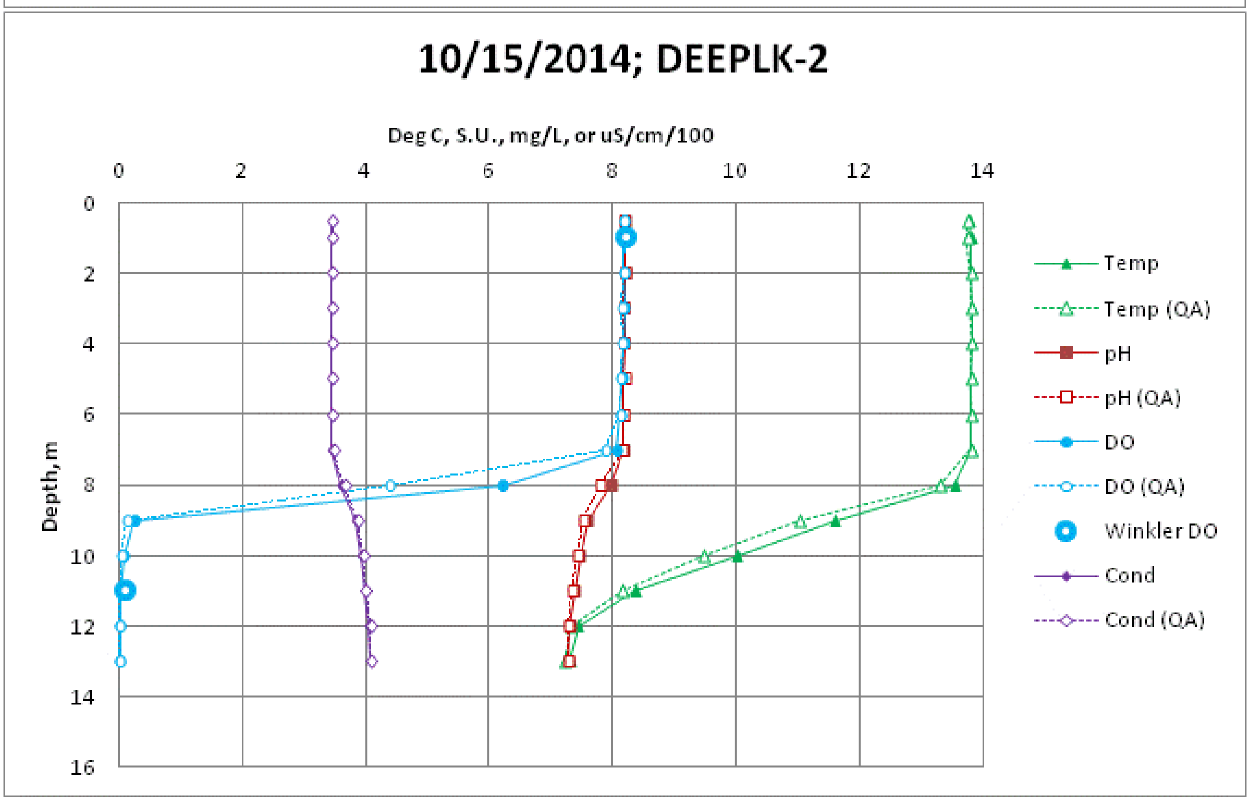


Figure 3 (continued). Lake measurement profiles showing temperature, pH, conductivity, and dissolved oxygen in Deep Lake in May-October, 2014.

Lake profile conductivity and pH data from 10/15/2014 are qualified as estimates.

Other Chemistry and Measurement Data

Tables 3-6 present all data collected during the Deep Lake monitoring project other than the lake measurement profiles. Nutrient data collected from within Deep Lake was collected as composite samples. Two composite samples taken at each sampling site, one representing the epilimnion and one representing the hypolimnion. Each composite sample consisted of lake water collected from three depths within the appropriate layer.

Fecal coliform data collected from within Deep Lake were collected from a shallow depth, using a sampling pole. This was done because shallow depths where people recreate are of the greatest interest from a human health perspective.

Fecal coliform results in the inlet stream (North Fork Deep Creek) were found to be in excess of the water quality criteria. The water quality criteria specify a geometric mean of 50 cfu/100 mL and a 90^{th} percentile (or highest measurement if less than 10 samples) of 100 cfu/100 mL. A geometric mean of 219 cfu/100 mL and a high measurement of 1200 cfu/100 mL were observed in the inlet stream. Fecal coliform results at the sites measured in the lake and in the outlet stream did not exceed water quality criteria.

Nutrient concentrations in the inlet stream and in the epilimnion of the lake were moderately low. Nitrate-nitrite concentrations ranged from 14 to 41 ug/L in the inlet stream and from non-detect range to 16 ug/L in the epilimnion of the lake. Total phosphorus concentrations ranged from 13.6 to 54.8 ug/L in the inlet stream and from 7.3 to 18.4 ug/L in the epilimnion of the lake. However, nutrient concentrations in the hypolimnion of the lake showed an increasing trend throughout the summer, reaching maximum values of 369 ug/L of ammonia and 236 ug/L of total phosphorus during October. It is likely that these nutrients will be distributed through the water column during lake's fall turnover, creating a risk of algae blooms.

Secchi depth measurements were taken at the same locations where nutrient composite samples and lake measurement profiles were collected. Secchi depth provides a measurement of lake clarity; larger results indicate clearer water and smaller results indicate more turbid water.

Table 3. Nutrient sample results.

Date	Site	Layer	NH_4	NO_2-NO_3	TPN	OP	TP
5/5/2014	DEEPLK-INLET	Stream	0.01 U	0.041	0.18	0.0135	0.0548
5/21/2014	DEEPLK-INLET	Stream	0.01 U	0.028	0.158	0.0107	0.0519
	DEEPLK-1	Epilimnion	0.01 U	0.016	0.209	0.0039	0.0168
		Hypolimnion	0.01 U	0.037	0.25	0.0043	0.0176
	DEEPLK-2	Epilimnion	0.01 U (0.01 U)	0.01 U (0.01 U)	0.186 (0.204)	0.0034 (0.003 U)	0.0184 (0.0178)
		Hypolimnion	0.01 U (0.01 U)	0.028 (0.03)	0.237 (0.244)	0.0035 (0.0035)	0.0165 (0.0164)
	DEEPLK-OUTLET	Stream	0.01 U	0.01 U	0.166	0.003 U	0.0126
6/25/2014	DEEPLK-INLET	Stream	0.01 U	0.027	0.2	0.0116	0.0277
	DEEPLK-1	Epilimnion	0.01 U	0.01 U	0.172	0.0042	0.0127
		Hypolimnion	0.033	0.01 U	0.273	0.0263	0.0473
	DEEPLK-2	Epilimnion	0.01	0.01 U	0.171	0.0041	0.011
		Hypolimnion	0.012	0.01 U	0.209	0.0132	0.0295
	DEEPLK-OUTLET	Stream	0.01 U	0.01 U	0.151	0.0038	0.0097
7/16/2014	DEEPLK-INLET	Stream	0.01 U (0.011)	0.015 (0.015)	0.106 (0.151)	0.0106 (0.0107)	0.0226 (0.0226)
	DEEPLK-1	Epilimnion	0.01 U	0.01 U	0.154	0.003 U	0.013
		Hypolimnion	0.157	0.01 U	0.419	0.0805	0.115
	DEEPLK-2	Epilimnion	0.01 U	0.01 U	0.158	0.0031	0.0125
		Hypolimnion	0.121	0.01 U	0.373	0.0645	0.109
	DEEPLK-OUTLET	Stream	0.01 U	0.01 U	0.17	0.0031	0.0112
8/19/2014	DEEPLK-INLET	Stream	0.01 U	0.014	0.152	0.0113	0.024
	DEEPLK-1	Epilimnion	0.01 U	0.01 U	0.14	0.0031	0.0096
		Hypolimnion	0.154	0.016	0.426	0.0895	0.132
	DEEPLK-2	Epilimnion	0.01 U	0.01 U	0.145	0.0033	0.0076
		Hypolimnion	0.265	0.01 U	0.487	0.116	0.16
	DEEPLK-OUTLET	Stream	0.01 U	0.01 U	0.152	0.003 U	0.007
9/17/2014	DEEPLK-INLET	Stream	0.01 U	0.021	0.138	0.0078	0.0136
	DEEPLK-1	Epilimnion	0.01 U	0.01 U	0.144	0.003 U	0.0073
		Hypolimnion	0.296	0.01 U	0.451	0.143	0.184
	DEEPLK-2	Epilimnion	0.01 U	0.01 U	0.144	0.003 U	0.0104
		Hypolimnion	0.19	0.01 U	0.392	0.132	0.176
	DEEPLK-OUTLET	Stream	0.01 U (0.01 U)	0.01 U (0.01 U)	0.164 (0.151)	0.003 U (0.003 U)	0.0082 (0.0087)
10/15/2014	DEEPLK-INLET	Stream	0.01 U	0.015	0.138	0.0073	0.0141
	DEEPLK-1	Epilimnion	0.01 U	0.01 U	0.138	0.0036	0.0128
		Hypolimnion	0.335	0.01 U	0.478	0.171	0.21
	DEEPLK-2	Epilimnion	0.01 U	0.01 U	0.132	0.0031	0.0106
		Hypolimnion	0.369	0.01 U	0.495	0.19	0.236
	DEEPLK-OUTLET	Stream	0.01 U	0.01 U	0.13	0.0037	0.0096

Results are in mg/L as N or P.
Values in parentheses are QA replicate sample results.
U: The analyte was not detected at or above the reported result.
J: The analyte was positively identified. The associated numerical result is an estimate.
UJ: The analyte was not detected at or above the reported estimated result.

Abbreviations: NH_4: ammonia nitrogen; NO_2-NO_3: nitrate-nitrite nitrogen; TPN: total persulfate nitrogen; OP: orthophosphate; TP: total phosphorus

Table 4. Streamflow, total suspended solids, and other measurement data at inlet and outlet sites.

Date	Site	Flow (cfs)	TSS (mg/L)	Temp (°C)	Cond (uS/cm)	pH (S.U.)	DO (mg/L)	Winkler DO (mg/L)
5/5/2014	DEEPLK-INLET	71	41	6.90	320	8.28	-	10.75
5/21/2014	DEEPLK-INLET	93	48 J	9.66	272	8.07	10.20	10.15
	DEEPLK-OUTLET	101	3	13.80	333	8.46	11.26	11.3
6/25/2014	DEEPLK-INLET	34	12	13.48	328	7.76 J	10.39 J	
	DEEPLK-OUTLET	39	1 U	18.80	307	8.06 J	11.32 J	
7/16/2014	DEEPLK-INLET	21	8 (9)	15.66 (16.00)	325 (325)	8.25 (8.27)	9.89 J (9.74 J)	
	DEEPLK-OUTLET	23 (23)	5	23.00	298	8.48	9.86 J	
8/19/2014	DEEPLK-INLET	14	5	15.54	373	8.31	-	9.6
	DEEPLK-OUTLET	12	1	22.88	308	8.44	-	9.6
9/17/2014	DEEPLK-INLET	6.3	2	11.55	386	8.31	11.12	11.1
	DEEPLK-OUTLET	6.9 (7.7)	1 U (1 U)	18.09 (18.20)	323 (323)	8.36 (8.37)	10.30 (10.48)	10.3 (10.5)
10/15/2014	DEEPLK-INLET	6.4	2	9.05	399	8.31	10.92	10.8
	DEEPLK-OUTLET	6.8	1 U	13.77	338	8.23	8.69	8.8

Values in parentheses are QA replicate sample results.
TSS: Total suspended solids
U: The analyte was not detected at or above the reported result.
J: The analyte was positively identified. The associated numerical result is an estimate.
Dissolved oxygen data are generally corrected using Winkler titration results. If no Winkler results are available, then meter results are qualified with a J.

Table 5. Fecal coliform data.

Date	Site					
	DEEPLK-INLET	Lake sites, samples taken within 1-2 ft of surface				DEEPLK-OUTLET
		DEEPLK-1	DEEPLK-A	DEEPLK-B	DEEPLK-C	
5/5/2014	180 J	-	-	-	-	-
5/21/2014	130 J	2	7 J	2 J	18 J	65
6/25/2014	460	1 U (1 U)	1 U	1 U	1 U	1 U
7/16/2014	160 (170)	12	1 U	1 U	1 U	14
8/19/2014	1200 J	1 U (1 U)	1 U	59	2	16
9/17/2014	190	1 U	1 U	1 U	1 U	1 U (1 U)
10/15/2014	60 J	1 UJ	1 U	1 UJ	1 U	2
Geometric mean	219	2	1	2	2	6
Max result	1200	12	7	59	18	65

Results in cfu/100 mL.
Values in parentheses are QA replicate sample results.
J: The organism was positively identified. The associated numerical result is an estimate.
U: The organism was not detected at or above the reported limit.
UJ: The organism was not detected at or above the reported estimated limit.

Table 6. Secchi depth measurements.

Date	DEEPLK-1	DEEPLK-2
5/21/2014	2.2	2.1 (2.3)
6/25/2014	5.1	5.2
7/16/2014	3.5	4.0
8/19/2014	5.5	5.6
9/17/2014	4.6	4.7
10/15/2014	5.7	5.3 (5.7)

Results are depths in meters.
Values in parentheses are QA replicate measurement results.

Analysis and Discussion

Mass Balance and In-Lake Concentration Graphs

Figures 4-10 show mass balances and in-lake concentrations of nutrients and total suspended solids (TSS). The mass-balance graphs are essentially a comparison of inlet loads and outlet loads. Load is defined as the total mass of a substance or pollutant being carried by the stream per unit of time, and it is calculated as [concentration] x [flow]. Net load is calculated as [inlet load] – [outlet load]. Therefore, a positive net load means that the lake is acting as a sink for a particular constituent, whereas a negative load means the lake is acting as a source. These graphs show that Deep Lake acts as a sink for sediment, nutrients, and fecal coliform, trapping the vast majority of sediment, nutrients, and fecal coliform that enter the lake via the inlet. One exception to this is organic nitrogen (which constitutes the vast majority of total persulfate nitrogen). Organic nitrogen entering Deep Lake may be recalcitrant, or resistant to remineralization, passing through largely unchanged.

Sediment trapping during the springtime is particularly notable. During the May sampling event, approximately 10,000 kg/day (11 US tons/day) of suspended sediment were being trapped by Deep Lake. In other words, most of the sediment being delivered to the lake through the inlet stream permanently settles out in the lake.

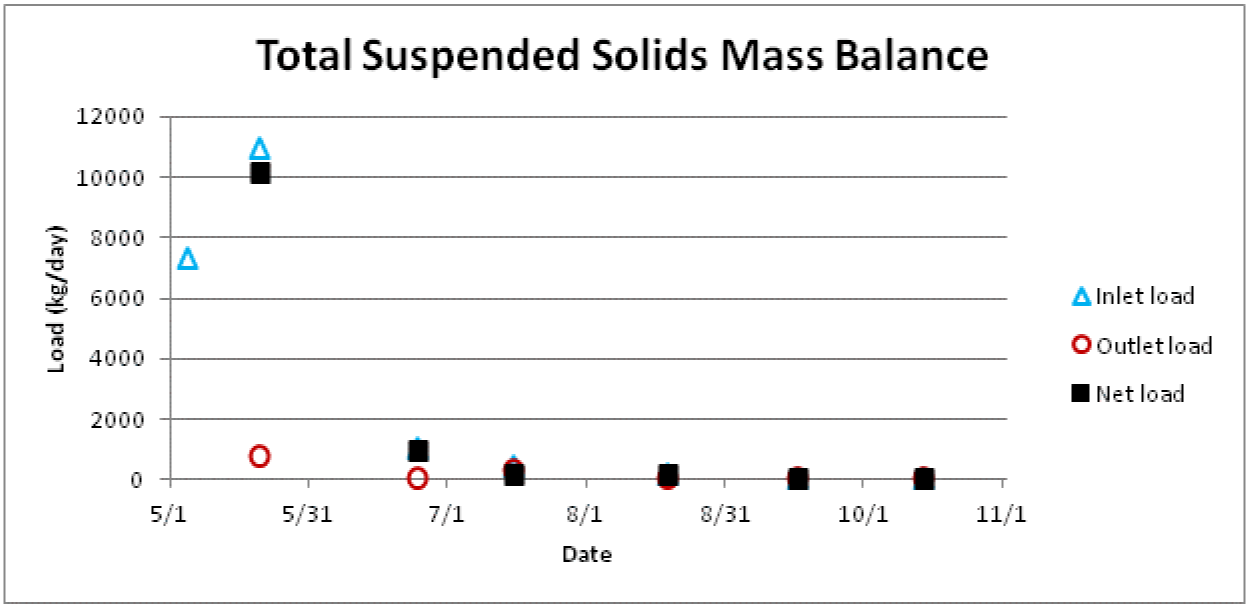


Figure 4. Total suspended solids mass balance.

Total suspended solids concentration in the lake were not sampled.

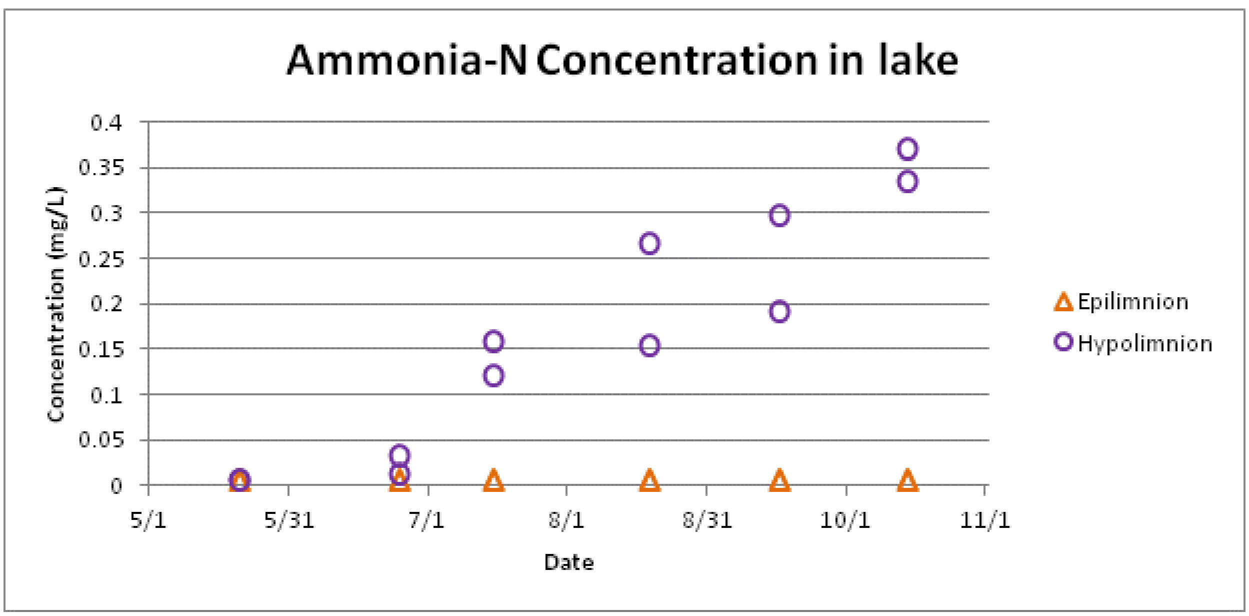
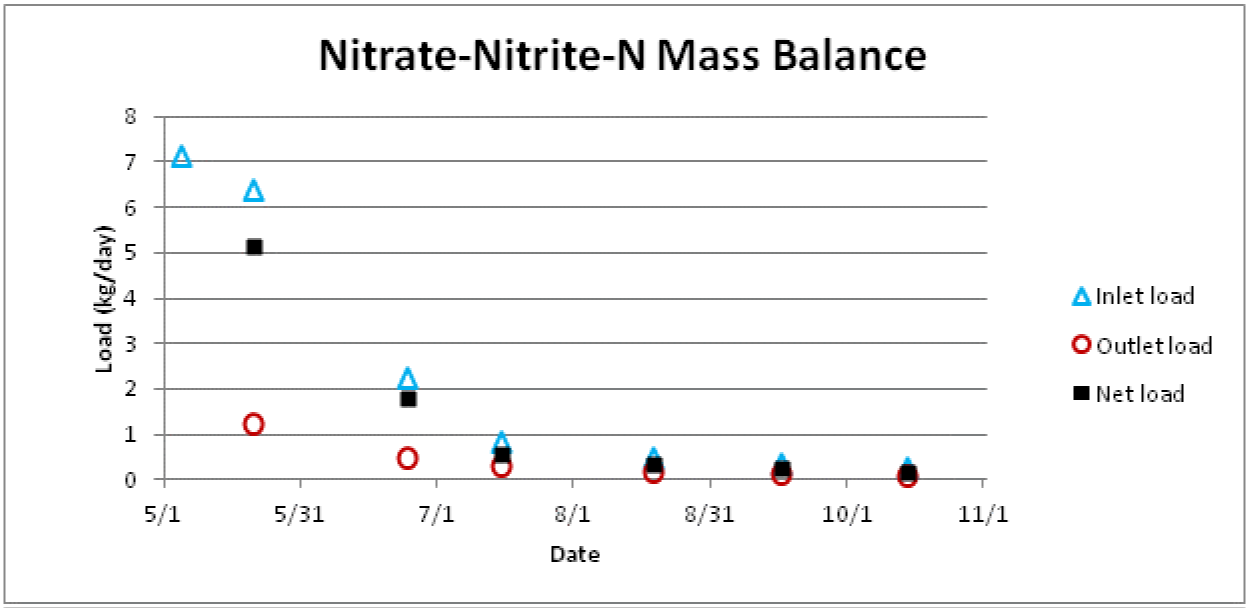


Figure 5. Ammonia-nitrogen concentration in the lake.

A mass balance for ammonia-nitrogen could not be calculated because the vast majority of inlet and outlet concentration results are non-detects.



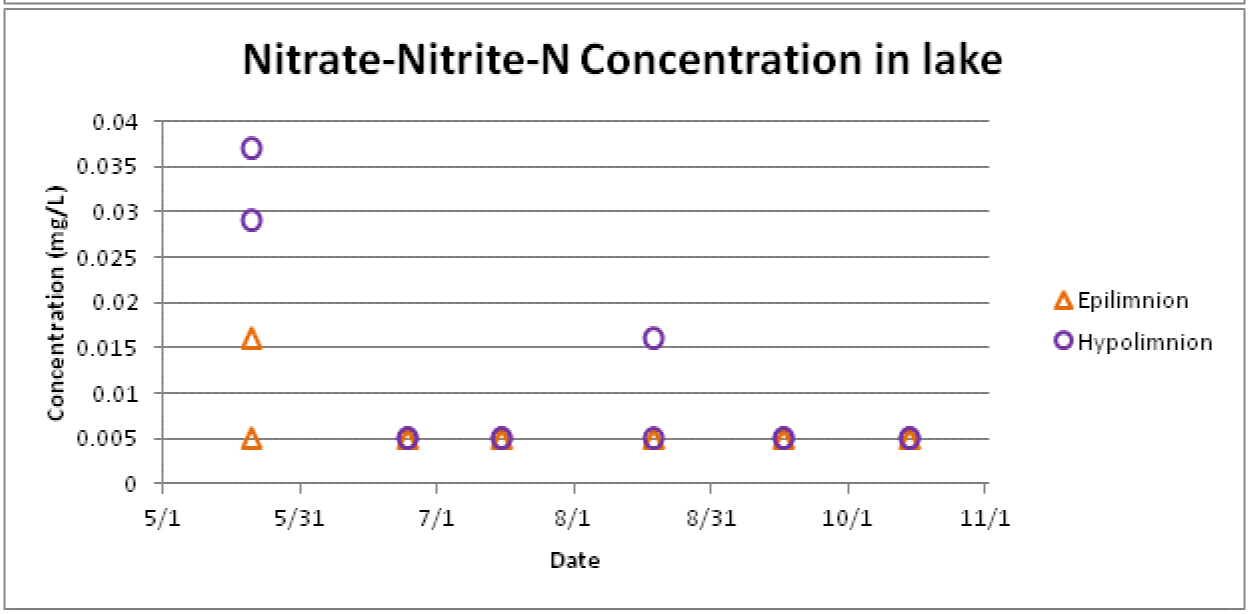
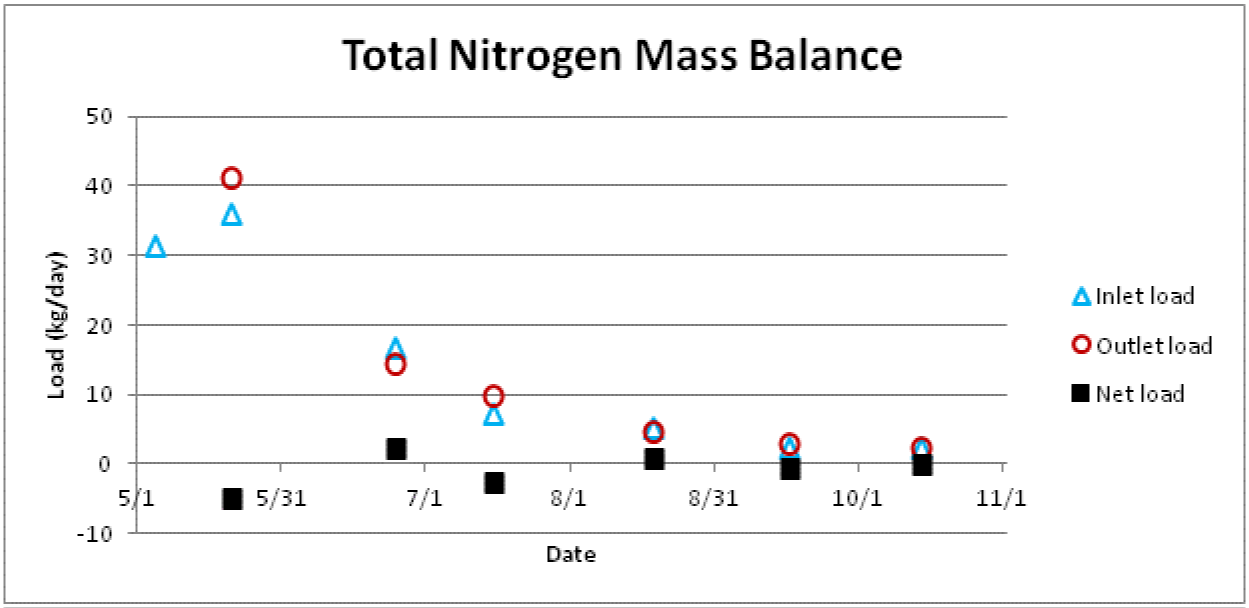


Figure 6. Nitrate-nitrite-nitrogen mass balance and concentration in the lake.

For the mass balance, all outlet concentrations are non-detects. Outlet loads are calculated assuming concentrations are half the detection limit.



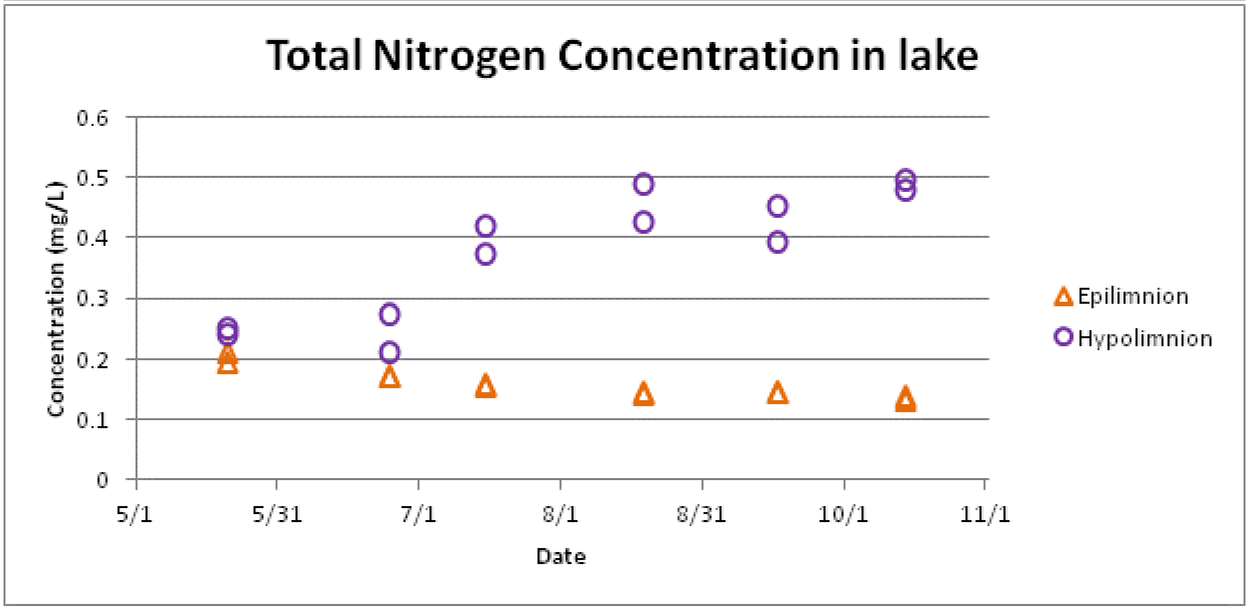


Figure 7. Total nitrogen mass balance and concentration in the lake.

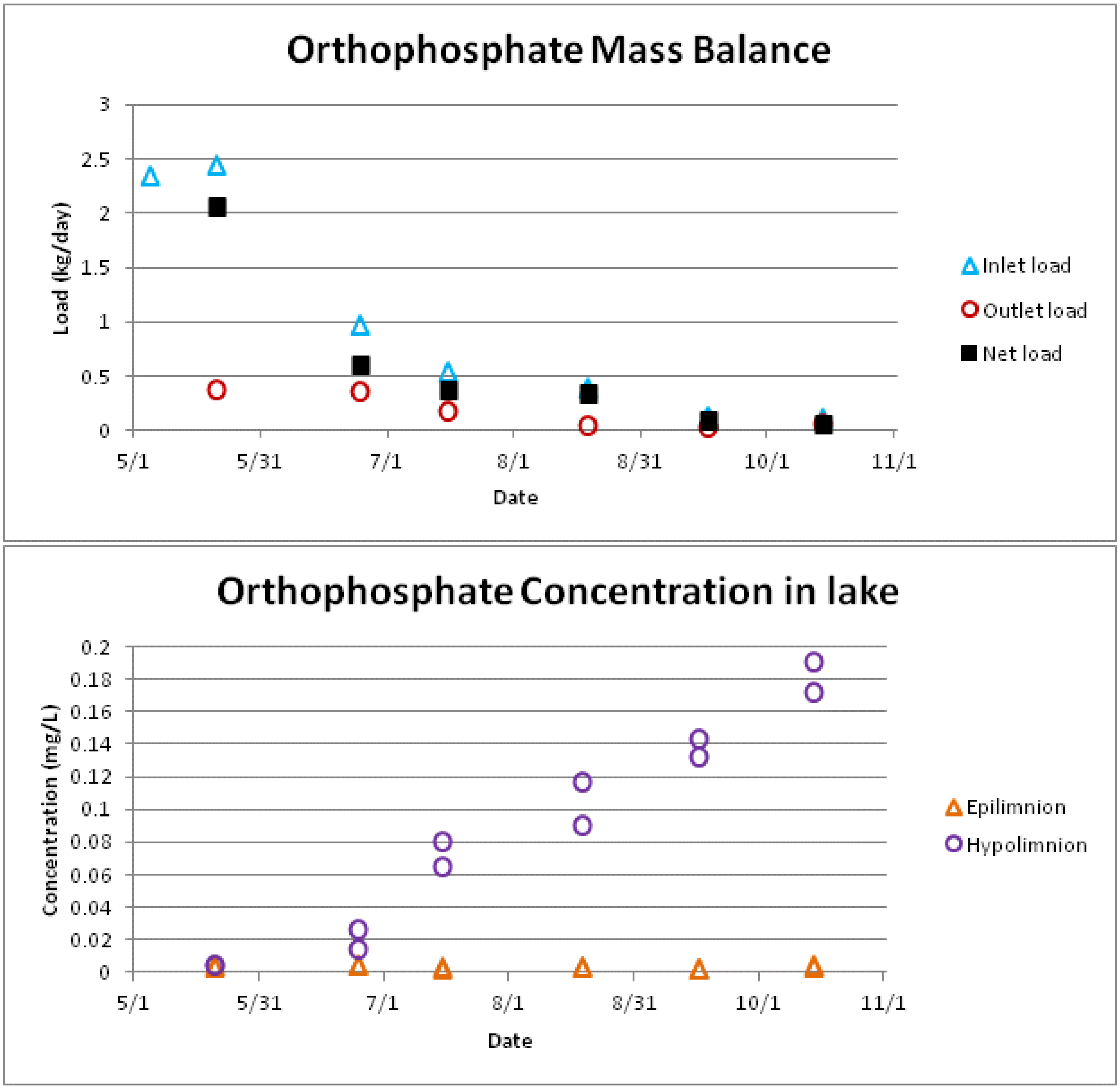


Figure 8. Orthophosphate mass balance and concentration in the lake.

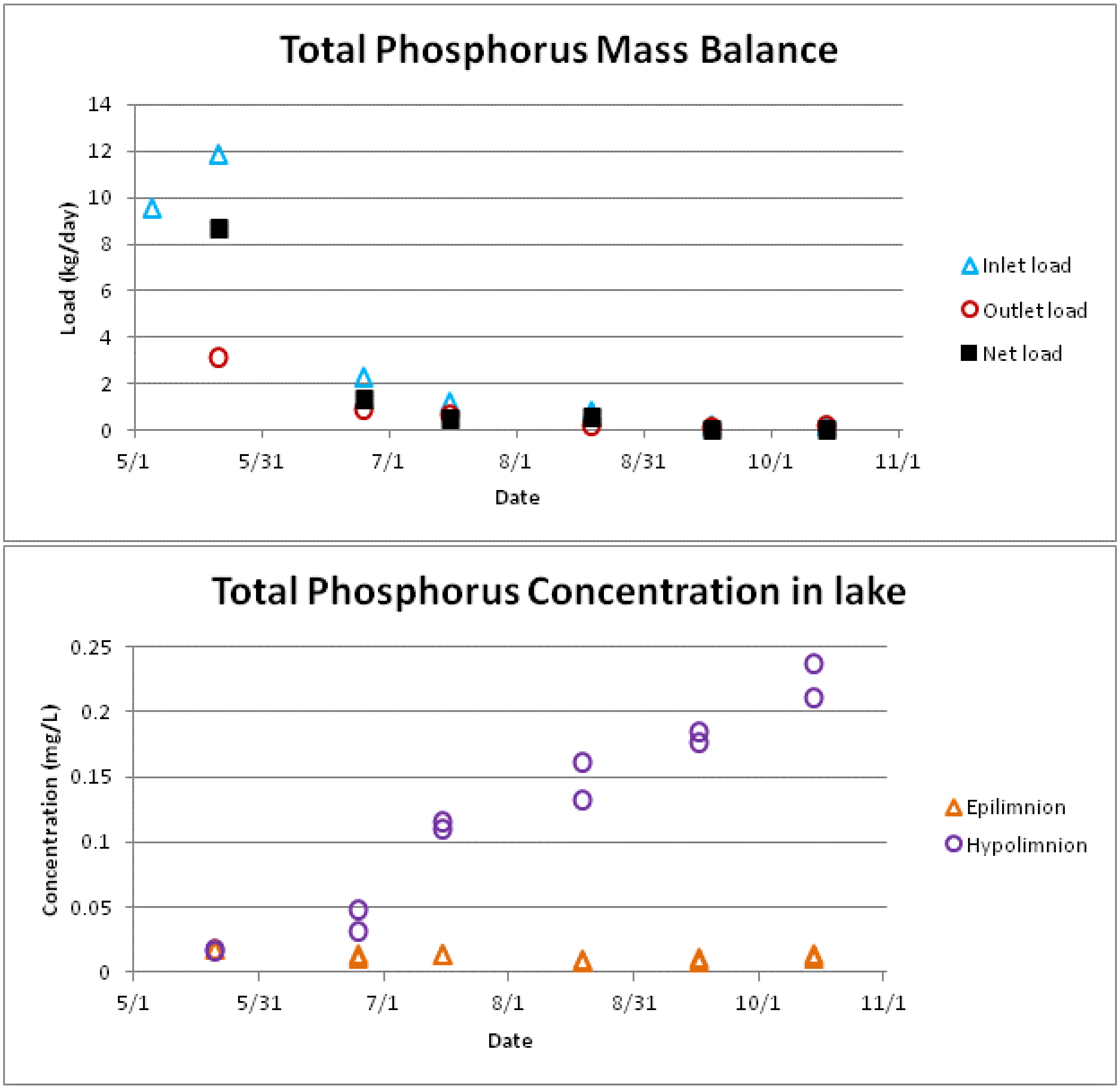


Figure 9. Total phosphorus mass balance and concentration in the lake.

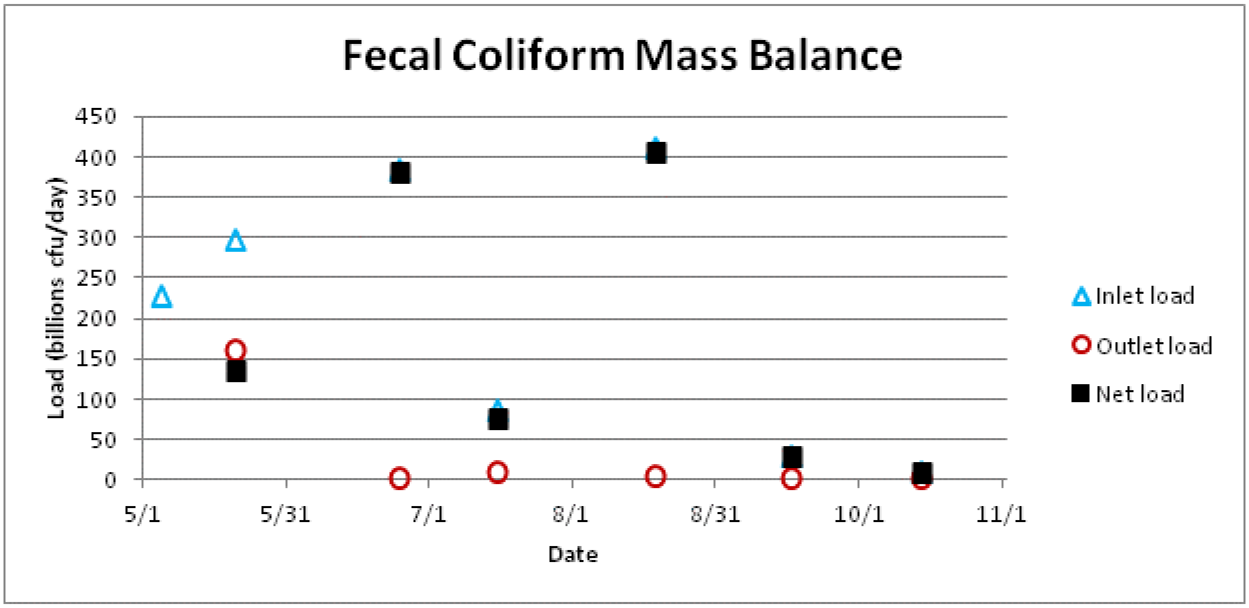


Figure 10. Fecal coliform mass balance.

Fecal coliform concentrations were sampled at four locations in the lake. These results can be found in Table 4.

Trophic State Index Calculations

Table 7 presents trophic state index calculations for Deep Lake. Separate calculations are made for each sampling date. The trophic state index used is the one developed by Carlson (1977). It can be calculated from Chlorophyll *a* data, epilimnion total phosphorus data, and/or secchi depth data. Calculations here are based on total phosphorus and secchi depth data, as those two parameters were collected during this study. Trophic state index calculations based on Secchi depth measurements were in excellent agreement with calculations made from total phosphorus.

The trophic state index is an index of the total amount of biological material (biomass) in the lake at a given time. The index has a scale of approximately 0 – 100, with 0 representing an extremely oligotrophic state and 100 representing an extremely eutrophic state. It is important to note that the trophic state index is not intended to be an indication of "water quality" as such, but of the biological state of the lake. A more eutrophic lake is one with more plant/algae biomass.

More information about how to interpret a trophic state index is available at http://www.secchidipin.org/index.php/monitoring-methods/trophic-state-equations/

Table 7. Trophic state index calculations for Deep Lake.

Date	TSI calculated based on epilimnion total phosphorus	Interpretation	TSI calculated based on secchi depth	Interpretation
5/21/2014	45	Mesotrophic	49	Mesotrophic
6/25/2014	40	Oligotrophic-Mesotrophic	36	Oligotrophic-Mesotrophic
7/16/2014	41	Mesotrophic	41	Mesotrophic
8/19/2014	35	Oligotrophic-Mesotrophic	35	Oligotrophic-Mesotrophic
9/17/2014	36	Oligotrophic-Mesotrophic	38	Oligotrophic-Mesotrophic
10/15/2014	40	Oligotrophic-Mesotrophic	35	Oligotrophic-Mesotrophic

Comparison to Previous Data

Ecology's now-defunct ambient lake monitoring program monitored Deep Lake during 1989, 1990, 1993, 1994, 1997, 1998 and 1999. This monitoring normally included at least two visits per year to the lake, one in late spring and one in late summer. One location was monitored, corresponding approximately to the DEEPLK-1 location in this study. The inlet and outlet streams were not monitored. Table 8 presents a summary of key results from this monitoring program, along with results from the current study for comparison. Overall, the results from 2014 are very comparable to the results from 1989-1998. The hypolimnetic anoxia appears to be much the same now as it was previously, and the trophic status of the lake appears to be much the same.

Table 8. Summary of findings for Deep Lake from Ecology's ambient lake monitoring program, 1989-1999, along with findings from this study for comparison.

Year	Month	Trophic state index (TSI) based on			Range of anoxic depths [7]
		Chlorophyll a	Total Phos.	Secchi depth	
1989 [1]	June	40	41	37	10m +
	September	43	40	35	8m +
1990 [2]	May	--	48	41 [8]	9m +
	September				--
1993 [3]	May	39	39	32 [8]	Not anoxic
	August				8m +
1994 [4]	May	--	--	--	14m (at bottom)
	August				9m +
1997 [5]	May	34	41	41 [8]	Not anoxic
	August				9m +
1998 [6]	--	--		40 [8]	--
1999 [6]	June	--	48	40 [8]	Not anoxic
2014 (This study)	May	--	45	49	13m +
	June		40	36	8m +
	July		41	41	8m +
	August		35	35	9m +
	September		36	38	9m +
	October		40	35	9m +

[1] Rector and Hallock, 1991
[2] Rector and Hallock, 1993
[3] Smith, 1996
[4] Smith, 1997
[5] Smith et al., 2000
[6] Bell-McKinnon, 2002
[7] For this table, "anoxic" is defined as DO < 0.5 mg/L. For the 2014 data, the range of anoxic depths is taken from profiles at DEEPLK-1, as this corresponds to the location monitored during 1989-1997.
[8] TSI based on average of Secchi depth measurements collected throughout the season by volunteers.

Comparison to Nearby Lakes

Table 9 summarizes findings by Ecology's ambient lake monitoring program for other comparable nearby lakes, along with data from Deep Lake for comparison. Lakes included in this table are lakes located in Pend Oreille, Stevens, or Ferry counties, which are of somewhat comparable size and depth to Deep Lake.

Table 9. Summary of findings for nearby lakes, along with findings from Deep Lake for comparison.

Lake	County	Area (acres)	Max Depth (m)	Year	Month	TSI			TSI estimate[1]	Description of Dissolved Oxygen (mg/L)
						Chll a	Total P	Secchi		
Black	Stevens	70	14	1993	May	39	33	36	OM	DO > 5 at bottom
					Sep					Anoxic below 8m
Browns	Pend Oreille	84	11	1999	Jun	33	43	33	OM	DO > 9
			9?		Jul					DO > 8
			7.4		Aug					DO > 8
			6.1		Sep					DO > 8
Curlew	Ferry	921	40	1999	Jun	41	47	37	M	Anoxic near bottom
					Jul					Anoxic below 25m
					Aug					Anoxic below 25m
					Sep					Anoxic below 10m
Davis	Pend Oreille	152	45	1990	May	--	43	37	OM	DO = 7.5 nr bottom; > 8 elsewhere
					Aug					DO = 3.9 nr bottom; > 6 elsewhere
Deer	Stevens	1110	23	1999	Jun	32	48	29	OM	DO > 5 near bottom
					Jul					DO > 1 near bottom
					Aug					DO < 1 near bottom
					Sep					DO < 1 near bottom
Ellen	Ferry	78	10	1993	May	38	33	37	O	DO < 1 near bottom
					Aug					Anoxic below 8m
Gillette	Stevens	47	26	1999	Jun	35	50	38	M	Anoxic below 10m
					Jul					Anoxic below 6m
					Aug					Anoxic below 8m
					Sep					Anoxic below 8m
Horseshoe	Pend Oreille	141	46	1998	Jun	62	45	47	ME	DO < 2 near bottom
					Jul					Anoxic near bottom
					Aug					Anoxic near bottom
					Sep					Anoxic near bottom
Leo	Pend Oreille	43	11	1993	May	37	38	35	OM	Anoxic near bottom
					Aug					Anoxic below 6m
Loon	Stevens	1100	30	1999	Jul	--	37	34	OM	DO < 1 near bottom
N. Twin	Ferry	744	17	1990	Aug	--	41	31	M	Anoxic below ~9-10 (?) m
Pierre	Stevens	110	23	1993	May	38	35	36	OM	Anoxic below 10m
					Aug					Anoxic below 7m
Sacheen	Pend Oreille	317	12	1990	May	--	49	40	M	Anoxic below 9m
					Aug					Anoxic below 5m
Thomas	Stevens	170	17	1999	Jun	--	53	39	M	DO < 1 near bottom
					Aug					Anoxic below 8m
Waitts	Stevens	472	21	1993	May	35	42	33	OM	Anoxic near bottom
					Aug					Anoxic below 10m
Deep (This study)	Stevens	210	15	2014	May	--	45	49	OM	Anoxic near bottom
					Jun		40	36		Anoxic below 8m
					Jul		41	41		Anoxic below 8m
					Aug		35	35		Anoxic below 9m
					Sep		36	38		Anoxic below 9m
					Oct		40	35		Anoxic below 9m

[1] O: Oligotrophic; OM: Oligomesotrophic; M: Mesotrophic; ME: Mesoeutrophic

As Table 9 shows, a variety of conditions exist in comparable lakes in northeastern Washington. Most of these lakes are classified as oligomesotrophic or mesotrophic, with only one oligotrophic lake and one mesoeutrophic lake. Dissolved oxygen conditions vary considerably between lakes. Certain lakes have generally abundant dissolved oxygen throughout, such as Browns Lake and Davis Lake. Other lakes have low dissolved oxygen near the lake bottom, but do not have a large anoxic zone; examples include Deer Lake, Loon Lake, and Horseshoe Lake. Still other lakes have a large anoxic zone in the lower portion of the lake during the summer months; these include Deep Lake along with Pierre Lake, Sacheen Lake, Lake Thomas, Waitts Lake, and others. Among lakes classified as Oligomesotrophic, four (Browns, Davis, Deer, and Loon) did not have significant anoxic zones, while five (Black, Leo, Pierre, Waitts, and Deep) did.

It needs to be noted that the trophic state and dissolved oxygen of lakes are only two aspects of overall water quality. Other parameters that could be compared include fecal coliform and pH. It was beyond the scope of the ambient lake monitoring program to assess the inlet and outlet streams of lakes, so issues such as sediment trapping were not reported.

Conclusions and Recommendations

Conclusions

The key findings of this study were:

- The lower portion of Deep Lake is anoxic during the summer months. Anoxia was observed near the bottom during May, and from a depth of 8-10 meters to the bottom from June through October.
- Fecal coliform concentrations in the inlet stream exceeded the water quality criteria, with a geometric mean of 219 cfu/100 mL and a maximum result of 1200 cfu/100 mL. Fecal coliform concentrations at the locations sampled in Deep Lake did not exceed the water quality criteria.
- Significant sediment trapping occurs in Deep Lake. In May 2014, 10,000 kg/day (11 US tons/day) of sediment were being deposited in the lake.
- Nutrient concentrations in the inlet stream and the epilimnion of the lake were moderately low. The lake traps the majority of nutrients that enter via the inlet stream.
- Secchi depth and total phosphorus data indicate that Deep Lake is oligomesotrophic.
- The trophic state and the anoxic hypolimnion observed in Deep Lake in 2014 are very similar to what was observed in Deep Lake by Ecology during previous monitoring from 1989 through 1999.

Recommendations

- Best management practices should be implemented along the inlet stream (North Fork Deep Creek) to reduce fecal coliform concentrations and control sediment delivery to Deep Lake. Such actions would also be likely to reduce nutrient delivery to Deep Lake.
- If there is a desire or need to further trace the sources of fecal coliform and sediment entering the inlet stream, an additional monitoring study could be undertaken by Ecology or a local organization. Such a study would need to monitor the several creeks that feed the inlet stream (O'Hare, Hartbauer, Silver, Sherlock, and Republican Creeks) as well as North Fork Deep Creek itself, with monitoring locations chosen to bracket potential sources.
- The homeowners around Deep Lake are encouraged to develop a Lake Management Plan. Information about management plans is available at the following link: http://www.nalms.org/home/lake-mgmt/lake-management-plans/lake-management-plans-home.cmsx
- Deep Lake should continue to be monitored by a local organization. At a minimum, monitoring could consist of regular Secchi depth measurements, which will allow for a calculation of trophic state comparable to what can be achieved by collecting total phosphorus data. It should also include monitoring for toxins during suspected blue-green algae blooms. If the monitoring organization has the desire and means, the effort could be expanded to include monitoring of lake total phosphorus and monitoring of inlet fecal coliform and sediment.

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Appendices

Appendix A. Data Quality

Sample Data Quality

Ecology took replicate field samples for laboratory parameter analyses. Field replicates are two samples collected from the same location and as close to the same time as possible. Ecology collects field replicates to check the precision of the entire process of sampling and analysis. Laboratory duplicates consist of two subsamples taken from the same sample container and analyzed separately. These serve to check the precision of the lab analysis. Manchester Environmental Laboratory assesses bias for certain parameters through the use of matrix spikes.

Field replicates and laboratory duplicates with result values of less than 5 times the reporting limit (RL) were analyzed separately. These low-level sample results often have a higher relative variability than higher sample results.

Duplicate precision targets and bias targets were met for all parameters (Tables A-1 and A-2) except lab precision for nitrate-nitrite nitrogen and fecal coliform. For both of these parameters, most of the duplicate pairs were non-detects, and a very small number of duplicate pairs above the detection limit were available to assess precision. The fact that lab precision was calculated to be significantly higher than total precision for these two parameters (which should not happen) supports the interpretation that these calculations are hindered by the small number of duplicate pairs.

Ecology submitted field blanks for analysis along with samples from four of the sampling events (Table A-3). In addition, Manchester Laboratory routinely ran lab blanks along with each analytical batch. All field and lab blanks resulted in non-detects.

The precision and bias results from this study generally indicate that sample data are of a high quality.

Table A-1. Lab precision and bias results.

Parameter		Number Samples	Number Duplicates	% Duplicated	# Duplicates above RL	Target Precision	Median %RSD[1]		Target Bias[2]	Average Bias
							<5x RL	>=5x RL		
Ammonia-Nitrogen		37	5	14%	2	10% RSD	0.0%	--	±10%	-2.9%
Nitrite-Nitrate Nitrogen		37	5	14%	1	10% RSD	12.9%	--	±10%	+1.8%
Total Persulfate Nitrogen		37	5	14%	3	10% RSD	--	0.9%	±10%	-3.0%
Orthophosphate		37	5	14%	3	10% RSD	1.1%	--	±10%	-1.4%
Total Phosphorus		37	6	16%	5	10% RSD	3.4%	7.1%	±10%	-6.0%
Total Suspended Solids		13	2	15%	2	15% RSD	--	1.7%	--	--
Fecal Coliform	50th %ile of duplicate pairs	37	7	19%	2	20% RSD	--	41.3%	--	--
	90th %ile of duplicate pairs					50% RSD	--	51.8%[3]	--	--

[1] Results at the detection limit were excluded from consideration.

[2] The target for bias specified in the QAPP was 20% relative percent difference (RPD). However, average bias is a more useful measure, because it includes the direction as well as the magnitude of bias. Both average bias and bias RPD results for this study meet targets for all parameters.

[3] This is 90th percentile rather than median % relative standard deviation (RSD).

Table A-2. Total precision (field + lab) results.

Parameter		Number Samples	Number Replicates	% Replicated	# Replicates above RL	Target Precision	Median %RSD[1]	
							<5x RL	>=5x RL
Ammonia-Nitrogen		37	4	11%	0	10% RSD	-- [2]	-- [2]
Nitrite-Nitrate Nitrogen		37	4	11%	2	10% RSD	2.4%	--
Total Persulfate Nitrogen		37	4	11%	4	10% RSD	--	6.2%
Orthophosphate		37	4	11%	2	10% RSD	0.3%	--
Total Phosphorus		37	4	11%	4	10% RSD	1.4%	--
Total Suspended Solids		13	2	15%	1	15% RSD	--	8.3%
Fecal Coliform	50th %ile of duplicate pairs	37	4	11%	1	20% RSD	--	4.3%[3]
	90th %ile of duplicate pairs					50% RSD		

[1] Results at the detection limit were excluded from consideration.

[2] Total precision for ammonia-nitrogen could not be evaluated, because all replicates were non-detects.

[3] Median and 90th percentiles of %RSDs could not be calculated for fecal coliform, because there was only one duplicate pair above the detection limit. The result shown is the %RSD result for that one duplicate pair.

Table A-3. Field blank results.

Date	TSS (mg/L)	FC (cfu/ 100 mL)	NH_4 (mg/L)	NO_2-NO_3 (mg/L)	TPN (mg/L)	OP (mg/L)	TP (mg/L)
6/25/2014	1 U	-	0.01 U	0.01 U	0.025 U	0.003 U	0.005 U
7/16/2014	1 U	1 U	0.01 U	0.01 U	0.025 U	0.003 U	0.005 U
8/19/2014	1 U	1 U	0.01 U	0.01 U	0.025 U	0.003 U	0.005 U
9/17/2014	1 U	1 U	0.01 U	0.01 U	0.025 U	0.003 U	0.005 U

No FC blank was submitted on 6/25/2014.

Hydrolab Data Quality

Ecology calibrated all field monitoring equipment according to manufacturer specifications, using certified standards. Hydrolab® meters were calibrated before each monitoring event, and calibrations were checked after each event to assess calibration drift.

Conductivity and pH accuracy were assessed through calibration post-checks. Dissolved oxygen (DO) accuracy was assessed through comparison with Winkler titration results, and most DO data were corrected based on Winkler results, using either a bias or a linear regression correction method. Table A-4 shows the targets to accept, qualify, or reject data.

Table A-4. Accuracy targets for conductivity, pH, and DO.

Parameter	Accuracy range to:		
	Accept	Qualify	Reject
Conductivity	≤ 5%	> 5% and ≤ 10%	> 10%
pH	≤ 0.2	> 0.2 and ≤ 0.5	> 0.5
Dissolved oxygen	≤ 4%	> 4% and ≤ 10%	> 10%

All hydrolab data were assessed to be accurate within target values with the following exceptions:

- For the June 25, 2014 survey, pH and DO data collected from the stream sites were qualified.
- For the July 16, 2014 survey, DO data collected from both the stream and lake sites were qualified.
- For the September 17, 2014 survey, pH data collected from the lake sites were qualified.
- For the October 15, 2014 survey, conductivity and pH data collected from the lake sites were qualified.

Qualified data were still used and are presented in this report with either a "J" qualifier code or a reminder below the graph (e.g. Figure 2) that data are qualified. The accuracy range of this data should be kept in mind when interpreting it.

Other Measurement Data Quality

Flow and Secchi disk measurements were replicated to assess overall measurement precision. To replicate Secchi disk measurements, two different personnel took a measurement without telling the other their result. Replicate flow measurements were taken immediately following the initial flow measurement, using the same channel cross-section. Table A-5 shows precision results for these parameters.

Table A-5. Precision results for flow and secchi depth.

Parameter	Number Measurements	Number Replicates	% Replicated	Target Precision	Median %RSD
Streamflow	13	2	15%	20%	3.9%
Secchi depth	12	2	17%	-- [1]	5.8%

[1]A target for precision was not set for Secchi depth in the QAPP.

Appendix B. Glossary, Acronyms, and Abbreviations

Glossary

Anoxic: Devoid of oxygen. In aquatic environments, this means dissolved oxygen concentrations at or near zero.

Conductivity: A measure of water's ability to conduct an electrical current. Conductivity is related to the concentration and charge of dissolved ions in water.

Dissolved oxygen (DO): A measure of the amount of oxygen dissolved in water.

Epilimnion: The shallow or upper layers of a lake.

Fecal coliform (FC): That portion of the coliform group of bacteria which is present in intestinal tracts and feces of warm-blooded animals as detected by the product of acid or gas from lactose in a suitable culture medium within 24 hours at 44.5 plus or minus 0.2 degrees Celsius. Fecal coliform bacteria are "indicator" organisms that suggest the possible presence of disease-causing organisms. Concentrations are measured in colony forming units per 100 milliliters of water (cfu/100 mL).

Geometric mean: A mathematical expression of the central tendency (an average) of multiple sample values. A geometric mean, unlike an arithmetic mean, tends to dampen the effect of very high or low values, which might bias the mean if a straight average (arithmetic mean) were calculated. This is helpful when analyzing bacteria concentrations, because levels may vary anywhere from 10 to 10,000 fold over a given period. The calculation is performed by either: (1) taking the nth root of a product of n factors, or (2) taking the antilogarithm of the arithmetic mean of the logarithms of the individual values.

Hypolimnion: The deep or lower layers of a lake.

Load: The amount of a substance or pollutant being carried by a stream per unit of time. Defined as [concentration] x [streamflow].

Parameter: Water quality constituent being measured (analyte). A physical, chemical, or biological property whose values determine environmental characteristics or behavior.

pH: A measure of the acidity or alkalinity of water. A low pH value (0 to 7) indicates that an acidic condition is present, while a high pH (7 to 14) indicates a basic or alkaline condition. A pH of 7 is considered to be neutral. Since the pH scale is logarithmic, a water sample with a pH of 8 is ten times more basic than one with a pH of 7.

Pollution: Contamination or other alteration of the physical, chemical, or biological properties of any waters of the state. This includes change in temperature, taste, color, turbidity, or odor of the waters. It also includes discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state. This definition assumes that these changes will, or are likely to, create a nuisance or render such waters harmful, detrimental, or injurious to (1) public health, safety, or welfare, or (2) domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or (3) livestock, wild animals, birds, fish, or other aquatic life.

Relative percent difference: The absolute value of the difference between duplicates expressed as a percent of the duplicate mean.

Salmonid: Fish that belong to the family *Salmonidae*. Species of salmon, trout, or char.

Surface waters of the state: Lakes, rivers, ponds, streams, inland waters, salt waters, wetlands and all other surface waters and water courses within the jurisdiction of Washington State.

Total suspended solids (TSS): The suspended particulate matter in a water sample as retained by a filter.

90th percentile: A statistical number obtained from a distribution of a data set, above which 10% of the data exists and below which 90% of the data exists.

Acronyms and Abbreviations

Cond	Conductivity
DO	Dissolved oxygen
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
FC	Fecal coliform
HUC	Hydrologic Unit Code
QA	Quality assurance
RL	Reporting limit
RPD	Relative percent difference
RSD	Relative standard deviation
TSI	Trophic state index
TSS	Total suspended solids
WAC	Washington Administrative Code
WRIA	Water Resource Inventory Area
%ile	Percentile

Units of Measurement

°C	degrees centigrade
cfs	cubic feet per second
cfu/100 mL	colony forming units per 100 milliliters
kg/day	kilograms per day
m	meter
mg/L	milligrams per liter (parts per million)
S.U.	standard units
ug/L	micrograms per liter
uS/cm	microsiemens per centimeter, a unit of conductivity
US tons/day	US tons per day